# MINING ENVIRONMENTAL HANDBOOK

## Effects of Mining on the Environment and American Environmental Controls on Mining

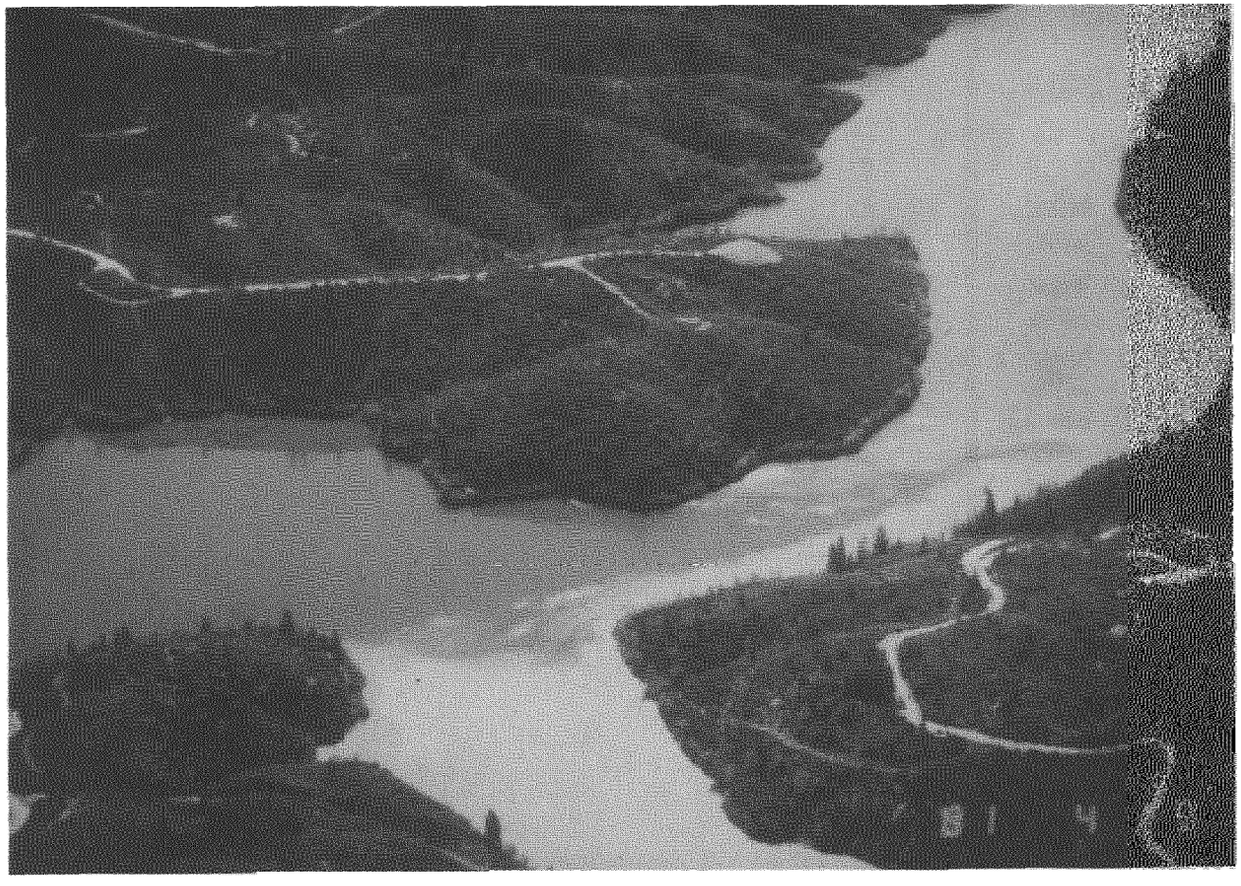
Editor

Jerrold J Marcus

Imperial College Press

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Acid Mine/rock Drainage (AMD) originating from the shut-down Iron Mountain Mine. The AMD is visible as a dark plume entering the clear spring creek arm of the Keswick Reservoir along the Sacramento Rivier just above Redding, California. (*Courtesy of U.S. EPA and CH2M HILL.*)

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Editor

**Jerrold J Marcus**

*San Mateo, USA*

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# PREFACE

Most people who donated their efforts on this *Handbook* are readily identified either as Editors or Contributing Authors. Without them, it would have never been completed. However, quite a few individuals, in addition and otherwise unlisted, provided essential services and their generous dedication demands identification. A prime example are the executive assistants, secretaries, and computer specialists who graciously helped: the most notable examples are Mary Curto, Linda Duff, Roger Dyas, Cheryl Gross, Eva Miller, Pam Olson, Gill Porter, Leslie Wells, Eric Zahl, and Tammy Van Zyl. Lou Prosser of the now defunct U.S. Bureau of Mines especially contributed continually and in many ways as also did Ivan Uranowitz and Bill Mote of the Northwest Mining Association and Tom Hilliard of the Minerals Policy Committee. Clayton Parr and Marghret Van Buskirk provided critical input into Chapter 2. Michael Drozd, Ray Lowrie, and Alan Gilbert were always willing to lend an extra hand as needed (Alan, at times, even lent two). Other "White Knights" of note include Lou Cope, Keith Dyas, Barb Filas, and Deepak Malhotra. Barbara Dygert provided extraordinary encouragement and support. The firms of Amax Gold, Sherman and Howard, and Knight Piésold offered extended assistance, and their contributions warrant special notice. Finally, without the efforts of Lane White, taking on the onerous task of copy production, this volume would have never been completed.

On a very personal note, the Editor wishes to thank the staff of the College of San Mateo, who imparted sufficient knowledge on the use of a PC to get this job done; Fred Leif of the U.S. EPA who invited a partially tamed old fox into his chicken coop; and most notable of all, to Evelyn, a miner's wife and life's companion, for continued strong editorial and, much more importantly, emotional support.

In conclusion, the Editor, a mining operator and planner by training and dedication, has had the opportunity in the last few years to meet and work with highly committed environmentalists. Miners and environmentalists are not very dissimilar in the strength of their convictions and are overwhelmingly good people. A continued environmentally and economically sound mining industry will take the cooperation of all interested parties (as the political expression goes: "we need everyone under one big tent"). Let us once and for all put aside the ruinous "we versus they" mentality, and remember: "the enemy is us" (all of us). If this *Handbook* provides nothing else but bringing together, even in a very small way, all of those involved in mining environmentalism, then it must be deemed a success. ***Please help make it so!***

*Jerrold J. Marcus*
*San Mateo, California*
*June 1996*

# HANDBOOK KEY PERSONNEL

## EDITOR:

**J. J. Marcus**
1569 De Anza Blvd
San Mateo, CA 94403-3940

## ASSOCIATE EDITORS:

**F. K. Allgaier**
Office of Audit and Evaluation
Department of Interior
P. O. Box 25007, Mail Stop D 119
Denver, CO 80225

**J. A. Cordes**
Room 102, Chauvenet Hall
Colorado School of Mines
Golden, CO 80401

**D. R. East**
Knight Piésold
1050 17th Street, Ste 500
Denver, CO 80265-0501

**N. W. Kirshenbaum**
Placer Dome, U. S., Inc.
1 California Street
San Francisco, CA 94111

**R. W. Phelps**
Engineering and Mining Journal
29 North Wacker Drive
Chicago, IL 60606

**L. A. Pirozzoli**
Black Horse Inn
Route 3, Box 240
Warrenton, VA 22186

## CHAPTER EDITORS:

**F. R. Banta**
Amax Gold
9100 East Mineral Circle
Englewood, CO 80112

**G. E. Conrad**
Interstate Mining Compact Commission
459 - B Carlisle Drive
Herndon, VA 22070

**L. W. Cope**
Placer Consultant
111 Emerson Street, #723
Denver, CO 80218

**M. A. Drozd**
Detox and Treatment Consulting, Inc.
7205 South Chase Court
Littleton, CO 80123-4940

**B. A. Filas**
Knight Piésold
1050 17th Street, Ste 500
Denver, CO 80265-0501

**A. J. Gilbert**
Sherman & Howard
3000 First Interstate Tower North
633 Seventeenth Street
Denver, CO 80202

**J. M. Johnson**
Golder Associates, Inc.
200 Union Boulevard, Suite 500
Lakewood, CO 80228

**P. Keppler**
Popham, Haik, Schobrich & Kaufman, Ltd.
1200 17th Street - Suite 2400
Denver, CO 80202

**A. J. Krause**
TerraMatrix, Inc.
1475 Pine Grove Road, Suite 109
P. O. Box 774018
Steamboat Springs, CO 80477

**J. T. Laman**
In-Situ Inc.
210 S. Third Street
P. O. Box I
Laramie, WY 82070-0920

**R. L. Lowrie**
1694 North Woodhaven Drive
Franktown, CO 80116

**D. Malhotra**
Resource Development Inc.
11475 West Interstate 70, Frontage Road North
Wheat Ridge, CO 80033

**C. A. McLean**
13805 Ginger Loop
Penn Valley, CA 95946

**J. A. Murray**
Bechtel, Inc.
Box 3965
San Francisco, CA 94105-1895

**C. Parrish**
Canyon Resources
13142 Denver West Parkway, Suite 250
Golden, CO 80401

**R. L. Schmiermund**
Knight Piésold
1050 17th Street, Ste 500
Denver, CO 80265-0501

**D. W. Struhsacker**
Environmental Permitting and Government Relations
Consultant
3610 Big Bend Lane
Reno, NV 89509

**T. Van Haverbeke**
Room 102, Chauvenet Hall
Colorado School of Mines
Golden, CO 80401

**D. J. A. Van Zyl**
Golder Associates, Inc.
200 Union Boulevard, Suite 500
Lakewood, CO 80228

## PRODUCTION EDITOR:

**R. L. White**
2816 South Fenton Street
Denver, CO 80227

## EDITOR AT LARGE:

**K. E. Dyas**
15968 Quarry Hill Drive
Parker, CO 80134

# LIST OF CONTRIBUTING AUTHORS

**S. Alfers**
Alfers & Carver
The Equitable Building
730 Seventeenth Street, Suite 340
Denver, CO 80202

**M. Allender**
Allen Brand Public Relations
427 Broadway
Jackson, CA 95642-2416

**F. K. Allgaier**
P. O. Box 260589
Lakwewood, CO 80226

**J. L. Armstrong**
Phelps Dodge Corporation
2800 North Central Avenue
Phoenix, AZ 85004

**R. A. Arnott**
ERM - Rocky Mountain, Inc.
5950 South Willow Drive, Suite 200
Greenwood Village, CO 80111

**A. Babich**
Environmental Law Institute
1616 P Street, NW
Washington, DC 20036

**R. Backer**
U. S. Bureau of Mines
East 315 Montgomery Avenue
Spokane, WA 99207-2291

**B. C. Bailey**
Noranda Minerals
12640 West Cedar Drive
Lakewood, CO 80228

**A. C. Baldrige**
Battle Mountain Gold Company
5670 Greenwood Plaza Boulevard, Suite 106
Englewood, CO 80111

**F. R. Banta**
Amax Gold
9100 East Mineral Circle
Englewood, CO 80112

**B. J. Beckham**
Woodward-Clyde Consultants
Stanford Place 3, Suite 1000
4582 South Ulster Street
Denver, CO 80237-2637

**R. T. Beckman**
2642 South Kline Circle
Lakewood, CO 80227-2749

**D. L. Bentel**
Steffen, Robertson & Kirsten
1755 East Plumb Lane, Suite 241
Reno, NV 89502

**Z. T. Bieniawski**
Pennsylvania State University

**S. Blackstone**
415 West 2nd Avenue
Windermere, FL 34786

**G. Blankenship**
Planning Information Corporation
1625 Broadway, Suite 2670
Denver, CO 80202

**J. Bokich**
Knight Piésold
1050 17th Street, Ste 500
Denver, CO 80265-0501

**C. L. Boldt**
U. S. Bureau of Mines
East 315 Montgomery Avenue
Spokane, WA 99207-2291

**A. Born**
Alumax, Inc.
Peachtree Parkway
Norcross, GA 30092-2812

**S. D. Botts**
Echo Bay Mines
6400 South Fiddlers Green Circle - Suite 1000
Englewood, CO 80111-4957

**A. Brown**
Adrian Brown Consulting
155 South Madison
Denver, CO 80209

**D. E. Brown**
Lilburn Corporation
110 Blue Ravine Road, Suite 209
Folsom, CA 95630

**M. L. Brown**
Golder Associates
4104 - 148th Avenue, N.E.
Redmond, WA 98052

**T. H. Brown**
Western Research Institute
Office of Engineering
365 North 9th Avenue
Laramie, WY 82070

**T. D. Burke**
ARS
P. O. Box 701
Virginia City, NV 89440

**J. K. Burrell**
Riverside Technology, Inc.
1600 Specht Point Drive, Suite F
Fort Collins, CO 80525

**L. J. Buter**
Newmont Gold Company
1700 Lincoln Street
Denver, CO 80203

**S. P. Canton**
Chadwick & Associates, Inc.
5676 S. Sycamore St., Suite 101
Littleton, CO 80120

**J. W. Chadwick**
Chadwick & Associates, Inc.
5676 S. Sycamore St., Suite 101
Littleton, CO 80120

**C. C. Clark**
U. S. Bureau of Mines
East 315 Montgomery Avenue
Spokane, WA 99207-2291

**W. J. Clark**
Westec
5600 South Quebec Street, Suite 307D
Englewood, CO 80111

**D. J. Conklin Jr.**
Chadwick & Associates, Inc.
5676 S. Sycamore St., Suite 101
Littleton, CO 80120

**G. E. Conrad**
Interstate Mining Compact Commission
459 - B Carlisle Drive
Herndon, VA 22070

**L. W. Cope**
Placer Consultant
111 Emerson Street, #723
Denver, CO 80218

**P. G. Corser**
TerraMatrix, Inc.
1475 Pine Grove Road, Suite 109
P. O. Box 774018
Steamboat Springs, CO 80477

**J. Cowan**
4141 Arapahoe Avenue, # 200
P. O. Box 4579
Boulder, CO 80306

**A. D. Cox**
Homestake Mining Company
650 California Street
San Francisco, CA 94108-2788

**C. A. Cravotta III**
U. S. Geologicial Survey
840 Market Street
Lemoyne, PA 17043

**A. W. Czarnowsky**
343 West Drake Avenue, Suite 108
Fort Collins, CO 80526

**J. T. Dale**
US EPA
999 18th Street, Suite 500
Denver, CO 80202-2405

**A. L. Dangeard**
MEED SA
51 rue Spontini
75116, Paris, France

**J. L. Danni**
Placer Dome, U.S., Inc.
One California Street, Suite 2500
San Francisco, CA 94111

**T. E. Davis**
Division of Land Resources
North Carolina Department of Environment,
Health, and Natural Resources
P. O. Box 27687
Raleigh, NC 27611-7687

**R. E. Deery**
Bureau of Land Management
3122 Christine Drive
Beltsville, MD 20705

**J. H. Desautels**
Parcel, Mauro, Hultin, & Spaanstra, P. C.
Suite 3600
1801 California Street
Denver, CO 80202

**M. A. Drozd**
Detox and Treatment Consulting, Inc.
7205 South Chase Court
Littleton, CO 80123-4940

**R. Dutton**
Planning Information Corporation
1625 Broadway, Suite 2670
Denver, CO 80202

**R. T. Dwyer**
National Mining Association
1920 N Street NW, Suite 300
Washington, DC 20036-1662

**R. H. Early**
Sedgwick James of Colorado
2000 South Colorado Blvd., Suite 5000
Denver, CO 80222

**T. P. Erwin**
Erwin, Thompson, & Hascheff
333 Holcomb Avenue
Reno, NV 89509

**A. J. Fejes**
5775 South Kline
Littleton, CO 80160

**B. A. Filas**
Knight Piésold
1050 17th Street, Ste 500
Denver, CO 80265-0501

**L. H. Filipek**
U. S. Geological Survey
MS 972, Box 25046, Denver Federal Center
Denver, CO 80225

**R. B. Finkelman**
U. S. Geological Survey
956 National Center
Reston, VA 22092

**W. G. Fischer**
Trona Associates, Inc.
381 Bramwell Street
Green River, WY 82935-4838

**J. E. Florczak**
Continental Bank
231 South La Salle Street
Chicago, IL 60697

**S. Foreman**
Resource Management International, Inc.
La Plaza - 4340 Redwood Highway - Building B
San Rafael, CA 94903

**C. H. Gardner**
Division of Land Resources
North Carolina Department of Environment,
Health, and Natural Resources
P. O. Box 27687
Raleigh, NC 27611-7687

**W. Garrett**
Nevada Environmental Consultants
7530 West Sahara, Suite 108
Las Vegas, NV 89117

**A. J. Gilbert**
Sherman & Howard
3000 First Interstate Tower North
633 Seventeenth Street
Denver, CO 80202

**R. Griffith**
Heller, Ehrman, White, & McAullife
333 Bush Street
San Francisco, CA 94104-2878

**M. Hames**
Kilborn Engineering (B.C.), Ltd.
400-1380 Burrard Street
Vancouver, B. C., Canada V6Z 2B7

**C. J. Harmon**
PanEnergy Field Services, Inc.
370 17th Street, Suite, 900
Denver, CO 80202

**E. F. Harvey**
Browne, Bortz, & Coddington, Inc.
155 South Madison
Denver, CO 80209

**E. F. Haase** (Deceased)

**B. W. Hassinger**
Smith Environmental Technologies Corp.
304 Inverness Way South, Suite 200
Englewood, CO 80112

**D. J. Helm**
University of Alaska Fairbanks
Agricultural and Forestry Experiment Station
533 East Fireweed
Palmer, AK 99645

**M. E. Henderson**
Westec
5250 Neil Road, Suite 300
Reno, NV 89502-2341

**M. J. Hlinko** (see also Mark E. Smith)
Vector Engineering, Inc.
12438 Loma Rica Drive, Suite C
Grass Valley, CA 95945

**M. J. Hrebar**
Mining Engineering Department
Colorado School of Mines
Golden, CO 80401

**K. Johnson**
Johnson Environmental Concepts
P. O. Box 330
17 Main Street
Rapid City, SD 57709

**J. M. Johnson**
Golder Associates, Inc.
200 Union Boulevard, Suite 500
Lakewood, CO 80228

**S. W. Johnson**
Riverside Technology, Inc.
1600 Specht Point Drive, Suite F
Fort Collins, CO 80525

**T. Keith**
EDAW, Inc.
240 East Mountain Avenue
Fort Collins, CO 80524

**J. J. Kendall**
TerraMatrix, Inc.
165 South Union Blvd.
Lakewood, CO 80228

**A. Kent**
Golder Associates
4260 Still Creek Drive, Suite 500
Burnaby, BC V5C 6C6

**P. Keppler**
Popham, Haik, Schnobrich and Kaufman Ltd.
1200 17th Street - Suite 2400
Denver, CO 80202

**F. E. Kirby**
US Office of Surface Mining
1999 Broadway, Suite 3320
Denver, CO 80202

**R. L. P. Kleinmann**
Department of Energy
Pittsburgh Research Center
P. O. Box 18070
Pittsburgh, PA 15236

**A. J. Krause**
TerraMatrix, Inc.
1475 Pine Grove Road, Suite 109
P. O. Box 774018
Steamboat Springs, CO 80477

**J. Kreps**
Knight Piésold
1050 17th Street, Ste 500
Denver, CO 80265-0501

**A. L. Kuestermeyer**
Behre Dolbear & Co., Inc.
275 Madison Avenue
New York, NY 10016

**J. T. Laman**
In-Situ Inc.
210 S. Third Street
P. O. Box I
Laramie, WY 82070-0920

**R. M. Larkin**
U. S. Forest Service
Toiyabe National Forest
1200 Franklin Way
Sparks, NV 89431

**M. C. Larson**
Ballard, Spahr, Andrews & Ingersoll
1225 17th Street, Suite 2300
Denver, CO 80202

**T. V. Leshendok**
U. S. Department of Interior
Bureau of Land Management
P. O. Box 12000
Reno, NV 89520-0006

**L. Levy**
Planning Information Corporation
1625 Broadway, Suite 2670
Denver, CO 80202

**A. Lewis-Russ**
Titan Environmental
7939 East Arapahoe Road, Suite 230
Englewood, CO 80112

**B. J. Licari**
10981 Race Track Road
Sonora, CA 95370

**R. L. Lowrie**
1694 North Woodhaven Drive
Franktown, CO 80116

**W. J. Lynott**
Office of Environmental Analysis
Minnesota Pollution Control Agency
520 Lafayette Road
St. Paul, MN 55155

**L. J. MacDonell**
Hazen and Sawyer
4000 Hollywood Boulevard
Seventh Floor, North Tower
Hollywood, FL 33021

**D. Malhotra**
Resource Development Inc.
11475 West Interstate 70, Frontage Road North
Wheat Ridge, CO 80033

**J. J. Marcus**
1569 De Anza Blvd
San Mateo, CA 94403-3940

**W. E. Martin**
Environmental Policy Center
Mineral Economics Department
Colorado School of Mines
Golden, CO 80401

**J. K. McAdoo**
JBR Consultants
134 West Maple
Elko, NV 89801

**G. E. McClelland**
McClelland Laboratories, Inc.
1016 Greg Street
Sparks, NV 89431

**L. A. McDonald**
Hazen and Sawyer
4000 Hollywood Boulevard
Seventh Floor, North Tower
Hollywood, FL 33021

**C. A. McLean**
13805 Ginger Loop
Penn Valley, CA 95946

**G. C. Miller**
University of Nevada
Mail Stop 330
Reno, NV 89557

**Z. C. Miller**
Davis, Graham, & Stubbs
370 17th Street, Suite 4700
Denver, CO 80202

**P. G. Mitchell**
Downey, Brand, Seymour, & Rohwer
555 Capital Mall - 10th Floor
Sacramento, CA 95814-4686

**R. T. Moore**
Poudre Environmental Consultants, Inc.
966 Wagon Wheel Drive
Fort Collins, CO 80526-2632

**K. W. Mote**
Northwest Mining Association
414 Peyton Building
Spokane, WA 99201-0790

**F. F. Munshower**
Reclamation Research Unit
106 Linfield Hall
Montana State University
Bozeman, MT 59717

**J. A. Murray**
Bechtel, Inc.
Box 3965
San Francisco, CA 94105-1895

**E. P. Newman**
Harding Lawson Associates
707 17th Street, Suite 2400
Denver, CO 80202

**D. K. Nordstrum**
U. S. Geological Survey
3215 Marine Street
Boulder, CO 80303

**P. V. O'Conner**
Westec
5600 South Quebec Street, Suite 307D
Englewood, CO 80111

**J. O'Hearn**
Morrison - Knudsen Co., Inc.
P. O. Box 2011
Oak Ridge, TN 37831-2011

**L. Orser**
Echo Bay Minerals Company
P.O. Box 1658
Battle Mountain, NV 89802

**S. J. Pachet**
Knight Piésold & Co.
1600 Stout Street, Suite 800
Denver, CO 80202-3129

**C. Parrish**
Canyon Resources Corp.
14142 Denver West Parkway, Suite 250
Golden, CO 80401

**R. C. Pease**
Siskon Gold Corporation
350 Crown Point Circle, Suite 100
Grass Valley, CA 95945

**J. A. Pendleton**
Division of Minerals and Geology
State of Colorado Department of Natural Resources
1313 Sherman Street,
Denver, CO 80203

**R. W. Phelps**
Engineering and Mining Journal
29 North Wacker Drive
Chicago, IL 60606

**S. M. Pirner**
Division of Environmental Regulation
South Dakota Department of Environment
and Natural Resources
Joe Foss Building
523 East Capitol
Pierre, SD 57501-3181

**E. O. Pitschel**
Soriano Corporation
7207 Cart Gate Drive
Houston, TX 77095

**P. C. Rusanowski**
Raven Environmental Services
628 Basin Road
Juneau, AK 99801

**L. K. Russell**
Coeur D'Alene Mines Corp.
505 Front Street
Coeur D'Alene ID, 83816-0316

**W. M. Schafer**
Schafer & Associates
P. O. Box 6186
Bozeman, MT 95715

**B. J. Scheiner**
BCD Consulting
2802 Union Chapel Road
Northport, AL 35476

**W. Schenderlein**
Riverside Technology, Inc.
2821 Remington Street
Fort Collins, CO 80525

**E. M. Schern**
Phelps Dodge Corporation
2800 North Central Avenue
Phoenix, AZ 85004

**R. L. Schmiermund**
Knight Piésold
1050 17th Street, Ste 500
Denver, CO 80265-0501

**J. W. Schwarz**
Pacel, Mauro, Hultin & Spaanstra, P.C.
Suite 3600
1801 California Street
Denver, CO 80202

**B. F. Schwarzkoph**
Box 482
Forsyth, MT 59327

**C. Secrest**
EN-342
U.S. Environmental Protection Agency
401 M Street, SW
Washington, DC 20460

**S. K. Sharma**
Criterion Catalyst Company, L. P.
1800 East U. S. 12
Michigan City, IN 46360

**L. Sharp**
Woodward-Clyde Consultants
111 SW Columbia, Suite 990
Portland, OR 97201

**T. A Shepard**
Shepard Miller, Inc.
1600 Specht Point Drive, Suite F
Fort Collins, CO 80525

**J. Siegel**
MK - Environmental
7100 East Belleview Avenue
Englewood, CO 80111

**D. B. Simons**
Simons & Associates, Inc.
2601 South Lemay Avenue, Suite 39
Fort Collins, CO 80525

**M. M. Singh**
Engineers International, Inc.
98 East Naperville Road, Suite 201
Westmont, IL 60559-1595

**D. E. Siskind**
5812 Thomas Circle
Minneapolis, MN 55410

**A. C. S. Smith** (Deceased)

**D. A. Smith**
Fort Lewis College
Durango, CO 81301

**M. E. Smith**
Vector Engineering, Inc.
12438 Loma Rica Drive, Suite C
Grass Valley, CA 95945

**R. Spotts**
Riverside Technology, Inc.
1600 Specht Point Drive, Suite F
Fort Collins, CO 80525

**R. L. Spude**
National Park Service
12795 West Alameda Parkway
P. O. Box 25287
Denver, CO 80225

**R. G. Steen**
Air Sciences Inc.
12596 West Bayaud Avenue
Lakewood, CO 80228

**M. H. Stotts**
Kansas Department of Health and Environment
Waste Management Bureau
Forbs Field, Building 740
Topeka, KS 66620-0001

**D. W. Struhsacker**
Environmental Permitting and Government Relations
Consultant
3610 Big Bend Lane
Reno, NV 89509

**C. Taggart**
EDAW, Inc.
240 East Mountain Avenue
Fort Collins, CO 80524

**T. J. Toy**
Department of Geography & Geology
University of Denver
Denver, CO 80208

**R. K. "Ivan" Urnovitz**
Northwest Mining Association
10 North Post Street, Suite 414
Spokane, WA 99201

**T. Van Haverbeke**
Room 102, Chauvenet Hall
Colorado School of Mines
Golden, CO 80401

**D. J. A. Van Zyl**
Golder Associates, Inc.
200 Union Boulevard, Suite 500
Lakewood, CO 80228

**R. B. Vrooman**
Law Offices
615 Battery Street, 6th Floor
San Francisco, CA 94111

**R. C. Warner**
Department of Biosystems Engineering
and Agricultural Engineering
128 Agricultural Engineering Building
University of Kentucky
Lexington, KY 40546-0276

**R. Weyand**
Deloitte and Touche
Suite 1800
1560 Broadway
Denver, CO 80202-5151

**K. G. Whitman**
Whitman & Co.
1790 East River Road, #112
Tucson, AZ 85718

**D. Williams**
Homestake Mining Company
650 California Street
San Francisco, CA 94108-2788

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# Chapter 1
# INTRODUCTION

J. J. Marcus

## 1.1 FOREWORD

The objective of this chapter is to provide a foundation for the rest of the Handbook. It does so by initially describing the history and outlining the purpose, which is then followed by a definition of its structure or organization, which is immediately succeeded by a Reader's Guide for each chapter. Finally, it alerts the reader to the current rush of events that make for a short shelf life for some of the presented information, especially laws in force and controlling political events. Nevertheless, this Handbook is designed to be more a manual stressing basic principles that change little, rather than a textbook supplier of details that are constantly in transition. As such, the Authors and Editors have tried to focus upon more universal design concepts in the field. Even if specific examples become dated, the Handbook is meant to be an enduring repository of basic engineering theories that form the foundation of environmental protection in the mining industry.

## 1.2 PURPOSE OF THE HANDBOOK

The need for a mining environmental handbook, which would examine and define the dual effect of mining on the environment and the relatively new environmental controls on mining was evident for well over a decade. It first became apparent to the Editor during his employment as a consultant to the United States Environmental Protection Agency (USEPA) in the mid-1980s. Upon subsequent discussions with various mining industry peers, it became increasingly evident that a mining environmental handbook would be of value to more than just the staff of the government regulatory agencies and could also prove beneficial to operators, manufacturers, design engineers/consultants, environmentalists, legislators, and financiers. A handbook covering a wide range of topics was thought necessary for a variety of reasons:

- As a technical reference, design, and minerals operating practice source, and teaching tool primarily concerned with the entire mining industry with emphasis on the hard rock (metallic) portion.
- As a manual illustrating the steps and details required to bring a new mine into full environmental compliance.
- As a prod to mining industry professionals to stress the need to take the initiative in identifying and alleviating environmental problems in a dynamic milieu.
- As a point of agreement or departure, i.e., a technical working tool for discussions/decisions on the impact of mining environmentalism and the necessity for defining operating and remediation requirements.
- As a sounding board for new ideas or concepts.

Soon after project startup it was decided that to make the Handbook an effective tool:

*Every effort would be made* to produce an unbiased study that could be accepted by all interested parties with differing environmental perceptions, but not to restrict the introduction of contrasting points of view, especially when needed for purposes of illustration.

*The subjects treated would be limited* to mining and processing up to, but not including, the application of heat (the RCRA definition).

*A snapshot in time of the mid 1990s* would be presented. This recognized the dynamic nature of many of the topics under discussion, especially the status of American federal and state laws, and the charter of some of the regulatory agencies. The only exception is the chapter on the historical perspective of environmentalism.

*Generic data would be presented* wherever possible in the application of design principles.

*The work would be concentrated* on, but not completely confined to, the United States of America.

## 1.3 ORGANIZATION OF THE HANDBOOK

The Mining Environmental Handbook is arranged in a

conventional, step-wise fashion to follow the natural order of cause and effect. As a foundation for the technical information to follow, Chapter 2 examines the role of mining in the environment, and the growth and effect of environmental consciousness on mining. Chapters 3 and 4 outline the pertinent federal and state laws dealing with mine environmentalism. Following, are five key chapters, Chapters 5 through 9, which together form the technical heart of the Handbook, dealing with the why's, what's, how's, and who's; addressing issues such as environmental problem identification, available protection technologies, the permitting process, design of facilities, and management of the environmental effort. Chapters 10 through 14 treat specialized or individual mining situations, i.e. solution mining and in situ leaching; dredging and placer mining; coal; acid mine drainage; and uses of surface mines as landfills and repositories. Chapters 15 and 16 deal with costs and financial assurance requirements. Chapters 17 and 18 picture or amplify the preceding information either outside of the United States, or as case studies. Finally, Chapter 19 puts mining environmentalism in current and future perspective. A Directory of Lead State Environmental Agencies and a Glossary follow Chapter 19.

### 1.3.1 READER'S GUIDE

Chapter 1 has been prepared as a reader's guide, to indicate the purpose, philosophy, and any special circumstances that were taken into consideration during the preparation of each chapter. It should be noted that the third digit of each of the following sections of the guide also corresponds to the actual number of each relevant chapter.

### 1.3.2 HISTORICAL PERSPECTIVE

To set the stage for the remainder of the Handbook, a "warts and all" historical perspective of the interaction of mining and environmentalism is presented in Chapter 2. This chapter provides full coverage of the subject and includes some obviously contentious material, much of which is taken from direct quotes for added emphasis. The purpose of incorporating background details of this sort is not to feed the flames of controversy, but instead to provide an opportunity for better understanding some of the dissimilar ideas and emotions in play. This should then provide the understanding reader with a greater ability to deal with people who hold contrasting points of view. Specifically, the chapter is designed to establish an unbiased datum plane of the most up-to-date reference material, or flat playing field in terms of all the different environmental participants and issues, most particularly, as they see themselves. Major subjects treated are:

- The American mining industry in current (environmental) perspective.
- How did we get here (in terms of the present state of mining environmentalism).
- The environmental role of the federal and state governments.
- Some background material on the environmental organizations that may be involved with mining.
- An outline of the philosophies and methods employed by the environmental organizations that are interested in the mining industry.
- A listing and some background data on mining industry non-technical associations that may be involved in environmental matters, particularly lobbying.
- A listing of the relevant non-advocacy groups that usually deal in pertinent information.
- The factors involved in the call for a change in the federal mining law (especially in terms of environmental matters), areas of possible change, and position of some of the protagonists.
- An editorial calling for restraint and compromise building by all the disparate parties interested in mining and environmental control.

Emphasis of Chapter 2 is placed on California, not because of its relative quantity of hard rock mining, but due to the importance of the state as a leading center of environmental thought and legislative action.

Many people both directly and indirectly associated with this Handbook contributed information and ideas and immeasurably assisted by providing direction and information, helped moderate some stridency, and also pointed out errors in logic and substance. Nonetheless, the basic viewpoint presented is that of the Editor who, while endeavoring to provide objectivity, has also included some obvious middle ground editorial comments.

### 1.3.3 THE LEGAL BASES OF FEDERAL CONTROL

Chapter 3 describes the major statutes and ideas that comprise the federal environmental regulation of mining. Though state and local regulation remain important, federal environmental laws enacted over the past 25 years have established the underpinning of environmental protection throughout the United States. This body of federal law forms the core of modern regulation of mining activities

Chapter 3 begins with an overview of federal environmental law, including a broad description of major themes found in federal statutes. It also provides a guide to the organization of federal environmental law and regulations, and how to find them. The chapter then turns to separate descriptions of each of the major federal environmental statutes. Statutes addressed include the Clean Air Act, the Clean Water Act, the Resource Conservation and Recovery Act (or RCRA, see above), the Comprehensive Environ-

mental Response, Compensation, and Liability Act (or "Superfund"), among others. Finally, this chapter also contains a description of the environmental protection aspects of the public land laws.

### 1.3.4 ENVIRONMENTAL CONTROL AT THE STATE LEVEL

Chapter 4 stresses the importance of environmental control of mining at the state level, which is often overlooked, and even misunderstood. It is currently the most active in terms of actual regulation, and dynamic in relation to the new legislation being enacted or contemplated. Initially an attempt is made to define the state-federal allocation of responsibilities followed by an overview of state programs. The states of California, Minnesota, North Carolina, and South Dakota are then singled out for more detailed explanation. The Interstate Mining Compact Commission for the eastern states, and the Western Governors' Association for the western states are outlined in terms of their activities.

### 1.3.5 & 6 ENVIRONMENTAL EFFECTS OF MINING - TECHNOLOGIES FOR ENVIRONMENTAL PROTECTION

Chapters 5 and 6 are designed as complementary and parallel chapters. Chapter 5, "Environmental Effects of Mining," covers a broad spectrum of mining-related environmental effects associated with planning, operating, and closing all types of mining operations. The chapter is divided into the broad categories of land, water, biologic aspects, air, and cultural consequences. Under each broad category, there are descriptions of what is affected, an explanation of what causes the effects, and a general description of the nature of the effects.

Chapter 6, "Technologies for Environmental Protection," under similar broad categories of land, water, air, biologic aspects, and cultural consequences, describe the control technologies available to prevent adverse environmental effects, or to mitigate the effects that do occur. For each category of environmental effects described in Chapter 5, Chapter 6 describes the technologies, practices, and standards aimed at preventing, controlling, or remediating any adverse effects.

Like many aspects of the mining environmental field, technology is changing rapidly. In addition, there are essentially an unlimited number of site-specific problems and special cases. In approaching this complex universe of environmental effects and technologies, the intent of Chapters 5 and 6 is twofold. The first is to present a broad coverage of the major types of environmental effects and the current state of available technologies, to give the reader a sense of the nature of various environmental impacts and the current technological approach to these issues. The second is to assist those with specific environmental problems to solve them by providing a tool to zero in on the best solutions on the basis of similar problems and applicable solutions presented in Chapters 5 and 6.

### 1.3.7 ENVIRONMENTAL PERMITTING

Chapter 7 is a key chapter in the Handbook. It explains the "why" and then goes into significant detail on the "how" of environmental permitting. As such, it is expected that this chapter will prove useful if not indispensable to most users of this Handbook. After a stage setting introduction the following all encompassing topics are addressed:

- Defining mineral system characteristics that may affect the environment.
- Defining project site environmental conditions (The Baseline Evaluation).
- Defining legal and regulatory requirements.
- Developing a permitting strategy.
- The EIS process.
- Defining project impacts, developing mitigation, and reclamation planning.
- Engineering for permitting versus construction and mine development.
- Closure and post closure planning.
- Project monitoring.
- Public relations and communications programs.
- Political involvement.

As stressed in Chapter 2, while most contributing authors and key personnel are employed in the mining industry, care has been taken to omit any partisan comments. Nevertheless, the last section of Chapter 7, dealing with political involvement, has been presented from the operating miner's point of view. However, the message can be applied to any other point of view dealing with the mining industry.

### 1.3.8 SYSTEMS DESIGN

Chapter 8 focuses on the design process as applied to the disposal and containment facilities for mine tailings, waste rock, heap-leach ore, and associated process solution or leachate. Modern mining operations can develop large quantities of these materials, and have the potential for extensive environmental impacts if the process solutions and waste materials are not handled properly. The authors present up-to-date illustrations of how to properly design for this important task.

The authors present design standards, containment technologies, and disposal methods commonly used at mining sites today. The increasing emphasis on minimization of potential impacts to human health and the environment is described contrasting earlier standards that

placed greater consideration on low cost disposal and structural stability. The authors further conclude that the design goal of mine industry disposal and containment facilities, at the onset, must be based on successful closure as well as successful construction and operation. To accomplish this goal two key design aspects must be taken into consideration. They are: 1) the site-specific nature of the environmental protection requirements; 2) the need to properly integrate unit operations into sub-systems and then highly complex systems.

### 1.3.9 OPERATIONS ENVIRONMENTAL MANAGEMENT

On a generic basis for a medium to large size company, Chapter 9 is designed to place in perspective the environmental management requirements of a new mining project. The chapter's message is simple, that early, continuous, and coordinated environmental effort is required to ensure that a project's success is not otherwise impeded. In particular the concept of a "fatal flaw environmental evaluation" is preached prior to a project "go" decision in order to avoid permitting delays and the premature expenditure of major cash flows. The importance of Chapter 9 can not be sufficiently overstated for the success of a new project. Ongoing mining industry operators may also be introduced to new and useful information.

### 1.3.10 SOLUTION MINING AND IN SITU LEACHING

Solution mining and in-situ mining are at times mistaken for each other. They are distinct technologies adopted to different sets of geologic circumstances. Solution mining uses water as the solvent and creates caverns while extracting soluble minerals. On the other hand, in-situ leaching uses chemicals added to water to selectively extract minerals from permeable settings with no cavern creation. Section 1 of Chapter 10 describes solution mining technology and Section 2 describes in-situ leach technology.

### 1.3.11 PLACER AND ALLUVIAL MINING

Placer mining for gold has undergone a renaissance within the last few decades primarily because of the higher price for gold and better knowledge and available equipment. Chapter 11 presents an overview of the environmental impact of and a general description of placer mining. This is followed by a brief commentary on the general permitting and reclamation requirements. The next section offers a comprehensive study of the recent shallow ocean dredging off the coast of Alaska. Also in Alaska the problem of settlement of slimes is examined in terms of the use of flocculants. Finally, the usage of the hazardous element mercury is presented on a historic level and then its dangers and safeguards are pointed out.

### 1.3.12 COAL

The coal mining and processing industry, in part, has been examined throughout this Handbook. It is also treated by itself in Chapter 12 because of its unique position in the American mining environmental picture. Its status is dictated and illustrated by the large size, geographic diversity, and long history of the industry; special environmental problems of widespread land disturbance and surface subsidence; very long lasting environmental difficulties such as the production of acid mine/rock drainage, and waste piles subject to spontaneous combustion; and the establishment of a federal environmental regulatory agency for a single mined product.

Chapter 12 is meant to introduce the environmental professional to the issues and regulatory processes specific to the coal industry. Non-coal industry personnel should also take special note of the degree to which coal mines are regulated in the United States. Coal mining regulation may serve as a model for future governmental activities in other mining sectors.

### 1.3.13 ACID MINE DRAINAGE AND OTHER MINING-INFLUENCED-WATERS (MIW)

Chapter 13 presents a brief overview of natural waters affected by mining activities. Acid mine drainage (AMD) is shown to be a subset of all mining-influenced-waters (MIW), and not a universal characteristic. Five major characteristics are discussed. The weathering of sulfide minerals produce acidic, sulfur-rich waters with elevated iron and other metal concentrations. Sulfide mineral weathering is accelerated by bacteria such as *Thiobacillus ferrooxidans*, and the overall process is seen to consist of an initiation step followed by a propagation step. Neutralization of such waters through reactions with carbonate and silicate rock types raises pH and tends to cause the precipitation of metals, frequently resulting in turbidity due to suspended ferric oxyhydroxides. Geochemical processes that control the five major characteristics of MIW are discussed and shown to be interrelated but sufficiently unique to require individual examination for an adequate understanding of MIW production and attenuation.

The second part of the Chapter deals with cost estimates to remediate MIW. Values calculated have an order-of-magnitude level of accuracy, and should be accordingly employed. Nevertheless, the reader should be able to update and modify the data for site specific examinations.

### 1.3.14 USE OF SURFACE MINES AS LANDFILLS AND REPOSITORIES

There is a natural esthetic, environmental, and economic

synergism with the employment of abandoned surface mines as landfills or repositories. As landfills become more difficult to locate and permit, it is expected that old mines will be increasingly utilized. The purpose of Chapter 14 is to provide an overview of the design practices that are being currently used to meet most regulatory guidelines. Furthermore, observations are included on the use of these practices for current or abandoned mines. Finally, the advantages and disadvantages of developing and also operating waste disposal facilities within mined areas is included.

### 1.3.15 ECONOMIC IMPACT OF REGULATION

The purpose of Chapter 15 is to attempt to quantify the impact of environmental regulations on mining ventures in the United States. This can not be fully accomplished because all the effects of the current and projected environmental regulations can not be completely determined and the environmental benefits of many of the regulations are intangible and therefore difficult to measure in a conventional benefit-cost analysis.

Nevertheless, on a partial basis the environmental impact on a project's profitability can be determined by employing accepted engineering methods of mine project estimation. The results are startling. Comparing theoretically identical projects within and outside the United States, and further assuming equal pollution control requirements, a project outside the United States can be almost twice as profitable. This is attributable to two factors: increased data and report requirements and vastly increased time needed for approval. The net economic results are significantly-increased-direct costs of reporting, "taxi meter time," and a time value of money delay factor on the project.

Economic modeling of this kind is little past its infancy. It is desired, hoped, and expected that by the medium term advances in modeling and data gathering will result in more exact evaluations that will be of use to all interested in the mining industry.

### 1.3.16 FINANCIAL ASSURANCES

The concept that financial assurances should be demanded by regulatory agencies first appeared in the RCRA regulations several decades ago. They also stipulated that a formal closure procedure was required as well as a post closure observation period. In addition the idea gained ground that certain industrial activities required either catastrophic insurance or else standby funds during the course of normal operation. Gradually states began incorporating these requirements in their own regulations, and the federal government also expanded its initial requirements out of RCRA. Complete closure requirements for mining remain to be fully defined, however, the prudent mining company will ensure that proper allowances are provided for all new mining ventures as well as retroactively for older mines. Currently lacking definition are closure requirements, the types of financial assurances permitted, self-insurance acceptance criteria, the timing for submittal of assurance requirements, coverage and distribution mechanisms, and release criteria, post closure time requirements, any possibility of retroactivity, and grandfathering.

Nevertheless, a clear picture is emerging that outlines the situation for the mining industry. There is, however, one major sticking point, the great difficulty a mining company with less than an investment-grade-financial rating has in acquiring suitable support in the form of sureties or insurance.

### 1.3.17 INTERNATIONAL REGULATIONS

Chapter 17 deals with the international regulation of mining. Outside of the United States, environmental regulation of mining varies with the country involved. In the industrialized nations, environmental controls are similar to those in existence in the United States. In the developing nations, controls and practices vary significantly. In almost all of the developing nations, environmental laws have been legislated based upon those already in existence in the industrialized nations. However, in the developing nations the degree of actual mine industry environmental regulation varies greatly. As the situation in the United States is in flux, so the situation outside the United States is even more so. Consequently, it is patently impossible to provide an up-to-date comprehensive record of world mining environmentalism in a Handbook of this nature. Rather an attempt is made to offer general guidelines with representative examples. The practitioner is cautioned, before the fact, to gain an inclusive understanding of the environmental regulations and activities of any nation in which mining ventures are projected.

### 1.3.18 CASE STUDIES

Case studies selected for the Handbook illustrate the environmental challenges that face the mining community both on-the-ground and in public policy forums. Chapter 18 offers five widely varied studies. They describe efforts that have been undertaken to cleanup and reclaim old mine sites, to permit previously disturbed areas under current regulations, to permit a new site, and to influence legislation.

Two of the studies describe government actions under the Comprehensive Environmental Response Compensation and Liability Act (CERCLA), also known as Superfund, and the Superfund Amendments and Reauthorization Act (SARA). The Iron Mountain Case discusses the Environmental Protection Agency's effort to clean up the

mine waste and acid drainage at one major location in Shasta County, California. The study describes the complexities of trying to define the problem and to develop technical solutions.

The other CERCLA study discusses the events at Summitville, Colorado where a mine site is being managed by the federal and state governments under the response provisions of the Act. The company was substantially undercapitalized for a project of this size, and thus unable to effectively respond to the technical and environmental conditions at the site and the changing regulatory requirements. At the same time the state government found itself ill-prepared with regard to the resources and legislation necessary to address the complex regulatory problems. These two fundamental areas of private enterprise and state government failure led to a federal response. The Summitville Case has been highly controversial and has evoked a wide range of reactions. For some it has become a national "cause celebre" symbolizing abuse that can result from present day mining and ineffectual regulation. Others find the circumstances have been overstated by environmental activists and the press to serve a political purpose. The Summitville Case Study presented in this Handbook steps back from the controversy. It presents the authors view of what caused the problem and what can be learned based upon their review of public records.

One study illustrates efforts undertaken to solve environmental problems at old mine sites. At Ajo, Arizona the technical approach undertaken by the Phelps Dodge Corporation to control dust on dry tailings is described. The Phelps Dodge objective was to reduce the particulate matter emitted to the atmosphere and thus reduce the amount of dust blown into the nearby town.

The Alaska Juneau Case describes the comprehensive environmental planning and permitting efforts necessary for currently starting a mine. The shutdown Alaska Juneau operation is undergoing a review under the National Environmental Policy Act (NEPA) and other laws to obtain approval to reopen.

The last study, "Oregon - Things Look Different Here" describes the political process that occurred in the development of the Oregon Law regulating chemical process mining (notable heap leaching with cyanide). The case discusses the issues involved in the development of the legislation, the players perspectives, and the political twists and turns that resulted. It is a good example of how legislation is developed in the United States and the efforts that interested parties must put forth to work toward mutually acceptable solutions.

### 1.3.19 CURRENT AND PROJECTED ISSUES

Chapter 19, titled "Current and Projected Issues," reviews some of the major environmental concerns and questions affecting the mining industry, and examines trends that will likely have significant impacts on the industry in the next several years. The industry has made significant improvements in environmental protection during the last 30 years in response to environmental laws and public pressures. Although still often criticized for past and current mining practices, the industry continues to commit considerable resources toward reducing the environmental impacts of mineral exploration and development, as well as mine closure and reclamation.

The key environmental issues for mining discussed in Chapter 19 include revision of the Mining Law of 1872, regulation of mine waste material, land use restrictions, such as wetlands and habitat for endangered species, and requirements for reclamation and financial assurances. Chapter 19 contains comments by four authorities with different perspectives on how the industry has responded and will be impacted by these environmental challenges and trends.

Although most of the environmental laws have been enacted at the Federal level and delegated to the States, more and more control over resource development and operation is being exercised at the local and municipal and county levels. As a result, mining companies are having to involve local citizens in mine planning and obtain acceptance of the development in order to receive necessary permits. Another trend is the adoption of environmental laws and regulations in developing countries similar to the standards applicable to mining operations in the United States. With the recent congressional approval of the North American Free Trade Agreement and the emphasis on equal environmental protection in all countries, it is anticipated that the move toward global environmental standards will only accelerate.

The growing list of environmental requirements for mining and mineral processing facilities has had significant impact on the profitability of such operations. The stringent environmental standards adopted in the United States have adversely affected domestic mining firms, forcing many smaller marginal companies to cease operations. Only those companies that are well managed and have low cost operations will be able to survive in the competitive global market. A key for containing costs is to implement pollution prevention measures and stay ahead of new environmental requirements wherever feasible.

## 1.4 A WORD OF CAUTION

Normally the Latin expression *caveat emptor* is used to warn purchasers that they buy at their own risk. In this case the reader is emphatically cautioned that the field of mining environmentalism is argumentative and can be emotional, but not anymore so than other areas of environmental protection, or for that matter, other realms of social regulation. Debate over environmental protection in mining can be sharp and impassioned, and is currently

being carried out on many levels including the political, scientific, and technical. In addition it is open to very rapid change. Overall government strategies toward environmental protection have greatly shifted in basic ways several times since the late 1960s and early 1970s, and additional shifts should be expected. Therefore, all environmental information sources should be carefully checked for bias, accuracy, and timeliness or relevancy. This particularly applies to laws in force, groups having the authority to regulate, and the regulations themselves.

Caution is especially necessary when dealing with technical information in the environmental area. Quantitative and even at times qualitative data is lacking on many basic environmental processes (acid rain, global warming, etc.), and yet important policy decisions are even now being made in this information vacuum. Furthermore, even when data are available, interpretation is still subject to a great deal of uncertainty. The end result is that there is an honest lack of agreement over fundamentals by many people dealing with many of the issues pertaining to mining environmentalism. This problem leads to the intersection of technology and policy. Unfortunately, at least for the present, it must be expected that some government decisions (hopefully, as few as possible) will be made based on the best partial information at hand, and environmental protection management must accept and deal with these political realities in order to function.

Chapter 2

# DEVELOPMENT OF THE MINE ENVIRONMENTAL PRECEPT AND ITS CURRENT POLITICAL STATUS

J. J. Marcus

## 2.1 INTRODUCTION

In the first half of the 1990s, as this Handbook was being written, the American mining industry and its professionals were in a state of transition. On-going changes in the industry included ownership (18 of the 25 largest gold mines were foreign owned), mode of doing business, types of mining, methods and targets of exploration, extent and manner of competition, and, especially, public perception and degree of acceptance. The industry was truly at a significant crossroads.

This chapter's purpose is to place the mining industry in an overall historical and environmental perspective and then to suggest a moderating course of action in relation to possible mining law reform. As a first step, the environmental background of the American metallic (hard rock) mining industry is examined. Next, the development of environmental-consciousness, as an extended evolutionary process, is characterized. The role of the regulators is defined, and the principal environmentally concerned organizations are listed according to their philosophic points of view. Relevant mining industry organizations are also examined. Federal mining legislation, centered around the Mining Law of 1872, is then surveyed in light of possible modifications and future impact on environmental control. Finally, a call is made for a lowering of the current strident level of divisiveness, rhetoric, and politicizing by many of the interested parties in order to promote government-led compromise and consensus building on mining and the environment. Substantial background and source material is introduced to assist those who intend to pursue further investigations of points of interest.

## 2.2 AMERICAN MINING INDUSTRY IN PERSPECTIVE

The American mining industry, which predates the Revolutionary War, has played an essential role in the economic well-being and the national security of the United States. Its importance is manyfold: as a producer of jobs (numerous in relatively remote areas), as the source of essential raw materials, as a provider of indispensable fuels, and as a factor in support of the international balance of payments. Without mining, the development of the western United States as we currently know it, would not have been possible.

However, the cost of past mine development was high, as many early mine operators disregarded the damaging environmental consequences of their activities. At the time, these actions were both legally and even morally acceptable. The extent of damage to the environment caused by some mining operations was only understood after they had shut down, and many of the original owners have long since disappeared from the scene. Notwithstanding, serious environmental problems of yesteryear are still with us, such as abandoned radioactive tailings piles, mercury and other toxic heavy (base) metals entering the food chain, leakages and failures of tailings dams, invasion and depletion of aquifers, surface land subsidence and caving, acid mine drainage affecting wide areas, and abandoned mines requiring remediation. In some cases, environmental damage from mining is on-going at existing or recently mined sites, such as at Summitville, in Colorado. Several dozen (about 5%) Superfund sites are mining industry related. The authoritative book on this subject is *Mining America* (listed in the References).



**Figure 1** "We Were Giants" - A modern view of the Bingham Canyon mine near Salt Lake City, Utah, the largest man-made excavation in the world. The mine has been in production for about 90 years. (Photo courtesy of The Kennecott Corporation.)

### 2.2.1 PUBLIC ATTITUDE TOWARDS MINING

Public feeling towards the mining industry can be a catalyst, and at times a critical energizer, in the governmental decision-making. The American citizenry's opinion of industry cannot be ignored. This opinion was qualitatively sampled and the results presented during the American Mining Congress Coal Convention, May 3 - 5, 1992. Two papers of great interest were offered during the Communications Session: "What Do People Think Of Us? Some Insights Into Public Perceptions Of The Mining Industry," and "Changing Beliefs And Attitudes About Mining: How A Communications Audit Can Help." Both papers were written by S.A. LaTour and P.J. Houlden of Calder, LaTour and Associates Inc., based on a study commissioned by Caterpillar, Inc., for its film "Common Ground". Utilizing interviews with randomly selected people in the Chicago area, the following principal beliefs and attitudes were noted as being directed towards the mining industry:

- Mining is most strongly associated with underground methods.
- Above-ground methods scar the land.
- Mining is generally harmful to the environment.
- The mining industry exploits its workers.
- There is a lack of awareness of the benefits of mining for daily life.
- There is a lack of awarness of the mining industry's reclamation efforts.

Three films objectively describing mining, by the industry's own light, were subsequently shown to the people in the sample. The researchers found that no single film successfully counteracted all the negative beliefs of those interviewed, and some were not addressed at all. It was apparent, however, that many people's attitude towards mining had been changed to varying degree by these communications, although not all negative opinion was eliminated. Thus, it appears that the negative view many people hold of mining is somewhat superficial and can be altered by well prepared and factual information. In summation, the authors said, clear and credible communications have a substantial potential to change people's negative attitudes towards mining.

### 2.2.2 CHANGING PERCEPTIONS AND VIEWPOINTS OF THE EARTH SCIENTIST

The decades of the 1960s and 1970s brought a pivotal change in many earlier notions about mining. For up to a century, earth science professionals (mining and metallurgical engineers and geologists) were viewed and pictured themselves as being in control of the conditions and forces with which they were dealing. They felt they shared a heroic role in society. Among their ranks were presidents of the United States and Mexico, inventors, guerrillas behind the lines in the Philippines during World War II, authors of note, and even famous cartoonists. When the situation warranted, mining peole could and did do it all. The title of Chapter Two of *Mining America,* illustrates their credo by proudly proclaiming "...we were giants." Meanwhile, mining projects kept getting larger, as did their environmental effects, which were largely ignored.

The decade of the 1960s witnessed the birth of a new social and environmental awareness coupled with political activism throughout the general population. Professor Smith in *Mining America* called this wellspring of political activism "an environmental whirlwind." In the meantime, the old time miners had run out of worlds to conquer and manifest destiny had long since been fulfilled. Suddenly, Americans had to live within their means. In this new atmosphere, earth science professionals have come to see themselves in a



**Figure 2** Cyanide processing tanks at Viceroy Resource Corporation's Castle Mountain gold mine in California are designed to eliminate the problem of bird kills at heap leach operations.



**Figure 3** During the first year of operation at the Castle Mountain mine, more than 10,000 Joshua trees, cactii, and other plants were transported from the mine area to holding areas to await transplantation. Soil stockpiled from operational areas will be used for final reclamation.

different light. They view themselves in a time of rapid transition, participating in a profession that harvests nature's bounties, but with the maximum amount of care. The next decade should see the complete change from the old to the new style mining industry professional.

### 2.2.3 CHANGES IN INDUSTRY

Mining companies, as well as all heavy industries, have adjusted to the reality of factoring environmental consequences into their decision making. In addition to traditional decision-making criteria, new and sometimes unconventional, non-technical sources of information must now be utilized. This information at a minimum consists of a legal understanding of the current and projected key regulations that will impact a contemplated company decision; an appreciation of the natural environmental factors that may be affected; a forecast of the concerns of environmental groups that may be tracking the company's activities; and the anticipated response of the governing regulatory agencies.

Sources for this information may include consultants, mine lobbying organizations, regulatory agencies, or even environmental organizations. John D. Leshy, in his book *The Mining Law: A Study in Perpetual Motion*, is generally critical of the mining industry's environmental record. Still, he favorably mentions the positive accomplishments of AMAX and Homestake Mining in this connection. In a like vein, Jeff Zelms, CEO for the Doe Run company, describes another case of an environmentally proactive mining company. Finally, *The Financial Post* presented Viceroy Resource Company with an environmental award for business in 1992 (see Figures 2 - 4).

Mining companies now feel compelled to stress their positive environmental efforts, including massive recycling. Some foreign mining companies, such as Metallgesellschaft AG and INCO, have begun issuing yearly reports on environmental activities as companion pieces to their conventional annual reports.

### 2.2.4 REGIONAL ATTITUDES TOWARDS MINING

In the United States, the mining industry (hard rock, coal, and industrial minerals and rocks) is split into Western and non-Western areas, both by location and regional perceptions. Westerners are usually more forgiving of environmental impacts, due to the vastness of their region and relative isolation of the mines. Westerners understand the economic importance of mines to many Western communities and mining's role in the early development of the region. There are strong mining-advocacy as well as environmental groups in the West. In the non-West, with large, closely linked population centers, mainstream environmental groups support local resistance to the burning of waste at cement plants and to quarry openings and expansions. To illustrate the depth of this Western versus non-Western division, there are two geographically separate, state-funded data-gathering agencies: the Interstate Mining Compact Commission (IMC) and the Western Governors' Association (WGA) (see *Sect. 2.7*, and *Chapter 4*) concerned with environmental control of mining.

## 2.3 WHERE ARE WE NOW?

The best way to understand why we are at the present high level of environmental concern over mining is by

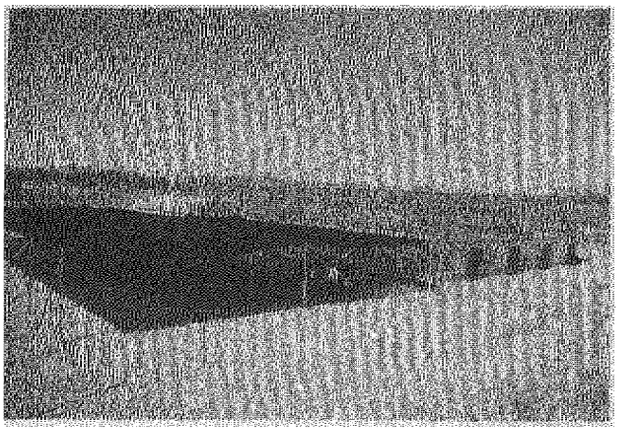


**Figure 4** Greenhouses at the Castle Mountain mine propagate native desert plants for use during reclamation.

trying to answer the fundamental questions: Where are we now and how did we get here? The existing measure of vigorous environmental concern is the end point in an increasing sequence of philosophical and social misgivings. Vague early concerns evolved over time into more specific environmental fears, which by the mid to late 19th Century came to include all industrial activity, with the mining industry as one of the focal points. The solution to industry's negative environmental impacts at first was declared to be conservation or best utilization of natural resources, i.e., elimination of waste and care for what was at hand, and multiple use of the resources. By the 1960s, legislators and regulators had come to believe that more was needed. The goal was broadened to include reclamation and after-the-fact best attempts at remediation. Eventually, this too was regarded as insufficient, and comprehensive regulation was deemed necessary and is herein referred to as environmentalism[1].

1) The term environmentalism refers to a recently coined doctrine. The *American Heritage Dictionary of the English Language*, defines it as "... advocacy or work towards protecting the environment from destruction or pollution." It is described by Von Altendorf as a... "Moral and political creed which emphasizes concern for humanity's dependence on flora, fauna, air, water, and other natural resources." In this Handbook the term is used in the following context for mining projects:

*The goal of environmentalism is to minimize any disruption of natural conditions during mining and to achieve long-term socially acceptable land use following cessation of operations. Thus designing for closure of facilities is a major aspect of environmentalism. Efforts customarily begin with a measurement of the local native state of the land. This is conventionally followed by a determination of the effect of mining on it. Subsequent operations and environmental planning and submission of documents to the regulatory agencies are usually performed concurrently. Regulatory requirements conventionally include the preparation of an Environmental Impact Statement/Report; Plan of Operations, Plans for Closure. Post Closure Monitoring and Remediation, and Emergency Response; and submission of all necessary permits. Suitable financial assurances available to protect the environment are also an indispensable ingredient for approval. Finally, with all the planning completed and regulatory conditions fulfilled, it is recognized that only carefully controlled implementation of the plans, with constant detailed feedback, is the key to reaching the desired target.*

Strong ideologic differences exist, not on the need for but on how to enforce environmentalism.

### 2.3.1 GROWTH OF ENVIRONMENTAL CONCERN

It is essential to realize that anxiety over some of the enviromental consequences of industrial development, including mining, actually existed millenia ago. By the dawn of the Bronze Age, mining (along with agriculture) as one of the earlier and highly visible modifiers of the natural ecology already had its detractors. This concern reappeared after the Dark Ages at the earliest beginnings of the Industrial Age, with mining as a hub, during the reign of Queen Elizabeth I in Great Britain. Prominent mining historian T.A. Rickard states that the term *mine* has the same root as *menace*, both of which were derived from the Latin *threat*. It can be conjectured that the threat was not only to life and limb of the miners of the time, but also to the environment. Ancient philosophers such as Seneca, Ovid and Pliny were not completely enamored with the march of technology and wrote about the negative aspects of mining. At the same time, on a practical level, attempts were already being made to stop deforestation and subsequent soil erosion in East Africa, the Cape Verde Islands, Ghana, India, China, and Lebanon. Indeed not only mining, but also forest conservation, became an early issue.

It was during the major reintroduction and expansion of mining and smelting in the 16th Century that environmental controls were first introduced in England: Coal burning was prohibited in London in order to reduce the atmospheric smoke. During the same period, Georgius Agricola, a physician and notably strong industry supporter, in *De Re Metallica*, the first modern text on mining, mentioned some of the negative effects of the industry on the environment and further refered to early restrictive Italian legislation. Later, social philosophers such as Henry Cornelius Agrippa, Edmund Spenser, John Milton, John Donne, and Baruch Spinoza led the way in portraying mining and industrialization in a negative light. In the 18th Century, the first real attempt at environmental conservation occurred on the French island of Mauritius in the Indian Ocean. There, laws were passed to retain a goodly portion of the forests, protect the water supplies from industrial effluent, and prevent excess fishing. The successful Mauritius example was soon copied by the British in the West Indies and in India.

In the 19th Century, earlier philosophical qualms were redefined into more specific ecological fears by writers such as George Perkins Marsh in his book *Man and Nature*, and the European writers Alexander Von Humboldt, Alexander Gibson, Edwards Balfour, and Hugh F.C. Leghorn. At the same time, first attempts were made to protect vanishing species of birds in the

British colonies in Africa, India, and Oceania. During the early part of the 20th Century, the noted philosophers Martin Heidegger and George Santayana continued to question the widespread accepted belief in the supremacy of man on earth aided by the seemingly inevitable march of technology. Lewis Mumford said, "Mining originally set the pattern for later modes of mechanization by its callous disregard for human factors, (and) by its indifference to the pollution and destruction of the neighboring environment." In addition, the popular British novelists Richard Llewellyn and Alexander Cordell in their biting mid-century social commentaries *How Green Was My Valley* and *The Rape of the Fair Country* depicted the grim late-Victorian Era life of the miners and steel workers and also described the negative environmental consequences of mining on the beautiful Welsh countryside. They were all helping to sow the early seeds that would eventually flower into the birth of the current vigorous and political active environmental movement in the later part of the 1960s. On a current basis, the science-fiction novel *Jurassic Park*, by Crichton, can be interpreted, on a philosophical level, as a statement against the unchecked advancement of science and as a stark contrast to the view "we were (and still are) giants" *Sect. 2.2.2.*

A who's who of the American Environmental Movement derived from a list prepared by Peter Wild includes:

- Edward Abbey - novelist, especially of the prophetic *The Monkey Wrench Gang.*
- Ansel Adams - highly acclaimed photographer of nature, particularly of the western United States.
- John James Audubon - ornithological painter of the early 19th Century.
- Mary Hunter Austin - early 20th Century novelist/naturalist, who paved the way for Abbey and Leopold.
- David Brower - organizer and manager of the Sierra Club during the 1960s and then of the Friends of the Earth.
- Bernard DeVoto - novelist and classic western Pulitzer Prize winning historian of the mid-20th Century.
- William O. Douglas - self-made man, Supreme Court Associate Justice, and vocal environmentalist.
- Aldo Leopold - government employee (Forest Service), writer, and a founder of the Wilderness Society.
- George Perkins Marsh - pioneer author in 1864 of the first book extolling primitive environmentalism.
- Stephen Mather - millionaire businessman, Assistant Secretary of Interior who energized the early National Parks Service.
- John Muir - key early inspirational naturalist, writer, and founder and first president of the Sierra Club, and the "George Washington" of the environmental movement.
- Gifford Pinchot - proponent of conservation, government employee (Forest Service),Governor of Pennsylvania, and writer.
- John Wesley Powell - Civil War veteran, explorer of the Grand Canyon, and government employee (U. S. Geological Survey), a leader in setting up initial regional planning which was the forerunner of the conservation movement.
- Wallace Stegner - Pulitzer Prize winning author/historian, college professor, member of the Wilderness Society.
- Stewart Udall - politician, government employee (Department of Interior) in the epochal 1960s, and still a powerful political force.

At the same time, interesting countervailing environmental opinions have received little attention. Sheldon Wimpfen writing in *Mining Engineering* states: "Many believe that man is almost wholly responsible for the degradation and pollution of the environment. This is a full scale example of man's arrogance as his contributions seem almost puny when compared to natural processes." Wimpfen then mentions lightning, which fixes nitrogen in the atmosphere, and major volcanic eruptions such as Krakatoa, and lately Mount St. Helens, Kilauwea, and Mount Pinatubo. He then remarks over significant past cataclysms such as the death of the dinosaurs, presumably caused by the impact of a huge meteorite in Central America, and the near recent Ice Age. Messages such as Wimpfen's are messages to the converted. They do not seem to make any impact on the general public; or else the public feels there are controllable and uncontrollable environmental events and it leans, where possible, towards dealing with the former.

### 2.3.2 MINING IN THE UNITED STATES AND THE DEVELOPMENT OF THE ENVIRONMENTAL ETHIC

Although significant settlement of the United States did not occur until the mid-18th Century, the coincident advancement of the Industrial Revolution in Europe created a demand for raw materials or semi-finished products from the New World. Commodities eagerly sought were straight, tall, trees without knots for use as ships' masts, and pig iron for varied industrial purposes. During Colonial times and into the beginning years of the American Republic, low level concern over the environmental effects of mining was already being expressed over the budding operations in southeastern Missouri, the upper Mississippi Valley, the Tri-State District, and at Dahlonega, Georgia. However, it was the

fast growing iron industry that made the first major visual impact. Spread out over most of the original colonies were numerous deposits of bog iron derived over geologic time from iron in solution that had settled out or been deposited along many East Coast streams after encountering natural limy conditions. Siliceous (hard rock) ores and sea shells were available for flux, and most blast furnaces of the time were crude and small.

The first metallurgical operations utilizing bog iron to produce pig iron date back to 1643 in Massachusetts. By 1700, annual production of pig iron was 1500 tons. This total increased to 10,000 tons in 1750, and to 30,000 tons by the time of the Revolutionary War, when the American rate of production was greater than both England and Wales, and ranked third in the world. Only wood was used in the reduction process, and whole geographic areas, especially in Pennsylvania, had their timber cut and without replanting became denuded. Ultimately, as had already occurred in Great Britain, coal had to be substituted because of the emerging lack of timber, and thus the U.S. coal mining industry was born. Other mining activity of note prior to the California Gold Rush included base metals extraction stretching from Franklin Furnace, New Jersey, to Austinville, Virginia; early gold mining in the Carolinas and Georgia; lead mining mostly for providing metal to be cast into musket balls in the mid and upper Mississippi Valley; and Lake Superior copper.

The writer Peter Wild, when referring to this earlier period of settlement and industrial activity on to the end of the 19th Century, analyzed the events from an ecological standpoint. With deep emotion, he concluded that "Perhaps no country in history altered its environment as quickly as did the United States in the first dozen or so decades of its existence. Cheap land, new technologies, and a swelling population - the very factors that gave the new nation muscle - also tended to leave the land a shambles, (many of) its wild species extinct or pushed into remnant populations." Even from the beginning of this huge undertaking, members of both the American Philosophical Society and the American Academy of Arts and Sciences, founded respectively in 1743 and 1780, expressed concern about the management of America's natural resources. In this connection, such famous early writers as Jefferson, Emerson, Thoreau, and Agassiz were the spiritual forefathers of the American environmental movement. However, it was not until large-scale hydraulic gold mining began in California a century and a half ago, that an intellectual uneasiness by the few quickly turned to widespread alarm by many, in a localized area, over the ecological impact of mining. This original concern was not *per se* over the environment, but rather by competing economic interests over the responsible use of our natural resources.

While a series of local objections periodically appeared, it was not until the late 1960s that initial worries over industrialization and mining crystallized into full-scale apprehension, both on the national and international levels. It was at this time that influential legislators such as U.S. Senator Vance Hartke ended up calling mining "...a runaway technology...(that) poisoned our air, ravaged our soil, stripped our forests..., and corrupted our water sources." During this period reclamation was deemed to be the answer to the problem, and the Clean Air, Solid Waste Disposal, Water Quality, National Environmental Policy (NEPA), and Resource Conservation and Recovery (RCRA) and Surface Mining Control and Reclamation (SMCRA) Acts as well as an authorization for the preservation of the National Wilderness, were all passed by the U.S. Congress. From that period to the present, except for a failed attempt at retrenchment in the early 1980s, a ground-swell of public concern continued to build. With this concern came a realization that planning to counter the detrimental effects of industrialization, especially including mining, was warranted.

### 2.3.3 EARLY ENVIRONMENTAL CASES

The author Robert L. Kelley describes the onset of one of the first legal decisions and laws in the United States dealing with the environmental effects of mining. His book is subtitled "A Chapter in the Decline of the Concept of Laissez Faire." In reality, Kelley goes much further, describing the birth of the hydraulic gold-mining industry immediately following the initial major placer mining period in California (1849-1852). He then notes the effect of unconfined dumping of hydraulic mine tailings into nearby surface waters and the resulting downstream damage done to farms, towns, and cities. While 10 rivers drain the Sierra Nevada Range to the west only the northern-most, the American, Bear, Yuba, and Feather Rivers, comprise the California hydraulic mining area.

In 1880, the California State Engineer prepared a report on irrigation and mining debris. In his report, he estimated that almost 700 million $yd^3$ of material (gravel) had been mined along the Yuba River; with a further 100 million $yd^3$ and 250 million $yd^3$, each, along the Bear and American Rivers. The U.S. Army Corps of Engineers estimated that in the period of 1849-1909, more than 1.5 billion $yd^3$ of gold-bearing material was mined by hydraulic methods. In addition, the Corps of Engineers estimated that some 40,000 acres of farm-land were seriously damaged and an additional 15,000 acres were partially damaged by flooding and the deposition of hydraulic mine tailings.

Kelley details the legal actions of the farmers and the reaction of the hydraulic miners. It was a classic Western showdown of competing economic interests, literally gold versus grain. After a period of intense legal



**Figure 5** Hydraulic mine operations in California. (Figures 2 - 7 are original documents placed in evidence during the historic Edwards Woodruff vs. North Bloomfield gravel mine court case, December 11, 1882. These photos are published courtsey of the California Historical Society and were take by Photographer J. A. Todd.)

skirmishing, the matter was taken out of the state courts. The California legislature passed the Drainage Act of 1880 to deal with the state's regional river control problems, including navigation, because river transport was heavily in use by that time. This entailed construction of several check dams, whose costs were paid for by a very unpopular statewide levy rather than solely by the hydraulic miners. Unfortunately, the winter of 1880-1881, brought torrential rains and continued catastrophe for many farmers in the drainage area. Simultaneously, the unpopular tax was proving difficult to sustain. Attempts to have the Act repealed were not successful; however, the state supreme court decreed the law unconstitutional, giving rise instead to federal intervention in regulating the waters of the state. A statute that was originally meant to only control mining gradually evolved into a much more comprehensive ordinance for river-wide reclamation.

In what eventually was to become a landmark legal action, Edwards Woodruff, a property owner in Marysville, brought suit in the Ninth United States Circuit Court of Appeals in San Francisco against the North Bloomfield Gravel Mining Company and other companies operating mines along the Yuba River. (The North Bloomfield Mine is now known as The Malakoff Diggins State Historic Park near Nevada City, California, and serves as an ever-present example of hydraulic mining). Judge Lorenzo Sawyer, a 49er and ex-miner, adjudicated the case. He started out with a complete understanding of all the important elements involved and initially made an extensive inspection of the mines and farmlands. In a well-reasoned, two-phased decision in 1884, the judge ruled that: 1) all the defendants were responsible for causing the debris problem and 2) hydraulic mining was not prohibited, but operators were enjoined from discharging mine wastes into the Yuba River. Additionally, the companies that owned the water rights, ditches, and dams were prohibited from supplying water for hydraulic mining from which tailings were being discharged. While the larger mines along the Yuba, Bear, and American Rivers were almost immediately shut down, smaller operations and hydraulic mines along the Feather River to the north, continued to operate without containment of the tailings. Gradually these too were forced to cease operations, so by 1890 unrestrained hydraulic mining in the Sierra Nevada (but not elsewhere as in the Trinity Alps west of Redding, to the north) had all but ended. (Figures 5 - 10 are historical

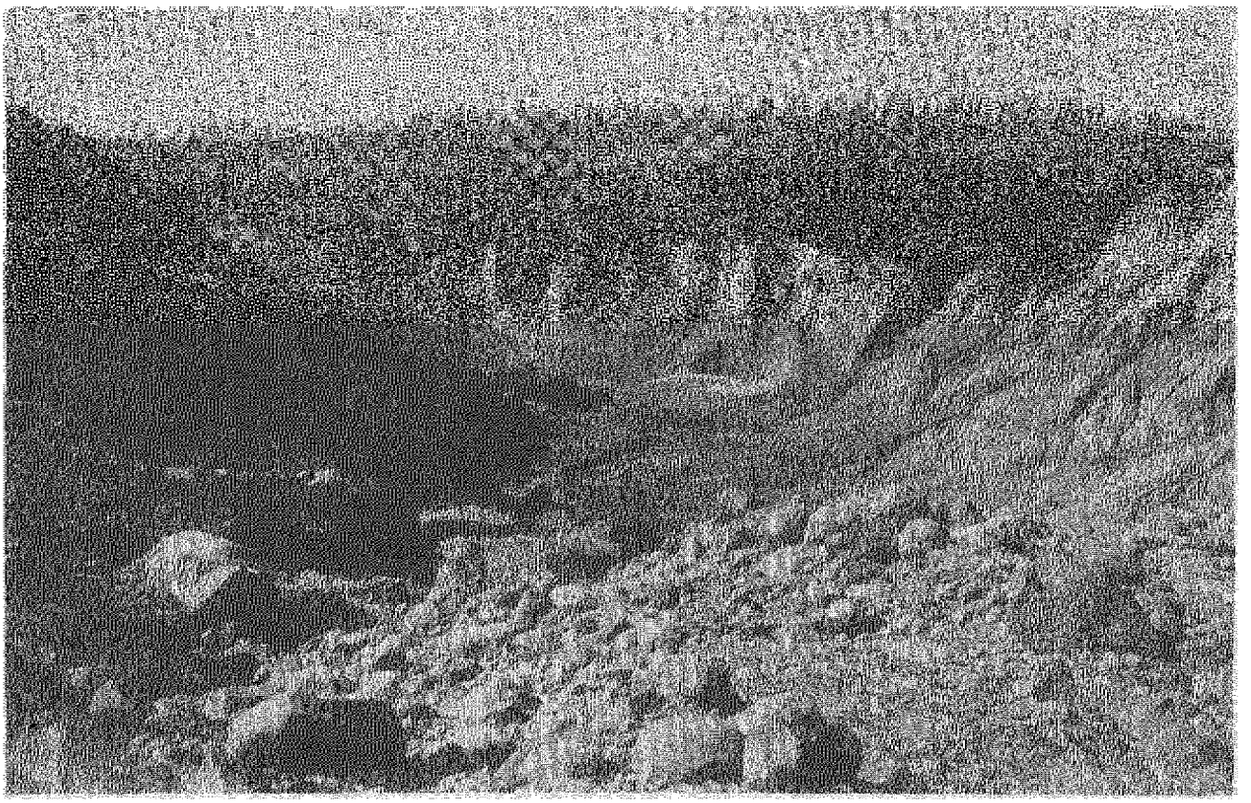


**Figure 6** How hydraulic mining changes the landscape.



**Figure 7** Hydraulic mine tailings, or "slickens," overflow a check dam that obviously failed to hold them.

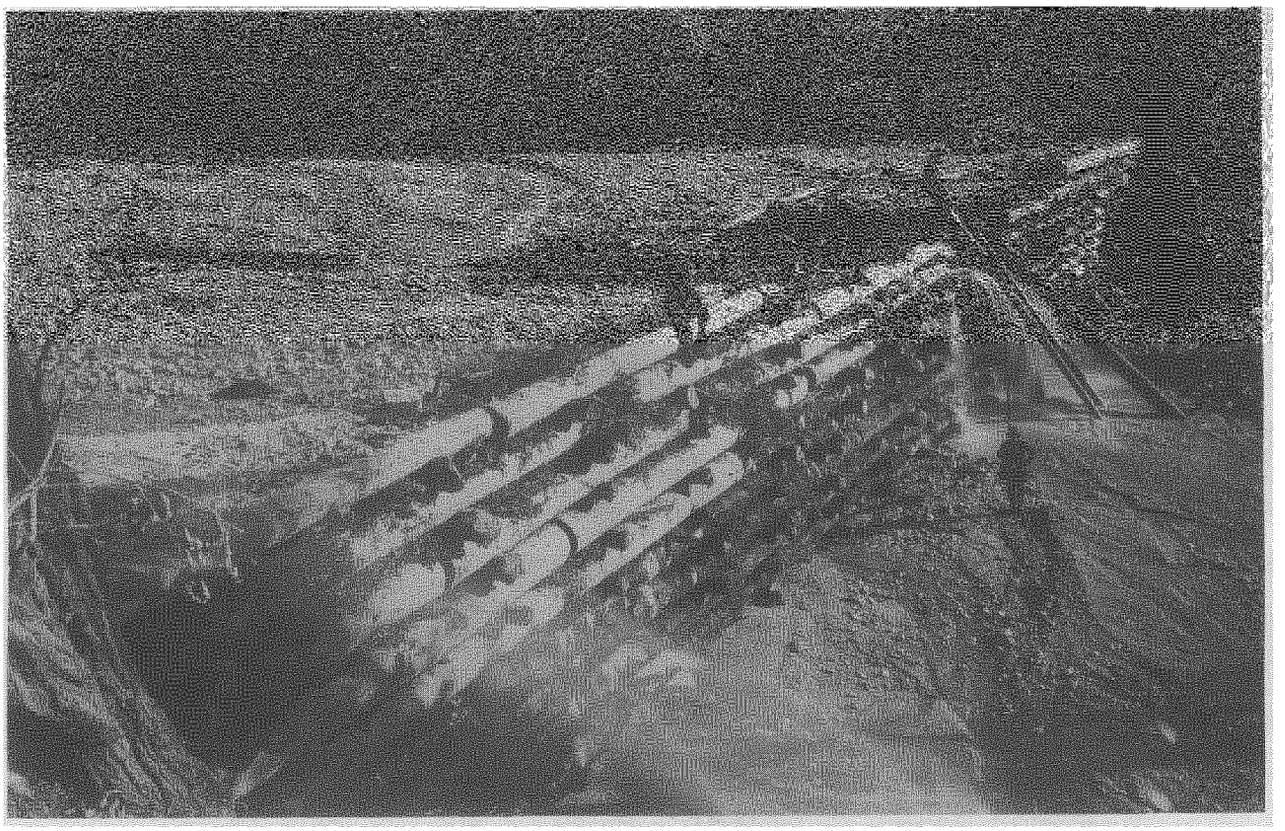


**Figure 8** A check dam filled to capacity: From all accounts, such dams were not engineered to handle the quantity of mine tailings actually dumped into the streams.



**Figure 9** Hydraulic mine tailings deposited at the "fall line" in the Sacramento Valley.

photographs taken as evidence for the Sawyer Decision. Figure 11 shows the scars in a hydraulic mined area some 110 years after the fact.)

Until 1892, a trade group known as the Hydraulic Miner's Association had represented the larger mine owners. In 1892, a new organization was formed, the California Mining Association, which was more democratic in composition and also admitted mine workers. At the same time, sentiment was growing that perhaps the pendulum of the Sawyer Decision had swung

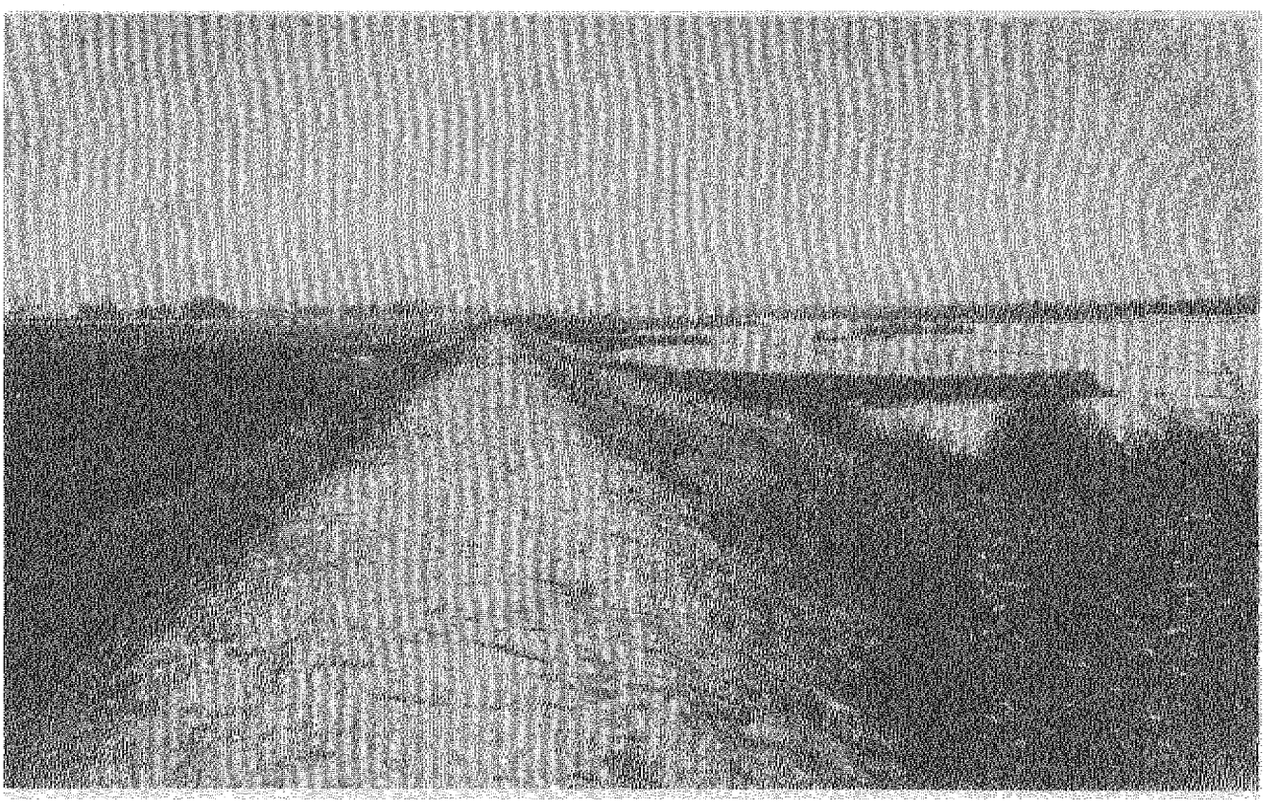


**Figure 10** The original notation on the photo states, "Shows to the right, devestated lands formerly known as Brigg's Orchard. In the center, the North Levee five miles south of Marysville. On the left, the pastures and grainfields of Mr. Teagarden."



**Figure 11** Some 110 years after the Sawyer decision, a current view of the Malakoff Diggins Historic Park: This is the site of the North Bloomfield hydraulic mine, where the scarred landscape is still not significantly healed over. At a glance, the result is similar to abandoned coal high walls in Appalacia.

too far and that some moderation was necessary. After much politicking, a bill prepared by Congressman Anthony Caminetti of northern California was passed and signed into law in 1893. The Caminetti Bill, amended in 1907, 1934, and 1938, called for the establishment of a California Debris Commission, which would regulate hydraulic mining so as to prevent damage to rivers in terms of both flood control and navigation. (See References, Hagwood, for historic details on the Commission.) To operate, each miner was required to submit plans for approval. The Commission was composed of U.S. Army Corps of Engineers professionals, the key personnel of which were appointed by the President. The law also carried a penalty clause. Finally, miners were not freed in any way from the power of the Courts. The window was opened for mines to operate, but under tightly controlled conditions. From 1893 until 1935, the Commission issued more than 800 work permits, but most were for small to mid-sized hydraulic operations. Large-scale, unrestricted dumping of mine tailings into streams quickly became a thing of the past, and it then took some 40 years for most of the tailings to be flushed out of the major river systems. Thus, it was established almost a century ago that miners do not have a compelling right to operate without regard to their impact on the community (and indirectly upon the environment). Furthermore, they could also be required to have permits to mine. The California Debris Commission was finally abolished by the Water Supply Development Act of 1986. However, the Commission's activities are being continued by the Corps of Engineers,

and are now being handled under Section 402 of the Clean Water Act.

Intermittent environmental events similar in principle to the hydraulic mining controversy in the California Sierra Nevada Range became the general pattern for the next century, as U.S. demand for minerals and coal skyrocketed. Miners, as well as operators of other basic industries, for the most part did not take account of the environmental consequence of their activities until people down-stream or down-wind began to actively complain and take legal action against them. In the case of mining, usually, reclamation (i.e. after-the-fact remediation) was then gradually implemented with varying degrees of success. In other instances, owners were enjoined from operating, or required to operate under strict controls, or, as in Oakland, California, in 1872, refused permission altogether to construct a smelter. Chronologically, the next series of cases centered around copper smelting at Butte, Montana; Ducktown, Tennessee; Salt Lake City, Utah; and even at the much smaller operation at Iron Mountain, California (Figure 12) by complainants derisively referred to as smoke farmers. The latter event is reported in passing in *Chapter 18* of this Handbook.

On the other side of the argument, William Clark, one of Butte's Copper Kings, was not shy in describing the advantages of smelter smoke to the health of the populace, asserting that it was "...believed by all the physicians of Butte that the smoke...is a disinfectant and destroys the microbes that constitute the disease (diphtheria), and furthermore the ladies were very fond of Butte because there is just enough arsenic there to give them a beautiful complexion." (Smith, D.A., 1987)

Also during this period, lead smelting at Selby, California, was investigated and operators were forced to take corrective action. On an international basis, Washington State apple growers compelled the imposition of restrictions on smelting at Trail, British Columbia. Interestingly, the Trail solution resulted in use of the sulfur offgas to produce a profitable fertilizer byproduct. During this period the current concept of environmentalism did not exist. Instead, the prevailing thought was centered around resource conservation and development, or multiple use management of public lands as defined by Gifford Pinchot, organizer of the U.S. Forest Service. This issue was considered to be sufficiently important by Pinchot and Theodore Roosevelt, as Progressives, for them to bolt the Republican Party, with its prevailing view of *laissez faire* capitalism. They organized the reformist Bull Moose Political Party in 1912. The wise use of natural resources to avoid highgrading was considered to be the most singular important problem associated with industry in general and mining in particular. However conservationists such as Pinchot were also acutely aware that forest denudation resulted in the erosion of topsoil and included this in their litany of complaints urgently needing rectification. Other voices, such as that of H.L. Mencken, were raised against pollution caused by unchecked industrial activity in large cities.

### 2.3.4 RISE OF MODERN ENVIRONMENTALISM

After a relatively long hiatus, the next major environmental push originated with the coal industry and its ongoing problems of subsidence, acid mine drainage, and lingering fires in refuse piles. By World War II, as underground mining increasingly gave way to surface stripping and contour mining, the coal mining industry became the target of increasingly negative environmental publicity. In 1939, West Virginia, quickly followed by Ohio, Illinois, Kentucky, and Pennsylvania, passed laws regulating surface coal mining. Reclamation, including re-contouring, reforestation, and construction of lakes and parks, to restore the large areas of land modified by mining quickly became the standard. Subsequently, the federal Surface Mining Control and Reclamation Act was passed and the Office of Surface Mining was established to regulate the coal mining industry nation-wide.

It became apparent during the last decades of the 20th Century that before-the-fact environmental planning was necessary to prevent many of the long-term problems created by mining. What constitutes environmentalism, and how it should be applied to current and future operations, forms the difficult nexus that is slowly being resolved. In the complex equation of how we should practice environmentalism, two important tenets gaining wider credence are that unlimited technological growth is not necessarily advantageous and that all species have equal value and, accordingly, should be protected from biological extinction. In this connection, Aldo Leopold wrote his classic book, *A Sand County Almanac,* as an ode to the beauties of nature. Leopold defined the *ecological conscience* as "...a state of harmony between men and land. This concept, now known as *biocentrism,* holds that nature, not humanity, is the measure of all things. Those interested in additional insight into the bewildering array of philosophic views on the nature of environmentalism should consult Michael G. Nelson's paper "Understanding the Environmental Movement: A Brief History and Assessment of Its Goals" (presented at the SME Annual Meeting, February 1993.)

### 2.3.5 THE ENVIRONMENTAL PROTAGONISTS

Tracking all the major participants in the great debate over the nature of, and requirements for, mine environmentalism is a significant task in itself. On an overall basis, they can be grouped into the following categories:

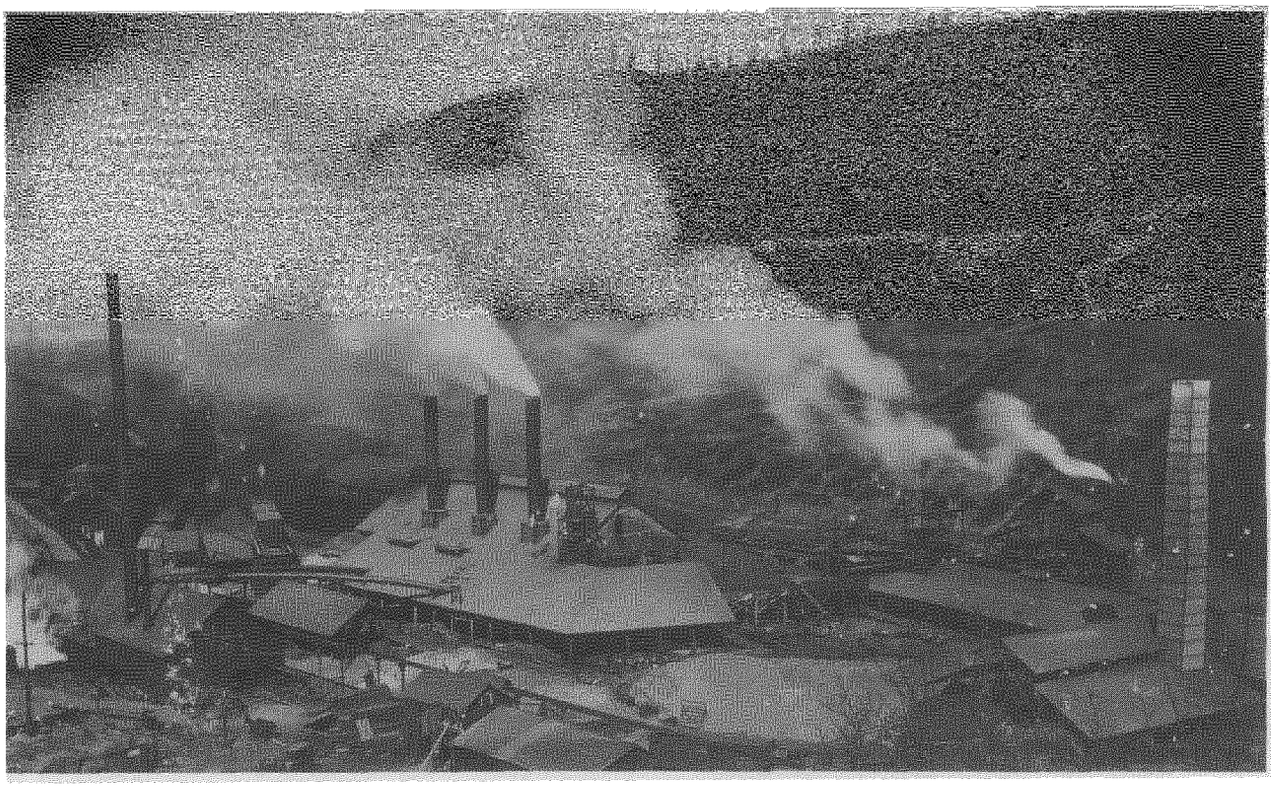


**Figure 12** Operations at the Iron Mountain mine near Redding, California, early in the 20th Century: this site is currently being remediated under Superfund legislation.

- **Legislators:** Federal and State
- **Regulators:** Federal, State and Local
- **Environmentalists:**

  Tier one or mainstream organizations
  "Deep" environmental or radical organizations
  Mining focused organizations

- **Mining Industry:**

  Mining companies:

  Major mining companies
  Junior mining companies
  Prospectors and independent/small miners

  National organizations:

  Lobbyists
  Trade organizations

  State organizations:

  Lobbyists
  Trade organizations

  Suppliers and other supporters:

  Equipment vendors
  Consultants
  Unions
  Allied Industries
  Financial Institutions

- **Neutral Data Gatherers**
- **Public**

There are a number of source books that may be useful in identifying the various players in the environmental arena, including the *Encyclopedia of Associations*, Gale Research, Detroit; *National Trade & Professional Associations of the United States*, Columbia Books, Washington, DC; the *Environmental Executive Directory*, Carrol Publishing, Washington, DC; and the Northwest Mining Association's Annual Directory. *Chapter 20* of this Handbook contains a "Directory of State Regulatory Agencies." There is no known organizational chart of the federal and state agencies that regulate the mining industry. Each mine operator must ascertain those regulators that have

authority over his operation, and these are subject to change without notice.

### 2.3.6 MISCONCEPTIONS OF SOME PROTAGONISTS

There is some misunderstanding among the different groups interested in environmental protection in the mining industry. Almost everyone involved starts from a similar core position of the need for environmental protection. Outside this large middle ground, on both ends of the spectrum are the radical fringes, which are small in number but which tend to receive inordinate publicity. For example, in industry there are many who are convinced that the mainspring of the present environmental movement is a well-placed group of original anti-Vietnamese War activists from the late 1960s and early 1970s, who found a new exploitable cause. In their zeal, ignorance, and/or political naiveté/agenda, the activists have blown the environmental situation completely out of proportion. Conversely, the mining industry is pictured by some of its opponents as still being intellectually and emotionally in the 19th Century.

Needless to say, the desire to limit the effects of mining on the environment in the United States has been around for well over a century, and even earlier than that in a loose philosophical sense. In addition, a strong desire to protect our planet is worldwide in scope and prominent throughout the industrialized nations.

A tiny minority of "tree spikers" or "ecoteurs," a newly coined word to describe environmental (ecological) saboteurs, existed in the recent past. To place all environmentalists in this category is both erroneous and self-defeating for the mining industry. Furthermore, calling them "tree huggers" and "greenies" is as productive as accusing all contemporary mine operators of "rape, ruin, and run." The overwhelming majority of environmental activists is law abiding. They fully realize that illegal acts alienate the public and eventually prove to be counterproductive. Similarly, the vast majority of mining industry personnel realize that they all live on "spaceship earth" and fouling the environment is self-defeating over the long haul. Any environmental risk is a strong deterrent to potential lenders and therefore tends to become a very serious matter for most mining companies. Some banks have created environmental screening committees to avoid loans to companies with high ecological risk.

Some environmentalists and mine operators are predisposed to negative notions about each other. At times, they exaggerate opposing positions. For example, one environmental publication wishing to have the mining law reformed speaks of "...the mining industry...rushing to buy almost $100 billion worth of public lands, for a tiny fraction of their worth." Undoubtedly this figure is somehow derived by estimating the gross value of the geologic resource, rather than the accepted practice of estimating the net present value of the minable and recoverable reserve. Conversely, representatives of the mining industry sometimes overstate the resources and political effectiveness of environmental groups. Erroneous information also exists to support partisan claims by those involved on either side of the debate. The U.S. Bureau of Mines distributed a "Customer Alert" identifying incorrect information published on the subject. Two situations were reviewed. In the first, the American Mining Congress overstated the number of mining industry employees according to statistics published by the U.S. Mine Safety and Health Administration, and secondly, the Mineral Resources Alliance underestimated the value of the non-fuel mineral production in Pennsylvania.

### 2.3.7 POLITICIZING THE DEPARTMENT OF INTERIOR

The federal Secretary of Interior is undoubtedly the most important position in the management of the nation's natural resources and control of the mining industry. It is at this level where most of the principles that affect the industry are established. Political appointments within the executive branch of the federal government are designed to establish the basis for each President's agenda. In the past, this has meant the relatively uncomplicated stewardship of the country's natural resources as the purview of the Department of Interior. This was especially true with appointment of such stalwarts as Franklin K. Lane, Harold Ickes, and Stewart Udall during this century. This pattern changed after the enactment of a flood of environmental laws during the 1960s and 1970s. Interpreting these laws and setting priorities and precedents has become highly selective and depends to a large degree on the agenda of the President of the United.

## 2.4 ROLE OF FEDERAL AND STATE GOVERNMENTS

Simply stated, the federal government and the states manage the affairs of the United States by a complementary allocation of legislative, executive, and judicial authorities. However, separation of these authorities may be indistinct and subject to change. In any case, environmental protection has become extremely important from a government point of view, if for no other reason than its overwhelming support among the American electorate.

### 2.4.1 THE FEDERAL GOVERNMENT

The Federal Government holds the primordial position of enacting, interpreting, and implementing the environmental laws of the United States, the most relevant of which, pertaining to the mining industry, are described in *Chapter 3*. Enacting legislation can be a painstaking process necessitating much political maneuvering. For example, in 1992, Congress tried to pass a reauthorization of the Resource Conservation and Recovery Act (RCRA) including continued delegation of authority to the states. This effort was stymied by conflicts over matters such as expansion of authority over non-waste substances such as heap/dump leach material and ore stockpiles, expansion of federal authority over state mine waste permits, inclusion of wastes from exploration projects, and vagueness over the program's application to new and inactive mine sites.

Mining regulation is often accomplished through those government agencies charged with the responsibility of managing the nation's resources. Agencies in this category include the Bureau of Land Management (BLM), the Forest Service (FS), the National Park Service (NPS), the Bureau of Indian Affairs (BIA), the Fish and Wildlife Service (F&WS), and the Bureau of Reclamation (BR). It should be noted that heavy criticism has been directed against the paired development and regulatory functions of these agencies. This duality of roles is considered by many to place those agencies in irreconcilable positions. Furthermore, streamlining government activity by merging agencies has been suggested again and again during the last half of this century, beginning with the Hoover Commission under President Harry Truman, continuing with the Grace Commission during the 1980s, and more during the Clinton Administration. This problem is illustrated by Cominco's Red Dog Mine, which started to operate in Alaska in the late 1980s. Road construction required the granting of 33 permits from seven different state and federal agencies. Construction of the port site necessitated an additional 20 permits and/or approvals from nine different state and federal agencies. For the operating facilities, dozens of additional permits were required. During the mid-1970s, Senator Floyd Haskell described the circumstances of the BLM, which had to administer several thousand public land laws accumulated since the birth of the Republic. His statement that "these laws are often conflicting, sometimes truly contradictory, and certainly incomplete and inadequate," still applies today.

Much current and future mining will occur on claims authorized under the General Mining Law. The BLM manages 1.1 million claims and traditionally receives 90,000 additional claim notices for processing each year. Except for the Forest Service, part of the Department of Agriculture, the other such agencies are within the Department of the Interior. Also affecting mining, in addition to the Department of the Army's Corps of Engineers (CE), are two purely regulatory agencies also heavily involved in environmentally safeguards, namely the Office of Surface Mining (OSM) and the Environmental Protection Agency (EPA).

Counterproductive and costly overlapping of federal regulatory responsibility among agencies exists. Undoubtedly, this results from a maze of programs, developed over time that, lack coordination and consistency. Failure to eliminate duplication of effort is attributed to jurisdictional disputes among the agencies. However, the problem can be more deeply rooted, and in many cases the actual turf battles hark back to the congressional-oversight committees and their desire to maintain their prerogatives. Compounding the problem are conflicting interests within some agencies and between agencies over development and protection. Whatever the cause of the problem, the net outcome can result in costly additional requirements on the mining companies by the different agencies, and sometimes in required goals that cannot be attained. Especially relevant are the comments of the General Accounting Office (GAO) in its report of December, 1992, entitled *Environmental Protection Issues*. It states: "Although EPA's regulatory programs depend heavily on scientific information...data often do not exist, or when they are available, are of poor quality and difficult to access and use. (The term "junk science" has recently been applied to this situation). Moreover, despite the fact that environmental programs are designed to clean up...pollution, EPA has not collected the information necessary to judge the success (or failure) of its programs." More to the point compliance costs are spiraling upward. According to an editorial in *Science*, Vol. 259, January 8, 1993, "In April 1992, 59 regulatory agencies with about 125,000 employees worked on 4,186 pending regulations...the fastest growing component of costs is environmental regulations." The GAO Report states that during the last 20 years about $1 trillion has been spent and/or invested in environmental protection. Furthermore, it states "...as a result of the legislation enacted over the last 20 years, American industry and government are currently spending about $115 billion per year to meet environmental goals, and the amount is expected to increase to $160 billion per year by the end of the decade." (It has been estimated that for every dollar spent on enforcement, industry spends some $10.) The EPA (References, Carlin, A.) estimates that in 1987, 82% of total environmental spending was locally derived, while the remainder came from the state and federal governments. By the year 2000 the EPA further estimates that the local share of the environmental costs will rise to 87%. Thus, the federal government is enacting more and more unfunded environmental mandates.

**Figure 13**

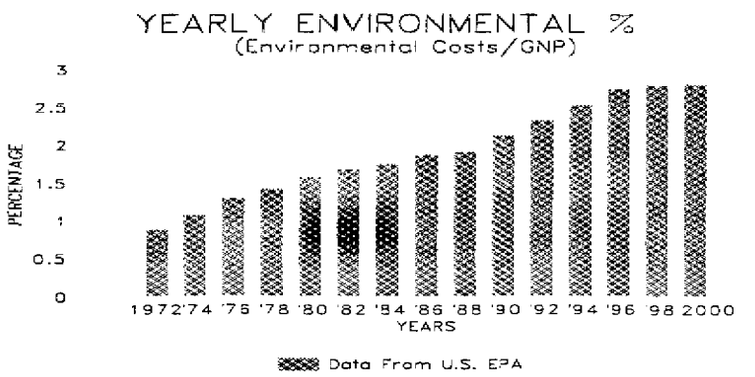



Figure 13 illustrates the growth of environmental costs as a percentage of the gross national product (GNP) from 1972 through 1990, and thereafter by projection. Based on the relatively slow growing U.S. economy, the question that immediately comes to mind is how the nation will be able to afford this expenditure? The corollary of course is how can we afford not to environmentally maintain and/or clean up the country? The dilemma is compounded in that expenditure can be quantified in economic terms, while success is difficult to judge on a cost effective basis.

Certainly, a step in the right direction is the bill S.2132, introduced by Senator Moynihan, D, NY, in the 102nd Session of Congress and entitled "The Environmental Risk Reduction Act." This Act proposed "To require the Administrator of the Environmental Protection Agency to seek ongoing advice from independent experts in ranking relative environmental risks; to conduct the research and monitoring necessary to ensure a sound scientific basis for decision-making; and to use such information in managing available resources to protect society from the greatest risks to human health, welfare, and ecological resources." It can only be hoped that a bill of this nature is quickly passed as the intent is beneficial to all. For its part, the GAO suggests greater use of non-regulatory alternatives for controlling smaller and diffuse sources of pollution. Furthermore, it recommends employment of market-based incentives. In summation, vast amounts of money have been spent on the environment; but apparently not in the most effective manner.

Not all agencies of the federal government manage or regulate; some promote education and health, others such as the State Department represent the people, others protect the people, etc. Of particular interest to the mining industry are agencies that perform basic research and gather, collate, and publish information of significant import. In this regard, the Bureau of Mines, now disbanded, and the Geological Survey have outstanding reputations for technical excellence. Unfortunately for the mining industry, the budget-cutting 104th Congress determined to eliminate the Bureau of Mines and the Bureau officially ceased to exist as of the end of 1995. Both the Bureau of Mines and the Geological Survey have been involved in researching, gathering and disseminating environmental information. From the industry's standpoint, it is hoped that the Geological Survey can continue this effort and undertake further research on specific projects, such as adit plugging or damming to prevent the outflow of acid mine drainage. An in depth analysis that indicates where and how the method can be properly employed should find broad and immediate application. Another important function for the Survey is the cataloging of abandoned mines and estimating the cost of their remediation (See *Sects. 2.5.3* and *2.8.1*). Completely separate from these two applications has been a recent step in the right direction with the formation and funding of a National Biological Survey whose task is to gather baseline data. However, the effort may still be too narrowly defined. The biosphere investigation while complex, is only a part of the data necessary for the proper management of all of our natural resources.

### 2.4.2 EMERGING ROLE OF THE STATES

The federal regulatory position over the mining industry is generally well understood. The regulatory importance of the states is customarily less appreciated and warrants more attention. As stated in *Chapter 4*, most mining environmental law is actually state law. State laws may well parallel federal laws, but they are based on the separate-and-distinct police powers granted to the states. Interestingly, this increased regulatory assumption by the states during the last decades of the 20th Century has matched the desire of the citizenry and even much of the federal government to have the states take on more of the regulatory control authorized to the federal government. The purpose of this transfer of control is to provide local regulators, who are usually much more conversant with on-site conditions, with greater decision-making authority. Actual control is delegated to individual states

after they enact comparable or even more restrictive legislation, prepare an acceptable regulatory program, and staff a suitable agency. The federal government still monitors the results. Some funding for administrating expenses may also be passed to the states. However; many states justly complain that they receive increased authority without comparable increases in funding. The decade old movement away from federal control of land has been called "the sagebrush rebellion." Its most vocal advocates urge transfer of all federal lands to state and/or private ownership. Interestingly enough, this was then Secretary of Commerce Herbert Hoover's desire back during the 1920s. A continuation of this "state's rights" issue has been the billing of the federal government by the State of Alaska for billions of dollars of lost revenue (an opportunity cost) on withdrawn land with minerals values (*Engineering and Mining Journal*, October 1993).

Meanwhile, states are preparing to receive more extensive environmental control over mining. Many are in the process of altering their existing laws. This situation is described in *Chapter 4*. To assist the states in getting up to speed, heretofore obscure organizations such as the Association of Abandoned Mine Lands Programs, IMC, WGA, and Western Interstate Energy Board, were created to develop policy, share ideas and information, and recommend jointly held positions. It is obvious that the future resolution of conflicts over mine environmentalism will occur more often within the states, and in some states at the local government level. With this end in mind, state mining associations, as well as local environmental organizations, are already getting ready for more activity and a much more complex set of conditions. However, a recent contravening trend may also be in the wings. A key controversial feature of one the newly proposed mining laws (see *Sect. 2.8)* calls for the federal regulators to exercise much greater day-to-day control than has been the case. Correspondingly, fewer responsibilities and lesser efforts by the states would result. The Secretary of the Interior, during the second half of 1993, vowed to put more punch into enforcement of environmental regulations on surface coal mines. He contended that federal-mining officials have let enforcement of the Surface Mining Control and Reclamation Act of 1977 slide for 16 years. Moreover, he said, the relationships between the federal and state governments is a mess due to the "bad faith" of past federal administrations. On this same tack, Senator Glenn, D-Ohio was reported in the *San Francisco Chronicle* (A4, Sept. 21, 1993) as castigating the Department of the Interior over environmental problems resulting from mining. Senator Glenn mentioned "soil, air, water contamination from mines and smelters. Children have been found playing in areas where contamination levels have been high enough to kill grazing cattle and horses" and death and injuries from mining-site hazards.

## 2.5 ENVIRONMENTAL ORGANIZATIONS

Environmental advocacy groups are invariably organized as non-profit corporations under U.S. Internal Revenue Service Code, Section 501 C-3, which includes educational and scientific organizations. It has been estimated that there are as many as 1,500 of them. These organizations differ markedly in terms of purpose, activities undertaken, area of interest, and degree, type, and extent of commitment. Stated another way, environmental associations are readily defined by the level of control they seek over new development, i.e., conservationist, preservationist, exclusionist, etc. A slightly oblique examination of those same three strands can yield the following different ideologic points of view:

- Environmental protection should be centered around the protection of human beings, with secondary protection provided to certain other animals and plants deemed necessary for human survival.
- All life and even inanimate objects have intrinsic values and should be protected.
- Based upon a value judgment, development and industry (from at least a moral point of view) is bad, and should be avoided to the greatest extent possible.

Associations can be further defined by their degree or type of involvement or the methods employed to gain their objectives. Degree of involvement and types of methods runs the spectrum from those few who feel that the end justifies the means, to legal interventionists, to activists, to data gathers and dispensers. Some lobby, others offer prizes, and still others attempt to generate public awareness. The non-activists can be subdivided into the NIMBY (not in my backyard) types, who only appear when certain close-to-home situations arise or conditions are noted; and the general sympathizers, who on occasion, are mobilized by activists (to write form letters or as concerned and enthusiastic supporters, to swell the crowds at special appearances or hearings of legislators or regulators). K.W. Mote (*Chapter 7*), points out that legislators are growing more sophisticated and are being less fazed by massive mailings. Instead they increasingly demand the facts without the usual public-relations hyperbole.

### 2.5.1 MAINSTREAM ENVIRONMENTAL ORGANIZATIONS

Environmental organizations can be separated into three categories: tier one, or larger mainstream associations; tier two, or mid-sized mainstream militant offshoots as well as regional clubs; and tier three, mainly small, single-issue groups. A list of the larger mainstream

environmental organizations that may be interested in mining was compiled. Based on published data the average mainstream association was formed prior to World War II, is composed of some 950,000 members, has a budget of $37 million, and has a staff of 237. Besides the National Wildlife Federation, and the World Wide Fund for Nature, which is reputedly the world's largest environmental group, most of the major environmental organizations average several hundred thousand members. Following is a list of major mainstream environmental organizations:

Ducks Unlimited
Earth Watch
Environmental Defense Fund
Izaak Walton League
National Audubon Society
National Parks and Conservation Association
National Wildlife Federation
Natural Resources Defense Council
Nature Conservancy
Public Citizen (The Ralph Nader group)
The Sierra Club
Trout Unlimited
The Wilderness Society
World Wildlife Fund
World Wide Fund for Nature

The Nature Conservancy believes in preservation by example and includes mining company members. It had a total 1992 net worth of about $850 million, and devotes 88% of its $100 million/yr budget to its programs. The programs mainly consist of purchasing and maintaining land, such as redwood forests or Frank Lloyd Wright's masterpiece of residential architecture, Falling Water, (western Pennsylvania) for the purpose of preservation. The Conservancy recently earned positive attention (*San Francisco Chronicle*, Feb. 17, 1993) for devising a plan in Texas to provide ecological islands while allowing for development around them. The Nature Conservancy's philosophy evolved from developing living museums of primeval America to protecting entire ecosystems including the human inhabitants.

Ducks Unlimited, which receives grants from numerous companies, and Trout Unlimited are primarily interested in preserving the habitat of the noted animals. The Environmental Defense Fund is composed of lawyers, scientists, and engineers who institute suits seeking to have the courts direct companies and government agencies to comply with existing laws. The Wilderness Society has attracted outstanding authors such as Aldo Leopold and the late Pulitzer Prize winning Wallace Stegner. The unlisted Richard & Rhoda Goldman Fund, in San Francisco, provides an interesting side-bar; it is self-funded and actively supports grassroots projects, and awards prizes, which total about $1 million/yr, to worthy individuals. Island Press bills itself as a publisher of books about the conservation of natural resources, specifically soil, land, water, forests, wildlife, and hazardous and toxic wastes. According to Island Press, "These books are practical tools used by public officials, business and industry leaders, natural resource managers, and concerned citizens working to solve both local and global resource problems." Even more noted as a nonprofit publisher is Resources for the Future, which describes itself as "...an independent...organization that advances research and public education in the development, conservation, and use of natural resources and the quality of the environment."

The mainstream environmental organizations are inclined to have similar viewpoints and employ analogous strategies of lobbying and litigation. However, it should not be misconstrued that they invariably see eye to eye with each other, particularly on tactics, and always present a monolithic front (*i.e.* opposite positions on NAFTA). At times different organizations attempt to reach and hold the same constituency, and therefore turf battles can erupt and hardening or even extremism of position can then occur in an effort to establish dominance. To generalize, the smaller the organization the more radical it tends to become.

### 2.5.2 SIERRA CLUB AS A PARADIGM OF MAINSTREAM ENVIRONMENTAL BELIEF

While the first regional Audubon Society club was organized in 1886, the birth of the environmental movement is usually associated with the establishment of the Sierra Club. It was founded in 1892, when a group of 27 individuals of diverse backgrounds, including the famous Naturalist John Muir, and strong common interest and purpose, banded together in San Francisco "...to do something for wilderness and make the mountains glad." Specifically the members agreed that the mountains, as exemplified by California's Sierra Nevada Range, were a national cultural heritage and resource that needed to be recognized, shared, and protected. Members were, and continue to be highly educated and motivated middle-class social progressives with a strongly developed morality. The aim was to retain the mountains as close as possible to their natural state of wildness coupled with an enjoyment of nature, usually by hiking. The early 20th Century decision to remove the Hetch Hetchy Basin (along the upper reaches of the Tuolumne River, where the club had a nearby retreat) from the Yosemite National Park System and convert it into a potable water reservoir for San Francisco area counties sparked the Club's entrance into politics. From that point, the Sierra Club felt increasingly obliged to press, by political means, for environmental consideration of new projects

(preservationism). This especially came about after the publication of Rachel Carson's 1962 landmark book *Silent Spring*, which dealt with pesticides' negative effect on the environment. Equally important but not as well known or influential outside the mining industry, was H.M. Caudill's *Night Comes to the Cumberlands*, which offered an unattractive look at coal mining in eastern Kentucky. This was followed by two Sierra Club "battlebooks" entitled *Stripping* and *Mercury*. The net result was to galvanize and energize a whole generation of environmentally concerned citizens so that club membership of 7,000 in 1952 and 16,000 in 1960 dramatically increased to 115,000 by 1970, 180,000 in 1980, and currently approximates 600,000. In retrospect, many observers feel that the environmental impetus had peaked by 1980. However, the attempt to roll back the perceived environmental "excesses" by the then Secretary of the Interior James Watt resulted in a re-energizing of the movement that has continued on to the present.

During this same period of dramatic increase in membership, the philosophy of the Club and its organization went through a series of structural changes, including expansion outside of the San Francisco Bay Area to the rest of California and ultimately into the entire nation. Furthermore, interest broadened from the mountains to the whole environment. It was at this point that a primary philosophic separation appeared between mostly government employed conservationists and non-government preservationists (see *Sect. 2.5*). The Club's position is presently somewhat pragmatic, varying on a case by case basis with a leaning towards preservation. After a period in the 1950s until the late 1960s of strong centralized control, the Club evolved into its current form of grassroots decentralization, or as verbally described "from the bottom up to the top." It has 15 regional and 57 state groups, 386 individual chapters, and a staff of 294. To the uninitiated, the organization does not follow the usual theory and precepts of effective corporate management. However it seems to work quite productively due to the strength of conviction and degree of enthusiasm of its members. Present per capita dues are $35/yr.

The effectiveness of the Sierra Club, and its ability to accomplish its objectives, does not solely rest on its large membership, nor its yearly budget of $35 million (of which less than 1% goes into so-called major [environmental] campaigns), nor with the efficacy of its several Washington, DC, lobbyists (whose efforts encompass several areas of concern only one of which is mining), nor with its nonprofit-making books and other publications. Its strongest asset is the perceived sincerity and knowledge of its members and their hard working dedication and zeal in striving for their goals. Due to the Club's very positive image, it has a readily available support group that is many times larger than the core membership. It can be quickly rallied on important issues, although this approach may be becoming less effective as previously pointed out. Nevertheless, the Club is in the enviable position of delivering messages that are listened to attentively by industry as well as state and federal governments. The Sierra Club's list of priorities changes to track public concern or follows the time-honored maxim "the squeakiest axle gets the most grease". Their interest in mining is now at a high intermediate level. The Club's 1993 list of environmental priorities was as follows:

Clean Water Act Reauthorization and Wetlands Protection
Wilderness Legislation
Ancient Forests Protection,
Fuel Efficiency Standards (For Motor Vehcles)
Endangered Species Act
National Forest Management
Mining Law Reform

During the 1994 Congressional elections mining law reform was strongly pushed by the Sierra Club.

The Club handles mining matters in a grid-like fashion in which overall areas of concern are treated by a mining sub-committee that is part of a public lands committee. In addition there are various state-wide mining committees dealing with state-and-local issues. Interestingly, there does not seem to be much coordination between the state organizations. Committee members are volunteers, who absorb out-of-pocket costs for travel, communications, etc. While few, if any, of the committee members appear to have hands-on industry operating experience, many have garnered a practical understanding of the operating factors that have an ecological impact. This knowledge was derived from field inspection experience, sometimes in combination with other industry technical education. The single mining issue deemed to be of paramount importance is revision of the federal mining law. At first blush this might not appear to be a conventional environmental consideration, however as mentioned in *Sect. 2.8*, it has recently become closely linked to current environmental politics and as such is a very "hot" issue. As would be expected, of all the aspects under discussion in terms of possible mining law alteration, the establishment of a federal royalty on mine production will be the most vexatious to solve. The first problem is determining the actual economic impact to the hard rock mining industry. There is no doubt that, under some proposed scenarios, the mining industry will suffer serious if not mortal damage (for a complete different evaluation see the last paragraph of *Sect 2.5.3)*. In fact, one of the most potent arguments used against the centrist environmental organizations, such as the Sierra Club, is that some of their proposals will unwittingly result in significant job losses in a

fundamental industry. A recent illustration is the June 30, 1993 decision of Federal District Judge Richey on a suit brought jointly by the Friends of the Earth, Public Citizen, and Sierra Club. Judge Richey ruled that the proposed North American Free Trade Agreement (NAFTA) constitutes a major federal action significantly affecting the quality of the human environment. This would have required a laborious and time-consuming environmental-impact statement (EIS) which probably would have ended the U.S.-negotiated trade pact with Canada and Mexico. On September 24, 1993, the U.S. Court of Appeals (for the District of Columbia) unanimously overturned Judge Richey's decision based on the premise that it had no authority to order such a review (EIS). These same anti-NAFTA environmental organizations also strongly lobbied Congress in a failed attempt to defeat its passage. Interestingly, the Audubon Society and the Natural Resources Defense Council support the agreement (see the last paragraph of *Sect. 2.5.1).* According to EPA Administrator Carol Browner, those two organizations called NAFTA "the most environmentally sensitive trade package in history."

The interest of environmental organizations is for the development of more comprehensive permitting and operating regulations. This primarily pertains to environmental protection and to governing the industry, with special concern over access to government lands. On the local level, individual chapters become involved in activities such as the adoption and\or modification of new state mining regulations, the permitting of new mines, and the monitoring of ongoing operations to ensure compliance with existing regulations. It is also at the local level that most of the popular support is generated. However, the Sierra Club's proactive efforts are not limited to lobbying. Additionally there is the offshoot Sierra Club Legal Defense Fund (SCLDF), established in 1970, that has a staff of 40, and a budget of $4.2 million/yr. The SCLDF's stated purpose is "...to use existing legal remedies to protect the natural environment of the United States and develop a realistic and enforceable body of environmental law through the implementation of existing statutes, regulations, and common law principles."

### 2.5.3 OTHER ENVIRONMENTAL ORGANIZATIONS

During the 1970s, influential Norwegian writer Arne Naess, in several widely circulated magazine articles, characterized the environmental movement as being either shallow or deep. Shallow to him included the mainstream organizations that were large, bureaucratic, and prone to make accommodations. Non-traditional environmental activity he labelled deep ecology and pronounced it "...heir to the environmental sensibilities of...Muir and Leopold." Further, Naess said "Ecologically responsible policies are concerned only in part with pollution and resource depletion. There are deeper concerns which touch upon principles of diversity, complexity, autonomy, decentralization, symbiosis, egalitarianism, and classlessness." Thus some within the second tier group seek to use environmental issues as the key to force a fundamental transformation of the present mode of society by drastically changing the contemporary life style. Notable organizations include:

Earth First
Friends of the Earth
Greenpeace
Sea Shepherd Society.

Friends of the Earth and Earth First, which uses the slogan "No Compromise in the Defense of Mother Earth," and "Back to the Pleistocene," were founded between one and two decades ago as more radical spinoffs from the Sierra Club and the Wilderness Society. Membership is in the mid five figures, or an order of magnitude less than the mainstream organizations. Of the two, Earth First is by far the more radical both in goals and methods. Susan Zakin in her *Coyotes and Town Dogs* offers a sympathetic view of some of the key personalties involved in both organizations with emphasis on Earth First.

Greenpeace speaks of some 3 million worldwide adherents and tends to operate more outside of the United States. The Sea Shepherd Society is an even more uncompromising outgrowth of Greenpeace. On occasion, some of these non-mainstream organizations appear to revel in their desire and ability to walk on the thinnest of judicial thin ice and to test the limits of the law. In the fascinating book *Green Rage: Radical Environmentalism and the Unmaking of Civilization*, author Christopher Manes outlines the philosophy and justification for what he also calls "monkeywrenching," which tends to be associated with Earth First. Interestingly, the late Edward Abbey in his novel *The Monkekywrench Gang*, created monkeywrenching as a self-fulfilling prophesy of what has now come to be known as ecotage. Currently, Greenpeace (Western Edition of *The Wall Street Journal*, Mar. 3, 1993) seems to have lost some steam and power, and perhaps most important of all, contributions. Reportedly, the leaders of Greenpeace are going through an reappraisal as to their future direction. Similarly, Earth First appears to have recently lost much of its stridency. The usual importance of the non-centrist organizations is not in their numbers or clout *per se*, but that over time, many of their ideas become co-opted by the mainstream organizations. (A prime example has been the activities of some first tier environmental organizations against United States approval of NAFTA, see *Sect. 2.5.2.* They opted to support "bioregionalism"

or "future primitivism," which is a pet theory of the deep ecologists.) Moreover, these secondary organizations have a tendency to gather headlines and in general make it more difficult and uncomfortable for the mainstream organizations to effect compromises. In addition, the non-centrist groups make the centrist groups appear staid and conservative by comparison, thus making them more credible and emotionally easier to deal with by government and industry. Finally, in the absence of positive results, an angry and frustrated public at times will increasingly support the fringe groups.

There are quite a few other regional bodies of note, many of which have as part of their title resources center, or environmental council or coalition. Other interested organizations may be associated with the League of Women Voters as in Colorado and South Dakota. There also is a third tier group of smaller organizations, by several orders of magnitude, but whose thrust is either mainly or fully directed towards the mining industry. They include:

Alliance for the Wild Rockies
Campaign for an Environmental Economy
Center for Alternative Mining Development Policy
Citizen's Mining Information Network, associated with SRIC
Clark Fork Coalition
Colorado Mining Action Project
Concerned Citizens for Responsible Mining
Mineral Policy Center (Clementine)
Project Environment Foundation
Save Lake Superior Association
Southwest Research and Information Center (SRIC)

Some of the above organizations are affiliated with Minewatch, which is based in London, England, and serves as a clearing house for mine environmental concerns. Also located in Great Britain is the Mining and Environmental Research Network (MERN), which is based at Sussex University. As an example of a "deep" single-issue international environmental organization, Minewatch describes itself as follows:

*"MINEWATCH is the 'brainchild' of Partizans [sic], the long standing campaigning group which seeks to minimize the damaging effects of RTZ, the world's most powerful mining company . . . (and) aims to gather and disseminate information on the nature of specific types of mining, with emphasis on their social/environmental/economic impact and their infringement primarily on indigenous land rights and land claims . . . (and) will link together communities affected by specific types of mining or the operations of particular mining companies, in order to strengthen their ability to negotiate with, or oppose mining plans . . . (and) will also build up special reports and a database of global aspects of mining which deeply concern indigenous and other land-based communities. For example, studies of mining royalties between various countries, or the differences between Environmental Impact Assessments in north America, south-east Asia, Britain, or Brazil. All users will . . . be invited to contribute to a regular newsletter . . . (which) will not only address specific mining 'problems' but discuss wider issues, such as the relationship between World Bank funding of hydro-electric projects and mining; the economic and environmental impact of recycling of certain metals; look at 'who controls who' in global minerals extraction and processing."*

These specialized associations each tend to have a membership that ranges from the upper three figures to the lower four figures. Annual budgets usually are in the six figures, and consequently some of those small single-issue organizations, otherwise lacking funds, must depend on the financial support of hidden, or not so hidden, angels with very particular agendas.

Of particular distinction is the Mineral Policy Center (MPC), which was founded by Stewart Udall and is located in Washington, DC. It seemingly has the ear of several sympathetic and influential Congressmen and recently appointed government officials. In mid-1993 the MPC published a booklet, entitled *Burden of Guilt*. In it they examine the problem of abandoned hard rock mines. MPC estimated that there are nearly 560,000 abandoned mine sites in the United States and that it will cost somewhere between $33 and $71 billion to remediate these sites. Interestingly enough, the low range total of $33 billion is the approximate value of all the 1992 non-coal mine production as estimated by the U.S. Bureau of Mines. The definitive analysis of the subject is United States Bureau of Mines Information Circular 8862. In a 51 year study commencing in 1930, the conclusion was reached that 0.25% of the land mass of the country was mined of which 47% (0.12% of total) had been reclaimed. Furthermore, hard rock mining amounted to only about 13% of the land mined. However, this study did not touch on remediation costs.

During the 3rd quarter of 1993 the MPC in conjunction with the National Wildlife Federation issued a large pamphlet entitled: "Not All That Glitters--An Evaluation of the Impact of Reform of the 1872 Mining Law on the Economy of the American West." This treatise by T.M. Power was especially designed to refute earlier works cited under *Sect. 2.8.2.* It presents a convincing counter argument that an 8% royalty against gross value mined when employed for abandoned mine land remediation will actually create more jobs than will be lost.

## 2.6 MINING INDUSTRY ASSOCIATIONS

Mining industry representatives are also usually designated as non-profit organizations under the IRS designation's Section 501-C-6 for business leagues. There are several different types of trade associations servicing the mining industry. Some are limited to a single commodity, *i.e.*, aggregates, salt, sulfur, etc. Other groups such as The Bituminous Coal Association represent the largest coal-producing companies that have contracts with the United Mine Workers' Union. Mid-sized and small non-unionized coal-mining companies tend to join the National Coal Operators' Association and/or other regional associations. The American Mining Congress and National Coal Association combined in 1995 to form the National Mining Association, which lobbies on behalf of its members and also provides a secondary role of technical information dissemination. Lobbying is also carried out on the state or regional basis by organizations such as the California Mining Association and the Northwest Mining Association, both of which cover a wide spectrum of mining operation and mineral commodities. The following is a mixed list of organizations that represent the mining industry. It is composed of national, regional and state wide organizations. It comprises both lobbying and trade representatives of specific mine products that run the gamut from hard rock and industrial minerals to coal.

National Mining Association
National Stone Association
Minerals Resource Alliance
Northwest Mining Association
Tri-State Zinc/Lead Ore Producers Association
State Mining Associations
American Coal Foundation
American Iron Ore Association
American Nuclear Energy Council
Anthracite Industry Association
Asbestos Information Association
Association of Bituminous Contractors
Bituminous Coal Operators' Association
Brick Institute of America
Cadmium Council
China Clay Products Association
Clay Minerals Society
Gypsum Association
Lignite Energy Council
National Aggregates Association
National Coal Operator's Association
National Ready Mix Concrete Association
National Sand & Gravel Association
National Slag Association
Non-Ferrous Metals Producers Committee
Open Pit Mining Association,
Perlite Institute
Phosphate Rock and Chemicals Export Association
Rocky Mountain Coal Mining Institute
Salt Institute
Sorptive Minerals Institut
Sulfur Institute
Vermiculite Association
Gold Prospectors Association of America
Mining Club of the Southwest

### 2.6.1 LOBBYISTS

Mining industry representatives who are collectively classed as lobbyists carry out a multitude of other tasks as well. Contrary to widespread speculation and misinformation, the Northwest Mining Association (NMA), as a case in point, reports that less than 5% of its annual budget goes for lobbying, and about 3% for legislative guidance. NMA states that about half of its budget supports the annual meeting, and about one quarter of the budget goes into salaries, rental, and out-of-pocket expenses. In fact, NMA considers its principal activity to be handling information. Mining industry representatives are involved in four fundamental activities which consist of many specific duties. Some of these duties actually relate to more than one of the activities; however, they are listed according to their single most relevant fit.

- Lobbying - Determining the contents and tracking the progress of proposed legislation and regulations; measuring the anticipated voting outcome of legislators on key bills; and pressing industry's position with the legislators in order to bring about a favorable result.
- Pursuing regulatory matters and concerns - Shadowing the progress of mining project permit applications; expediting and facilitating permitting approvals by regulatory agencies through knowledge of the intricacies of the passage procedures; serving as expert witnesses as the conditions warrant; submitting favorable input for inclusion into governmental reports and position papers.
- Empowering membership through information gathering/dissemination - Grouping legislators, regulators, investigators, political candidates, and news gatherers according to their philosophical bent towards the industry; finding out the "pressure points" of fence-sitting legislators, regulators, and investigators; keeping abreast of important court cases; building lists of consultants and contractors; maintaining a list of concerned citizens favorably disposed towards the industry; keeping abreast of the activities of environmental groups focused on

mining; gathering, collating, and disbursing pertinent general information; conducting research; coordinating data gathering and efforts with other associations, groups, companies, and concerned citizens; discovering the identity of the "off the organizational chart" key leaders and decision makers; and arranging for mass mailings and for groups of concerned citizens to appear at hearings and meetings.

- Providing education - Sponsoring major conferences; furnishing briefings, news releases, and interviews; promoting the industry and the products of the industry; arranging for special conferences and providing speakers to represent the industry at forums and public debates; supplying requested information to the press and to the general public; preparing and mailing newsletters; publishing pertinent information; warding prizes, scholarships, etc.; conducting industry tours for teachers, students, and the general public; providing videos for lay persons such as Caterpillar's "Common Ground."

### 2.6.2 NATIONAL MINING ASSOCIATION AND NATIONAL STONE ASSOCIATION

Lobbying refers to the act of trying to persuade legislators to favorable consideration of the mining industry. On the national level, two organizations stand out in terms of their proficiency in lobbying for different parts of the industry, the National Mining Association (NMA) and the National Stone Association (NSA). They do not take a direct part in politics, although they may endorse or reject politicians up for reelection, or least categorize and/or profile many of the legislators. Both are located in Washington, DC. The American Mining Congress, a fore-runner of the NMA was founded in 1897, making it one of the oldest lobbying organizations on the national scene. The current National Mining Association is the result of a merger in 1995 of the American Mining Congress and the National Coal Association. NMA defines its mission as the creation and maintenance of a broad base of political support for the mining industry of the United States in Congress, the administration and the media.

The NMA's membership is made up about 350 companies. In addition to many mining companies, this membership includes equipment manufacturers, engineering companies, banks, power companies, state mining associations, railroads, and several others that have a interest in maintaining a strong domestic mining industry. These companies are usually represented within the NMA by their Chairman or CEO. Most of NMA's members are large companies, and many have multinational operations and interests. Some in the industry have felt that the organization does little to represent the interests of smaller mining companies and that its political effectiveness has been hampered by a need for unanimous support for decisions on major issues. For instance, much on industry opposition to proposed changes in the mining law has been conducted outside the structure of the NMA and its forerunners and these organizations did not take strong positions on the demise of the US Bureau of Mines.

Among NMA's numerous standing committees are committees for the environment, lands, technology, safety and health, and communications. NMA's publishing activities include a bimonthly magazine, *Mining Voice*, and useful source books of facts, figures and background information on the mining industry, *Facts About Minerals* and *Facts about Coal*. NMA staff numbers about 80.

The NSA was founded in 1918 and represents the producers of 1 billion tons/yr of stone, which is the largest tonnage production of any mineral commodity. Stone, by the association's definition, consists of quarried material for use in construction, such as railroad ballast (road base), and, for chemical, metallurgical, or agricultural processing. The NSA has a membership of 425 (mostly companies), a staff of 20, and a budget of $2.5 million/yr.

### 2.6.3 CALIFORNIA MINING ASSOCIATION

A typical local/statewide example of a western mining-industry lobbying-organization is the California Mining Association (CMA). It was organized more than a century ago to represent one segment of the mining industry as already mentioned in *Sect. 2.3.3*, hydraulic gold mining. Over time, the old CMA disappeared. In 1977, a new CMA was formed to represent almost all facets of the hard rock, California mining industry, and has been expanding ever since to keep in step with the rapid increase in gold mining in the state during the last decade. The CMA was reestablished by a group of mining company executives who recognized that the industry required one strong voice to protect its interests in view of the growing political impact of environmental organizations. The CMA's mission statement declares "The...Association is dedicated to the advancement of responsible mining and the education of the public to the vital role of minerals and mining in our society." In this connection, CMA should be proud for recently sponsoring a very useful textbook, *Mine Waste Management*. Current membership is composed of 58 mining companies, 81 supplying companies, 138 individual members, and 3 (so-called) organizational members. The CMA is directed by a Board of Directors and a 10 member Executive Committee. Tactical operations are in the hands of an executive director who functions as COO. Actual lobbying is done by a contracted firm, while publicity is conducted by another specialized public relations firm. The CMA publishes an

annual magazine and a regular newsletter. Most of the efforts of the CMA are concentrated on the state level, but occasionally it also ventures out into the federal scene. The most recent example concerns efforts to amend or rescind the federal mining law. Meetings with comparable sister state organizations to coordinate overall objectives, policies, and strategies are held at least once a year, or as events warrant. Within California, the CMA is a member of the Mining Associations Coalition (MAC) with four regional aggregate associations. The level of effectiveness of the CMA is difficult to measure from the outside, yet it must be useful, as proven by its increasing number of new members. Undoubtedly, when the CMA talks, the state government, notably the legislators, and to a lesser degree the regulators, listen attentively. This in itself indicates quickly gained influence and effectiveness.

### 2.6.4 OTHER MINING INDUSTRY ASSOCIATIONS

Industry-related trade associations, by size, form a natural division with the smaller associations (china clay, perlite, vermiculite, etc.) characteristically having a staff of between one and ten and a budget under $500 thousand/yr. Larger associations (American Nuclear Energy Council, Phosphate Rock and Chemical Export Association, and Salt Institute, etc.) traditionally have a staff of 25 or more and a budget between $500 thousand and $5 million/yr. Trade associations all have one aspect in common, they devote a major portion of their time to trade promotion, and in many cases leave the high powered lobbying to the NMA, although some of the larger organizations are not averse to taking confrontational positions under certain specific sets of circumstances.

In addition to the previous list of industry representatives there are several other peripheral associations that are inclined to be located and directed towards efforts in the western states. They mainly represent ideologic supporters who take a strongly differing view of the perceived goals of the environmentalists. Key or code words they employ are balance, facts, wise use, credible approach, hidden agenda, etc. Organizations in this category, include:

American Council for Science and Health
Ayn Rand Society
Center for the New West
Coalition for Responsible Mining Law
Committee for a Constructive Tomorrow (CFACT)
Mineral Resources Alliance
Mining Information Institute, Inc. (MII)
Mountain States Legal Foundation
National Council for Environmental Balance
National Environmental Development Association
National Resource Associates
Resource Development Council
Western States Public Lands Coalition (People for the West)

At least in the western United States, there appears to be a somewhat counterbalancing similarity in the quantity of members, level of expenditures, degree of militancy, and prevalence of special funding between these organizations and those smaller environmental associations listed above under *Sect. 2.5.3* , whose major scope is the mining industry.

Finally, there are groups which may affiliate with the mining industry in a common cause. Obvious examples are the mining equipment manufacturers and suppliers such as Amigos in Arizona, and the oil-and-gas and geothermal producers. Less obvious is the forestry industry, which has many similarities with mining and shares a community of interests in that both industries desire to keep the public lands open to producers of basic raw materials. Somewhat further afield are the off-road vehicle owners, who also wish to keep as much of the country open to [real estate] developers and off-highway excursionists. On the other hand, builders or home owners on patented land and even on unpatented claims do not wish to see mining companies lose the rights they have gained under the 1872 Mining Law. A latecomer organization calling itself the Mineral Resources Alliance was formed in 1993 "committed to responsible and balanced changes to the mining law." It appears to be composed of hard rock mining companies, suppliers, and vendors. This alliance is the direct descendent of the Coalition of Hard Rock Mining Companies, (see *Sect 2.8)*, and appears to be the current focal point for the mining industry's defense of most of the provisions of the current mining law.

## 2.7 NON-ADVOCACY ORGANIZATIONS

There are quite a few important non-advocacy sources of information, some of which are not very well known. They include specialized think tanks founded by state governments, professional societies, or narrow-interest data gatherers and dispensers. They collective operate as IRS §§ 501-C-3, or 501-C-4, corporations and include:

American Institute of Professional Geologists
American Society for Surface Mining and Reclamation
Association of Abandoned Mine Lands Programs
Environmental and Energy Study Institute
Environmental Law Institute
Interstate Mining Compact Commission

**Table 1** Chronological Development of Major Federal Actions that Control Mining

| Event | Date | Importance |
|---|---|---|
| Mining Land Ownership Laws Initiated | March 3, 1807 | Reserved from settlement or sale the lead deposits of Indiana Territory and Louisiana Purchase |
| Appointment of U. S. Army Lt. Martin Thomas as "Superintendent of U. S. Lead Mines" | 1824 | Initial federal authority over U.S. mineral rights by instituting a leasing system. |
| Supreme Court case United States v. Gratiot | 1840 | Established right of Congress to manage public domain including mining sites |
| Mining Act | July 11, 1846 | Ended first attempt to regulate public mineral reserves by leasing |
| Mining Act | July 26, 1866 | First attempt to control mining of lode claims |
| Mining Act | July 9, 1870 | Amended previous act to include placer claims |
| General Mining Law of 1872 | May 10, 1872 | Current mining law still in use with key modifications |
| Mining Act | March 3, 1873 | Entry allowed on vacant coal lands |
| Establishment of the Geologic Survey | March 3, 1879 | Duties include geologic (strategic) studies on the public lands |
| Establishment of the Bureau of Mines | May 16, 1910 | Initially covering health and safety, conservation, and (tactical) research |
| Mining Leasing Act of 1920 | February 25, 1920 | Provided that non-metallics be acquired through leasing system and specifies amount of royalties, lease size and duration |
| Coal Mine Safety Act | May 7, 1941 | Provided for inspections of coal mines |
| Materials Act of 1947 | July 31, 1947 | Provided for competitive bidding on certain non-metallic deposits |
| Mining Act | July 16, 1952 | Amended previous Coal Mine Inspection Act to increase scope of its authority |
| Act of 1954 | August 30, 1954 | Authorized AEC right to issue mining permits for fissionable materials on public lands |
| Act of 1960 | March 16, 1960 | Provided for location and patent of up to 5 acres in conjunction with a placer mining claim |
| Federal Metal and Nonmetallic Mine Safety Act | September 16, 1966 | Act was passed to increase requirements for mine safety |
| Federal Coal Mine Health and Safety Act | December 30, 1969 | Imposes coal mine heath and safety regulation upon underground and some surface coal mines |
| Geothermal Steam Act | December 24, 1970 | Act authorized leasing of geothermal resources through competitive leasing |
| Federal Land Policy and Management Act (FLPMA) | October 21, 1976 | Requires recordation of mining claims with the BLM and regulates surface protection of the public lands |
| *Surface Mining Control and Reclamation Act* (SMCRA) | August 3, 1977 | Established the Office of Surface Mining, Reclamation, and Enforcement (OSM) apart from the Bureau of Mines, also requires reclamation of all surface mine coal lands |
| Federal Mine Safety and Health Amendments Act | November 9, 1977 | Repealed Act of 1966 and amended Act of 1969. Responsibilities for mine health and safety transferred from DOI to DOL which establishes the Mine Safety and Health Administration (MSHA) |
| Deep Seabed Hard Mineral Resources Act | June 28, 1980 | Established interim procedure for the development of hard mineral resources in the deep seabed pending adoption of international protocols |

National Environmental Satellite, Data, and Information Service
Resources for the Future
Rocky Mountain Mineral Law Foundation
Society of Economic Geologists
Society for Mining, Metallurgy, and Exploration: SME - AIME
Western Governors' Association
Western Interstate Energy Board,
World Environmental Center

Several of these associations are especially worth noting. The American Society for Surface Mining and Reclamation encompasses representatives from mining companies, federal and state agencies, and members of the academic community. It is comprised of 450 members who regularly engage in research and field demonstration and report on their efforts. The Interstate Mining Compact Commission and the Western Governors' Association are small publicly funded think tanks gathering and dispensing information relating matters of mutual interest including mining environmentalism and working directly with and for the state governments. The Rocky Mountain Mineral Law Foundation and the Environmental Law Institute tend to complement each other on the subject of mining environmentalism. They both are clearinghouses for the collection, collation, and dispatch of information. To sum up, these associations tend to be officially non-adversarial, and maintain and update some of the most extensive depositories of information available to assist those interested in gaining information on mining environmental affairs. These associations are inclined to be only moderately used at present, but more so during periods of higher interest on specific issues. Because of their unique set of background circumstances these non-advocacy societies can often be effectively used as conciliators between different parties seeking to resolve mine environmental issues.

## 2.8 FEDERAL MINING LAW REVISION

The Department of the Interior, as well as mining industry concerned environmental organizations, is recommending a comprehensive revision of the federal mining law, including the Mining Law of 1872, as a way to impose more encompassing and stringent regulations. It should be noted that many refer to all federal mining law as the Mining Law of 1872, which is only partially correct. The Mining Law of 1872 was already amended to a large degree by the Mining Lands Leasing Act of 1920, which was passed with conservation in mind. The Leasing Act specified that non-intrusive deposits such as coal, phosphates, sodium, potash, gilsonite, and oil and gas were henceforth subject to leasing rather than simple staking. An historical perspective of U.S. mining law development is presented in *Public Domain, Private Dominion, A History of Public Mineral Policy in America*, by Mayer and Riley. Table 1 offers an abstract of pertinent federal mining law derived from *Malley's Handbook of Mineral Law, Second Edition.*

### 2.8.1 POSITION OF THE ENVIRONMENTALISTS

Revision of the mining law applied to hard rock minerals and implementation of environmentalism are intimately tied together. If enacted many of these newly proposed, highly restrictive laws and regulations will protect the environment by greatly reducing the current level of mining activity, *i.e.*, indirect exclusionist preservationism. A recent book on the subject, *Crossing the Next Meridian*, was written by Professor Charles F. Wilkerson, who contends that changing times need new laws. He calls the "Lords of Yesterday" those laws that were used to encourage western settlement in the 19th Century, but which are no longer required. The first on his list of five is the General Mining Law of 1872, for which he supplies a concise history of birth and subsequent development and employment. Wilkerson offers a Western environmental resource use doctrine based on "sustainable development (which) should be limited so that natural assets will be available in sufficient quantity and quality for future generations."

John Leshy in an earlier book, critically examined many aspects of the 1872 Mining Law. He also recommends its replacement based on his findings in part that the mining law contains anachronisms and ambiguities, particularly in light of what criteria must be satisfied to constitute a mineral deposit, the difference between lode and placer claims, and the right of access, and doesn't serve the interests of the public or miners in developing mineral resources on the public lands.

A key issue for some of the environmental groups is a mandatory industry contribution into an orphan, or abandoned, land cleanup fund as a component of a fair share payment for the privilege of extracting part of the nation's patrimony with the precedent being an AML (abandoned mine lands) tax on U.S. coal production. This fund may be separate and distinct and in addition to any proposed royalty. The MPC, as noted in *Sect. 2.5.3*, estimated the minimum hard rock AML cleanup requirements to be approximately $33 billion. The MPC wishes to see some $400 million/yr collected to fund cleanup costs. However, environmentalists Mayer and Riley, *op. cit.*, propose that royalties should only be calculated against net profits, and not as most environmentalists wish, against gross revenues.

Several bills to reform or substantially revise the General Mining Law have been introduced in the last three Congressional Sessions. The debate has at times been acrimonious and has pitted the mining industry squarely against the more extreme environmentalists and preservationists. Thoughtful industry representatives are stating that some changes to the mining law are necessary, but wholesale scrapping of the principles that have been developed and that have worked for the last 150 years is not warranted and could destroy the domestic hard-rock mining industry. A number of difficult issues still need to be resolved before a reasonable compromise bill emerges that can achieve the objectives of both the mining industry and the mainstream environmentalists.

### 2.8.2 POSITION OF THE MINING INDUSTRY

The mining industry does not have a fixed point of view on the matter of revision or modification of the federal mining law. However, the industry believes that it has been given a bum rap bred by rhetoric and emotion that is much more powerful and socially acceptable than the cold-and-dull, impersonal science of accurate research/data. For them, too many people examine the past with revisionary eyes. Specifically, the mining industry states that about 32% of all United States surface area is owned by the government, and most of that is already "locked up" and off limits to mining. Conversely, less than half of 1% of the United States land mass has even been touched by mining. This is much less than any other acceptable forms of land dedication such as for towns/cities and for infrastructure.

The mining industry further believes it is significant that the WGA (see below) has stepped forward with a resolution to maintain primacy in reclamation control at the state level and also warns of the danger of excessive taxation/royalty. The industry's own attitude against full replacement of the mining law is as follows:

- Changing the law will serve to start a large new cycle of court cases over many issues that have already been resolved (i.e., the "Apex Law"), this will eventually require even greater expenses being incurred by the Department of Interior and the mining companies with no useful purpose, and also mean a great deal of added judicial review.
- As shown by a news article in the May, 1993 (North American) issue of the *Engineering and Mining Journal*, and subsequent articles in the same magazine by Evans and Dobra, significant royalties on the gross value of the mined product will be devastating to many of the already economically hard-pressed hard rock mining companies, many will be forced into a negative rate of return causing them to shut down operations (for a different interpretation see *Sect. 2.5.3)*. The net result of significantly higher taxation will actually result in less overall taxes into the federal coffers, as the goose laying the golden egg will have been strangled.

**Table 2** Worldwide Mining and Tax Comparison

| Country | Royalty* | Income Tax |
|---|---|---|
| Argentina | Royalties being cut to 3% | 30% |
| Bolivia | No royalties for new mines | 30% |
| Brazil | 0.2% to 3% paid to the states | 30 - 35% |
| Canada | No royalties | 45% |
| Chile | No royalties | 35% |
| Ghana | 3% to 12% | 45%+ |
| Indonesia | Negotiable 1% to 2% | 35% |
| Mexico | Royalties abolished in 1991 | 35% |
| New Guinea | 1.25% | 35%+ |
| Philippines | 5% projected to be cut to 2% | 35% |
| United States | Under discussion | 34%+ State |
| Zimbabwe | No royalties | 42.5% |

Compiled by Dr. Fred Barnard, Mining Evaluation Profiles, and presented in (Alaska) Resource Review, April 1993

(* Note: royalty calculation method not specified. Typically in the private sector hard rock royalty is calculated as a percentage of the net smelter return)

- As each hard rock mine is unique, so each mining environmental problem is also separate and distinct. Inflexible industry wide regulations are simply not workable.
- As hydrologic issues/remediation differs between the west and the rest of the United States so do geologic and marketing conditions differ between coal, salt, trona, oil and gas, and the so-called hard rock minerals, as does their normal business risks. Assuming what can work (i.e., leasing) in one industry segment can automatically work in another is false thinking (several oil companies learned this bitter lesson of differing business risks and basic

economics to their sorrow, when they acquired mining companies in the 1960s and 1970s).

- There also appears to be a major misconception over the basic principles of economic geology, exploration, and the economics of hard rock mine discovery. Viable mineral deposits are very few and far between and are randomly found usually near areas of igneous activity. The cost of finding new mines is prohibitively expensive. Who will find those new deposits, if the locator does not have the incentive of having first right to develop and mine them?
- Major problems will exist for ongoing operations if grandfathering is not judiciously applied.
- Many environmental laws that already regulate mining have been enacted. What is needed are not more conflicting and overlapping instructions, but rather comprehensive, well integrated, and streamlined workable rules. All United States commodities are under severe competition from foreign producers, *and current taxes are in line with much of the rest of the world* (see Table 2). More costly over-regulation will mean loss of domestic production and investment by the mining industry to outside areas that are less restrictive over the business of mining.

Also of contrasting interest to the environmental viewpoint is the statement of the Mining and Metallurgical Society of America in their *Position Paper on Federal Mining Legislation* dated May 1993. They conclude:

*"The basic provisions of the Mining Act of 1872 embody those concepts necessary for a healthy domestic mining industry. A viable mining industry is necessary for a high standard of living and a secure nation. It would be extremely unwise and counter-productive to completely replace this legislation. Changes in the Mining Act of 1872 can be accomplished through modifications that recognize the need to preserve and define the concepts of discovery, secure land tenure, self initiation, multiple use, and fair compensation to the public through reasonable rates."*

### 2.8.3 POSITION OF THE WESTERN GOVERNORS' ASSOCIATION

The WGA on June 22, 1993 adopted a policy statement whose principal points declared that

- Misrepresented non-mining use of claims should be prohibited and deficiencies in present, including environmental, laws should be corrected but additional repeating federal law is not needed. The states are the most appropriate level for regulation.
- If legislation goes forward with provisions for unsuitability reviews, then it should require the appointment of a federal advisory committee composed of state regulatory and mineral resource agencies and environmental and industry interest groups. The purpose of the committee would be to advise Secretaries of Interior and Agriculture (DOI and DOA) in the identification of unsuitable lands and the program design to reclaim abandoned mines. Existing land use planning and environmental laws should provide the basis for unsuitability of federal lands.
- A royalty should be authorized which provides a return to the federal and state government without causing a significant decrease of mining or exploration activity, the loss of jobs and the negative economic impact on mining communities and domestic mineral production. The royalty should be based on profitability, recognizing the cost of producing the mineral commodity, as well as the cyclical and international nature of the mineral markets.

### 2.8.4. THE RCRA OVERLAP

Although not part of federal mining law, the Resource Conservation and Recovery Act (RCRA) is still very important because of the possibility of extending its coverage of hazardous wastes to the mining industry. Customarily, federal statutes are limited up to a period of 5 or 10 years, and must be periodically re-authorized. A failed attempt was made in the 102nd Congress to redraft RCRA and to include federal mine-waste management regulations. Congressional disagreements arose over:

- Expansion of authority to include non-wastes such as heap/dump leach material and ore stockpiles.
- Inclusion of waste produced during exploration.
- Expansion of enforcement over state-issued mine waste permits.
- Possible extension of the program to operating and inactive mine waste sites.

Assuming both a revised federal mining law and that RCRA will be re-authorized in the near future, then it would be expected that either the DOI or EPA would be awarded primacy over hard rock mine waste storage and reclamation.

### 2.8.5 OVERVIEW

A careful evaluation of *Sect. 2.8* shows the deep-seated differences of opinion of most of the parties interested in

the possible revision of the federal mining law. First, there is no present clear cut consensus on what environmental protection is supposed to protect and how far to go to protect it, or else how far it is meant to go. Second, there is obviously a broad area of disagreement as to the meaning and significance of the technical information on hand. Thirdly, the issue of restrictions on the right of access and the right to mine on federal lands is under contention. Fourthly, the question of whether mining companies should pay the government over and above normal taxes, for the right to mine, and how much to pay including any contributions to an AML Fund, will probably be the most difficult point to resolve. On this last point there is already much heated debate whether additional taxes going into an AML fund will actually create or cost more jobs.

## 2.9 SUMMARY

The environmental ethic applied to mining has been evolving over a surprisingly long period of time but still lacks full definition. In the industrial world minor public skepticism, which has been around for centuries, slowly evolved into increasing apprehension, beginning during the mid-to-late part of the 19th Century. Lately, this feeling has turned to much more widespread disapproval over any actual or even imagined harmful impact of mining on the environment. In the United States a strong negative attitude first appeared during the era of hydraulic mining of gold in California. From that period to the present, anti-mining feelings, fueled by a series of sporadic episodes, have been gathering accelerated widespread momentum which crystallized to the point where seemingly the United States mining industry can now expect major new comprehensive regulations in the very near future. The actual impact is impossible to define. The determinant will be the definition of what constitutes necessary environmental protection, which is expected to be forthcoming in the near future, followed by the ability of the newly assigned regulators to manage the effort. A wildcard is the type and extent of any royalty or fee geared to abandoned mine reclamation. Again, the classic questions of how much, how to, and who must be first answered or defined before their impact can be determined. There are deep divisions among all the protagonists as to the necessity for and eventual impact of the contemplated new mining laws. Nevertheless, it is evident that those proposed mining laws which are actually draconian in nature will impose very severe restrictions, if not crippling conditions, on the hard rock mining industry, and the nation as a whole will accordingly suffer the consequences. Even if laws of this nature are not passed, the United States mining industry is uncertain of its future and is seeking to continue operations where the future is less in doubt.

At the same time, a hard-to-track large and bewildering array of organizations interested in mining and the environment with tremendous differences in outlook, priorities, and methods has appeared on the scene. Some of those associations may indeed have become cottage industries, with a few of the fund raisers reputedly garnering as much as 40% commissions. Nevertheless, their profusion, if nothing else, indicates the perceived importance of the mining industry's environmental issues. Likewise, the introduction of a Department of Environmental Science and Engineering at the Colorado School of Mines further emphasizes the growing importance of environmentalism on the mining industry. Environmentalism is not a flash in the pan but definitely a significant current and future consideration that must be taken into serious account within the mining industry. Prudent mining company executives not only environmentally plan for today, but also for the future. The overriding consideration that must be faced is that most Americans want some, as yet to be defined, positive action to be undertaken in order to at least protect if not better the environment, but without causing too much self-interference and "pain."

The federal and state governments, with the concurrence of the mining companies and the environmentalists, all with some caveats, are generally desirous of delegating decision making to the states with the hope that they can handle this very important responsibility. Without ignoring the political events occurring in the nation's capital, interested parties are also gearing up their activities at the state levels in anticipation of a subsequent future round of deliberations and activities. In the meantime, the United States mining industry is in an attitude of apprehension and flux, waiting to be further impacted by the anticipated environmental regulations. Environmentalists have staked out the moral high ground, and intercede when and where deemed necessary. They are constrained by the current medium priority level accorded the mining industry by the major organizations, a shortage of financial resources by the smaller, more mining focused organizations, and a lack of an overwhelmingly strong and concerted public interest. Nevertheless, much of the press and the public view of the mining industry is more negative than positive, as it commonly considers mining a significant polluter of the environment.

For its part, the mining industry is almost always on the defensive or reactive. As one mining executive put it in a cry from the heart "Yes! We were wrong in the past, but if only we are now left to our own devices (no more harassment by the environmental organizations which cause us to diffuse our energies), we *will* get our house in order according to the current regulations." Even with the founding some 18 years ago of the Mineral Information Institute, Inc. (MII), it is obvious that the mining industry is presently unable to get messages of

this sort across to the public at large, especially in light of periodic bad publicity even within the mining industry press, an example of which is the Summitville Mine in Colorado (see *Chap. 18* for details, and the article by Jones in *Mining Engineering*). When magazines such as *Time*, November 22, 1993, in its breezy style, take on the mining industry it is in trouble. Two videos on the importance of mining are "Out of the Rock," and "Common Ground," prepared respectively by the Bureau of Mines, and Caterpillar, Inc., appear to be directed towards high school students. Both seem to have had very limited circulation although they have been able to modify some people's originally negative view of mining. This critical lapse of concerted positive and effective public relations effort is directly attributable to a shortfall in funding, coordination, capability, opportunity, and possibly even in desire or hope. Furthermore, a difference of opinion generally between the larger, relatively well funded, mining companies and the so-called junior mining companies *vis a vis* revision of certain aspects of the federal mining law weakens the industry's general position before the federal legislators. This points out an important truism, that nearly all of the protagonists concerned with environmental protection of mining cannot be neatly catalogued into fixed, and all-encompassing, readily discernible positions. Instead, the mining companies, the environmentalists, the federal and state legislators and regulators are all consistently rethinking, modifying, and even shifting their opinions, and therefore the situation is highly fluid and very difficult to keep in constant focus by interested observers.

Recently in California, Oregon, and Colorado, new mining regulations were promulgated, and in each case, state mining associations as well as environmental organizations, were participants in the discussions. The resulting compromise was a written acceptance by all interested parties. It is hoped that this type of constructive spirit of intervention and settlement continues on remaining mine environmental issues, most especially the thorny critical question of what to do about the federal mining law. Failure to do so may mean an enacted solution which leaves everyone dissatisfied and benefits no one. Many of the non-adversarial data gathering organizations listed in *Section 2.7*, could be advantageously used to aid in this worthwhile process of consensus compromise building by supplying information and by even acting as promoters, mediators, or expediters among contrasting protagonists. Finally, there may be more common ground than normally considered between environmentalists and the mining companies. After all, if remediation is required how will it come about, and who has the requisite skills to accomplish the work, if not these very same mining companies. This mutuality of seemingly otherwise implacable interests has already started to develop in the timber industry. In *Chapter 18*, Maxine Stewart describes the Druid mine in Colorado, where re-mining was recently initiated. It should be noted that re-mining will not provide a quick fix solution, because it also can create new problems. Furthermore, re-miners will not be eager to work as long as threats of Superfund actions hang over their heads. Consequently, there are real issues (such as with re-mining) in which many of the protagonists can work together to attain mutual objectives. Unfortunately, in a postscript to her study Ms. Stewart illustrates why the effort failed because in her words "the regulatory system was not prepared to deal with this novel - yet very simple - approach".

What is urgently required is more positive consensus building. Since the House and the Senate could not agree, no new mining law was enacted during the 103rd Session of Congress. Undoubtedly, this issue of mining law reform will continue to be examined in the future. Hopefully, what will eventually emerge is a new atmosphere devoid of rhetoric, with the employment of sound basic information, and finally, good positive governmental leadership willing to encourage technical innovation and judicious financial risk. It is hoped that this Handbook proves to be a useful tool in helping to accomplish that goal.

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Chapter 3

# THE LEGAL BASES OF FEDERAL ENVIRONMENTAL CONTROL OF MINING

edited by A. J. Gilbert

## 3.1 INTRODUCTION

This chapter describes the federal laws that govern the environmental control of mining operations in the United States. It begins with a general discussion of how federal environmental law is formed, where it is found, and the fundamental policies it reflects. The remainder of the chapter addresses each of the modern environmental laws in turn. The structure of each law is described, and then its application to mining operations is discussed.

The environmental professional must proceed with caution in this area. Federal environmental law is massive, complicated, and constantly changing, and the text that follows is only a brief guide to this subject. An environmental professional will not be a lawyer after completing this chapter. He or she will, however, understand the outlines of federal environmental law. That is no small task.

As described in Chapter 4, state law, and to a lesser extent local law, are also important guides to conduct in the environmental area. State and local rules may differ from the federal rules described in this chapter, yet state and local law also binds the activities of the environmental professional. The reader must remain alert that in a particular state the descriptions below may be superseded or incomplete.

### 3.1.1 OVERVIEW

Modern environmental law is formed largely by recent federal statutes, modern federal agencies, and a constantly growing set of federal regulations and guidance documents. The federal courts, too, have assumed a lead role in the creation of environmental law over the past 20 years. The purpose of the first part of this chapter is to describe generally the structure and content of this federal environmental law, how it can be found, and the basic principles upon which it is built.

### 3.1.2 THEMES IN ENVIRONMENTAL LAW

The federal environmental laws reflect several disparate themes. These ideas, summarized in this section, run throughout this subject area.

*Policy choices.* Federal environmental laws are designed to implement one or more policies. Examples of such policies include the minimization of emissions or the balancing of the benefits of pollution reduction against the cost of the reduction. Various policies emerge repeatedly, in different combinations in different statutes, as the United States Congress picks and chooses among its options as it creates laws. Once the environmental profession understands these policies, an understanding of individual statutes is much easier to master.

*Science and law.* Environmental law is replete with mixed questions of scientific and social policy. The professional proceeding upon the assumption that science alone will answer questions is naive politically and scientifically. Most difficult environmental law decisions are made in areas of knowledge where science as yet has few answers.

*The importance of individual facts.* Federal environmental laws and regulations are designed to apply wide-ranging and abstract policies to very discrete factual situations. The laws involved draw careful lines between conduct approved and disapproved, sometimes make obscure distinctions, and at times also allow exceptions to turn out to be more important in practice than the overall rule. (The Bevill Amendment exception, which excludes certain mining wastes from hazardous waste regulation, is an example of the latter.) Close analysis always is needed to find the right answer for the particular situation before you.

The overview discussion in this chapter will help the reader form appropriate questions. It does not provide

enough detail to enable you to form answers with confidence.

*Uncertainty.* Uncertainty in federal environmental law is an unfortunate fact of life. It sometimes is difficult to decide upon the application of a particular rule to a fact situation, either because the rule is ambiguous or the application complex. A course of action must often be chosen without assurance that it ultimately will prove to be the best way to have proceeded.

*The structure of environmental laws.* At a suitable level of abstraction, federal environmental laws are not difficult to understand. All are directed at a specific problem. Choices have been made as to how to address that problem. The construction of a statute and the rules it contains reflect the strategy adopted by Congress to implement these policy decisions.

It is generally this level of abstraction which is reflected in the discussion which follows. The details of implementation usually provide the complexity and ambiguity inherent in federal environmental law.

*Ideas in environmental law.* As with any area of the law, federal environmental law embodies several themes which cut across the various statutes and environmental media. Once they are understood, the reader has made significant progress to understanding even unfamiliar laws, because these same approaches are adopted again and again.

First, cost and feasibility considerations usually are considered in federal environmental laws only *after* public health has been protected, in general. (This issue is at the heart of the debate in the mid 1990s over the cost of environmental regulation.) Second, federal environmental laws usually set out minimum standards which must be adopted by the individual states, but then the states are free to experiment and be more protective by adopting more stringent rules if they so choose. There usually is a tension between uniformity of federal environmental requirements (a policy which aids commerce, discourages site-selection shopping by industrial facilities, and allows for ease of administration) and the allowance of different laws in different states or locales (a policy allowing rules to be fine-tuned to reach the physical and political realities of local communities and experimentation). Third, the standards used in federal environmental law generally can be broken down into two principal categories; ambient and technology based. Ambient standards provide ceilings for the amount of pollution allowed in a particular environmental media, and thus are resource allocation tools. Technology-based standards require a particular level of control ("best available technology," for example) for a particular activity, regardless of the specific effect of the activity upon the ambient environment.

*History.* The history of the development of environmental protection in the United States explains how federal environmental laws have attained their present form. Prior to the modern federal environmental era, the battle for environmental protection was played out in the courts in negligence, trespass and nuisance cases. It usually focused eventually upon causation issues — whether the pollution created by a defendant had actually caused the harm asserted by the plaintiff. Modern federal environmental law removed most such controversies from the courts. Causation issues now usually are resolved in a more general and abstract sense during the rulemakings which create standards. Much of modern federal environmental law is a reaction to the shortcomings of a system in which all controversies were directed to the courts.

*Enforcement.* An understanding of the enforcement of federal environmental laws is important to an understanding of how federal environmental law works in practice. The practical structure of environmental law is set in a foundation of command and control regulation. Such rules lay out required courses of conduct and standards for compliance. They can be inefficient in an economic sense. In recent years, federal environmental law has begun to embrace market-oriented controls, in an effort to achieve equivalent control at less cost. For example, the Clean Air Act of 1990 contains an acid rain control program which depends upon the free trading of emissions rights credits to lower emissions of acid rain precursors in an economically efficient way.

*The role of the public.* The role of public perceptions and public participation in government activities is a key aspect of federal environmental law. This public approach is built upon the foundation of a strong identity in American culture with its natural heritage. Modern federal environmental law embraces the widely shared perception that public participation in government activity provides better social results, and legitimizes the actions taken. From a practical point of view, the environmental professional always must remember that the public plays a very substantial role in federal environmental law.

*Complexity.* Portions of federal environmental law are so complex, either through ambiguity or the level of detail presented, that virtually no one can obtain a full and clear understanding of the application of these rules to particular fact situations without great effort. The definition of solid waste under the hazardous waste program of the Resource Conservation and Recovery Act is a good example of this problem. Very simple questions can be very difficult to answer, or may have no certain answer.

*Paying for environmental protection.* Federal environmental law has moved away in part from notions of "fairness" of application. In recent years, statutes have been preoccupied with how to pay for needed environmental

remediation.

The rules of the Comprehensive Environmental Response, Compensation and Liability Act are the best example of this trend. In the environmental arena, the choice of who will pay usually is decided among groups of taxpayers or groups of industries. In this example, these choices are necessary because old waste disposal practices, lawful at the time undertaken, are now perceived to cause substantial ongoing pollution problems. The decision has been made to remediate these problems in order to protect public health and the environment, and the staggering associated expenses must be borne by someone.

*The role of the courts.* Many of the controversies over rules adopted under federal environmental statutes are routed eventually to the federal judicial system. As the scientific and engineering issues underlying these legal disputes become more and more complex and uncertain, it is legitimate to ask whether the courts are properly equipped and trained to resolve such controversies in sensible ways.

*Limitations on the use of resources.* The notion runs through federal environmental law that environmental resources are inherently limited. Whether it is the assimilative capacity of the ocean, the use of the atmosphere as a waste disposal sink, or the placing of contaminants within the earth's surface, the appropriate societal allocation of a limited resource is a principal focus of federal environmental law.

*Prevention of pollution.* Finally, it is always easier and less costly to avoid environmental problems in the first instance than it is to clean them up once pollution has occurred. The distinction between regulatory statutes, which seek to avoid pollution in the first instance, and cleanup programs, which seek to remedy the results of unfortunate activities in the past, is a fundamental aspect of federal environmental law.

### 3.1.3 APPROACHES INCORPORATED INTO FEDERAL ENVIRONMENTAL LAW

Federal environmental law contains several different tactics and techniques used to solve mining and other environmental problems. These approaches are distinct, and therefore adopt very different policies to reach their goals. The environmental professional should be aware of these distinctions. Otherwise, the vast array of federal environmental statutes, regulations, and guidance quickly becomes a policy morass.

*Land use controls.* A first subset of federal mining environmental constraints includes those rules imposed as part of an overall strategy of land use controls. These laws are directed at mining as a use of the land. The best example of this approach is the array of environmental protection rules in the statutes which make up the federal public land laws.

*Protection of environmental media.* A second type of federal environmental control on mining activities contains limits imposed more generally by Congress to protect a particular environmental resource. Under these laws, mining is only one of many types of industrial and other activities regulated. Indeed, if particular mining operations do not affect the resource involved, they are not regulated at all under these statutes.

Most environmental regulatory statutes fall within this category. For example, the Clean Air Act regulates emissions of air pollutants generally, and applies specifically to pollutants from crushing operations. The Clean Water Act regulates the discharge of heavy metals from a milling operation to a stream. Likewise, the Resource Conservation and Recovery Act regulates the disposal of various cleaning solvents by mining companies. As a final example, the Endangered Species Act and similar statutes force companies to cover cyanide-laden ponds, or to find other ways of making sure migrating birds and other animals are not injured as a result of their attraction to the installation.

*Preconstruction analysis of potential environmental damage.* A third policy approach is embodied in the federal government's very broad attempts to analyze and review the environmental effects of various mining and other activities before they are undertaken. The National Environmental Policy Act, the federal statute which requires environmental impact statements to be written, contains exactly this approach to environmental protection. It addresses mining activities, of course, as it addresses all other activities of a size and scope sufficient to trigger its requirements.

*Accidents.* A fourth set of federal environmental laws require particular responses to be undertaken as a result of accidents or other inadvertent releases of pollutants. These statutes can impose reporting requirements which are very important for mining operations from a practical point of view.

The best example of such a statute is the Comprehensive Environmental Response, Compensation, and Liability Act, which contains spill response cleanup features and reporting requirements important to the mining industry. Another example is the Emergency Planning and Community Right-to-Know Act, which has very important annual reporting requirements and spill release reporting requirements for the mining industry and other types of industrial activities.

Two other matters deserve mention here. First, the set of legal rules known as the *common law* can also be important to mining and environmental protection. The common law is a set of general rules for conduct which emerges from considering together the individual opinions

rendered by courts in particular fact situations. Since the courts in our judicial system follow precedent (decisions which have been made previously), environmental common law rules provide recognizable guidance for activities to be undertaken by mining companies and others in the future.

### 3.1.4 FEDERAL AGENCY INVOLVEMENT

A key to an understanding of federal environmental law is an understanding of the degree and type of involvement of the federal environmental agencies. These agencies include the United States Environmental Protection Agency, the Forest Service, within the Department of Agriculture, the Bureau of Land Management, within the Department of the Interior, and others. Much of the day-to-day application of environmental law lies in the work of these agencies. The environmental professional must know how these agencies are organized, and how they carry out their tasks in formal and informal ways. As important, the environmental professional must understand the legal boundaries which constrain the activities of these agencies. This section addresses these topics.

The first step is to define what an agency is. Simply stated, a federal agency is an organization formed within the Executive Branch of the federal government to carry out specific purposes. Such organizations have several important characteristics.

- Agencies are created by Congress. The typical agency is formed by a statute. That statute ordinarily is referred to as the agency's "organic" act.
- An agency has one or more statutory missions, set by Congress. The work of the agency is defined by these missions and by the statute which contains them.
- An agency often is empowered by Congress to make law, in the form of regulations.
- The actions of agencies are subject to statutory restrictions which are enforced by the courts. An agency's activities thus are subject to review by the courts, and can be overturned. Nevertheless, as described below, courts award agency activities great deference. In practical terms this means that agencies are usually entitled to make final decisions on important environmental matters, without fear of being reversed, so long as those decisions are reasonable.
- Agencies can act in ways that are very similar to the actions of Congress and the courts. The rulemaking activities of agencies are much like the exercise of the statutory powers of Congress. Agencies often hold hearings and convene administrative trials as well, and these are proceedings that look very similar to trials carried out in the Judicial Branch of the federal government.

The Constitution of the United States carefully separates the governmental powers distributed to the Executive Branch, the Judicial Branch, and Congress. Each of the three branches of the United States government is able to exercise powers that collide, at their edges, with the affairs of the other branches. Since federal agencies are divisions of the Executive Branch, some of the uncertainty and difficulty in environmental law arises from the gray areas at the boundaries of Executive Branch powers.

Court cases provide continuing examples of the effort to define which agency decisions properly lie within the Executive Branch's province, and which decisions have overstepped appropriate bounds and can be overturned by an exercise of the Judicial power. The environmental arena has been an especially active area for development of this aspect of administrative law. Similarly, agencies engage in a continuing struggle with Congress over how to administer the environmental laws. Sometimes the underlying law is itself changed by Congress, unhappy with an agency's administrative choices and activities.

### 3.1.5 HOW FEDERAL AGENCIES WORK

In order to carry out a mission under its statutory authority, an agency makes rules, and those rules are law that bind conduct. There are two general ways in which such rules emerge. First, the agency can engage in a rulemaking activity, publishing its proposed rule, taking comment, and promulgating a final rule. Second, the agency can adjudicate particular cases in trial-type settings, and rules will emerge from the agency's decisions in much the same way as the common law, described above, is created. Because agency adjudication-type rules usually are not important in the environmental area, they are not addressed below.

An agency faces two principal constraints as it promulgates a rule of conduct. The first constraint is substantive, and the second is procedural. From a substantive point of view, an agency's rule must lie within the boundaries formed by the delegation of Congressional authority found in the agency's organic statute. For example, the United States Environmental Protection Agency is not entitled to regulate the clear cutting of forests. By statute, that decision falls within the legal province of the United States Forest Service.

The scope of the delegation of Congressional authority in a particular statute often is not clear. For example, the Clean Air Act requires EPA to promulgate national ambient air quality standards as rules which, "allowing an adequate margin of safety, are requisite to protect the public health." Congress has provided no additional guidance as to what this very general mandate means, and EPA is left with the very difficult scientific and policy decisions necessary to give content to these words.

The second constraints upon agency rulemaking are procedural. Agencies must follow defined procedures in order to enact rules that are to have the force of law. These

procedures take two forms. The first is general, contained in a federal statute called the Administrative Procedure Act. Second, the individual statutes which guide the particular agency's conduct may also have particular procedures which must be followed. For example, the Clean Air Act contains substantial detail concerning procedural requirements for the promulgation of many air quality rules, and these requirements supersede those of the federal Administrative Procedure Act.

Many of the procedural guidelines that constrain agencies address the rights of the public to be informed of the activities of the government before they occur, to be allowed to comment, and to be informed of the government's final decisions. A continuum of types of procedures can be followed by agencies, depending upon the action they intend to undertake. These procedures range from an agency simply acting, and giving no notice to anyone, to the familiar rulemaking in which an agency publishes formal notice that it intends to take action, allows people to submit written or oral comments, considers those comments, and then makes a decision. An even more formal procedure used in some instances requires similar public notice but mandates a formal hearing as well, in which witnesses are cross examined and a decision maker from the agency sits in judgment. The latter hearing is much like a court proceeding.

These procedural and substantive constraints upon agencies are enforced by the Judicial Branch. This constraint upon agency activity is described in more detail below.

Agencies undertake a host of other activities that guide the conduct of the public in environmental and other areas. These include, for example, the issuance of formal, published guidelines in pamphlet or book form. Sometimes agencies publish policy statements in the *Federal Register*, or otherwise disseminate their views on how the law should be interpreted. Finally, some agencies issue letters to the public, and these letters contain the agency's views and policies on particular questions in particular fact situations.

A usual hallmark of these more informal agency guidance materials is that they are not well organized. It is often very difficult to find these materials, short of speaking with an agency expert already familiar with their existence.

Before leaving this topic, it is well to emphasize again the role of public participation in the activities of environmental agencies. Federal environmental law is at the forefront of the trend in American law to allow the public a right to participate to a substantial degree in agencies' work. As a result, the environmental professional must understand the practical reality that the perceptions of the public, and the reactions of the public, often guide the conduct of agencies. Sometimes these pressures result in agency decisions that otherwise, for scientific or practical reasons, might not have taken place.

### 3.1.6 FEDERAL AGENCY ENFORCEMENT

Federal environmental agencies have powers that allow them to enforce their rules. The tried and true traditional method of enforcement is for an agency to apply to a court to enforce the agency's rules against a private party. That enforcement often is accompanied by statutory civil or criminal penalties.

Increasingly in the environmental area, federal agencies are given enforcement rights directly, without the need for application to a court. Examples include the Environmental Protection Agency's ability to issue cleanup orders under the Comprehensive Environmental Response, Compensation, and Liability Act and the Resource Conservation and Recovery Act, and the same agency's ability to "ticket" certain violators of the Clean Air Act. These new procedures reflect Congress's perception of a need for more rapid, sure enforcement. If the private party chooses not to obey the order of the agency in these latter situations, the agency then returns to court to seek judicial enforcement of its order.

### 3.1.7 COURT REVIEW OF AGENCY DECISIONS

Much of formal federal environmental law is dedicated to an understanding of the appropriate limits to judicial review of agency decisions. The courts furnish a principal practical constraint upon agency activities, but the proper role of the courts is a complex matter. The underlying difficulty in judicial review of agency decisions flows from the structure of the federal government. When does the ability of the Executive Branch of government (through an agency) to make societal rules end, and when does the right of the Judicial Branch to make societal rules begin? The answer to this question varies according to the circumstances.

As a general rule, the ability of a court to overturn an agency decision is very limited. From a substantive point of view, in most instances the courts will allow an agency's decision to stand unless it is "arbitrary and capricious," a term of art originally found in the federal Administrative Procedure Act. This standard of review means that an agency's decision will not be overturned (often despite the fact that a judge believes that the agency was wrong) so long as the agency's decision was reasonable. That inquiry usually translates to an examination of whether the agency has taken into account and carefully considered all the factors mandated in the statute that governs the agency activity.

Agency actions also can be overturned if the agency has neglected to follow a procedural rule. The trend, however, in the federal environmental area is to restrict the ability of the courts to overturn agency activities on procedural grounds. Congress appears increasingly convinced that the need for substantive agency decisions overwhelms the need for strict procedural compliance. Congress increasingly has

more interest in rapid action in the environmental area than in making sure various procedural notification and timing requirements are met. The Clean Air Act provides a good example of this trend. Under that statute procedural violations do not invalidate a rule unless they are of such central significance that a court believes the rule likely would have been different had the procedural violation not occurred.

### 3.1.8 HOW TO FIND FEDERAL ENVIRONMENTAL LAW

The purpose of this section is to provide a general description of how legal materials are organized and where they are found. The environmental professional must have enough familiarity with these matters to be able to locate statutes, regulations, and important agency guidance.

The term "law" is a general description for many different kinds of rules. The fact that these rules must be obeyed is backed up by governmental sanction (a trip to jail, for example), or damages or an order to perform activities in a lawsuit brought by a third party. In the federal environmental area, the following kinds of rules are those that most often must be followed:

- Statutes, which are written rules enacted through traditional processes of Congress.
- Rules which emerge from judicial decisions in particular cases, known as the "common law."
- Executive orders, which are mandates proclaimed by the President in the form of published orders.
- Regulations enacted by administrative agencies, which are rules promulgated by following procedures required by statute.
- Various kinds of guidance documents are written by administrative agencies to assist persons to determine the propriety of various kinds of conduct. These include such things as policy statements in the preamble language to formal regulations, and memoranda and letter rulings issued by an agency.

Each of these aspects of federal environmental law has a place in a hierarchy of importance. For example, one can go to jail for the violation of a statute or regulation. In contrast, an act undertaken in contravention of an agency policy statement, without special circumstances, will not result in either criminal or civil penalties.

These rules are collected in various written compilations of legal requirements. The most important are as follows.

*Statutes.* Federal statutes are collected in several sources. The most commonly used source is a set of documents called the United States Code (or its companion volume, the United States Code Annotated, which contains relevant descriptions of court cases as well). The most widely used compilation of federal statutes is the United States Code Annotated published by West Publishing Company, which is a set of small brown volumes. These publications contain various indices, as well as "pocket parts" in the rear of a volume, to allow the reader to find provisions and keep up with statutory changes.

Statutes are organized in the United States Code by a title and a section number. The titles of the United States Code correspond to the major subdivisions of the statutory law, divided by subject area. For example, most federal environmental statutes are found in Title 42, Public Health and Welfare. (An exception is the Clean Water Act, found in Title 33, Navigation and Navigable Waters.) Each separate portion of an individual statute, found within a title of the United States Code, is assigned a separate section number. As an example, the first section of the federal Clean Air Act is located at Section 7401 of Title 42 of the United States Code. This provision is cited as *42 U.S.C. § 7401*, and is entitled "Congressional Findings and Declaration of Purpose."

When statutes first are enacted, they are published by Congress in a form referred to as a Statute at Large. Before they are assigned to a title and a set of section numbers within the United States Code, each provision of the Statute at Large is designated by an original section number, usually starting in the form "Section 1" or "Section 101."

Practitioners familiar with federal environmental statutes often will refer to a particular section of a statute using the United States Code form or the Statutes at Large form interchangeably. For example, as originally labeled in Statute at Large format, Section 309 of the Clean Air Act contains the federal enforcement provisions of the Clean Air Act. Section 309 is exactly the same provision as *42 U.S.C. § 7609*, the United States Code designation for the same language. Lawyers and other experts might refer to this same provision interchangeably as Section 309 of the Clean Air Act or Section 7609 of the Clean Air Act.

*Court decisions.* Court rules are collected in different fashion. As described above, rules that guide the conduct of mining companies, their employees, and other citizens emerge from case-by-case decisions of the Judicial Branch of the government — the courts. There are several levels of courts within the federal judicial system. The District Court is the trial court; the United States Courts of Appeals are the intermediate level of appellate courts; and the United States Supreme Court is the court of last resort in the United States.

Decisions from each of these courts are collected in volumes called "reporters." Federal district court decisions are collected in reporters which are called the "Federal Supplement," abbreviated as "F. Supp." The decisions of the federal Courts of Appeals are collected in the *"Federal Reporter."* It is now in the third edition, and is cited as "F.3d." The decisions of the Supreme Court are collected in

several different publications, but the formal citation to Supreme Court decisions is "U.S."

A single decision is published in a particular volume of a particular reporter, and at a particular page. Thus, case decisions are cited using that format. For example, an important case under the Clean Air Act, *Alabama Power Company v. Costle*, is cited as 636 F.2d 323 (D.C. Cir. 1979). That citation means that the case appears at page 323 of Volume 636 of the second edition of the *Federal Reporter*. The parenthetical tells you that the decision was made in 1979, and that the court that rendered the decision is the United States Court of Appeals for the District of Columbia.

*Executive orders.* Executive orders are mandates promulgated by the President. They are orders binding upon executive agencies, such as the United States Environmental Protection Agency or the United States Forest Service within the Department of Agriculture. Executive orders are published in several places as well. They appear originally in the *Federal Register*, a daily magazine-like publication of the federal government. Important executive orders in the environmental area are found, in addition, in notes within Title 42 of the United States Code Annotated.

Executive orders are cited by number and date. For example, an executive order that describes important protections for wetlands that are to be implemented by federal agencies is cited as Executive Order No. 11990 (Sept. 9, 1987). It is reprinted as a note following *42 U.S.C. § 4321.*

*Regulations.* Federal regulations are rules promulgated by administrative agencies within the federal government. These rules can be enacted only if authorized by the statute that guides the conduct of the agency involved. Court cases in the environmental area are often grounded in the issue of whether a regulation is properly enacted by EPA under this standard.

Federal regulations are collected in a series of colorful, soft-bound, thick pamphlets known as the Code of Federal Regulations. Because regulations change frequently, especially in the environmental area, these pamphlets are republished every year. Interim changes, and there are many, are found in the *Federal Register*, described above.

The Code of Federal Regulations is organized by title and section as well. For example, the environmental regulations of EPA are collected at Title 40 of the Code of Federal Regulations, a volume made up of nearly 15 thick, separate pamphlets. Again, the citation format for regulations follows that for statutes, using both a volume, or title, and section or part number. For example, EPA's New Source Performance Standards under the Clean Air Act are collected in 40 C.F.R. Part 61.

The organization of each volume of the Code of Federal Regulations is shown in the table of contents found at the beginning of each volume. That organization generally follows, for the Environmental Protection Agency, the environmental media involved.

Keeping up with changes in the Code of Federal Regulations is not a simple task. The federal government's formal procedure for announcing the proposal or promulgation of new regulations is publication in the *Federal Register*, described above. Both the Code of Federal Regulations and the *Federal Register* contain indexing devices that allow a researcher to update a regulation to the current date. Unless such updating is undertaken, one cannot be sure that the regulation printed in the Code of Federal Regulations is indeed the regulation currently in effect!

*Other guidance documents.* Environmental agencies, the United States Environmental Protection Agency in particular, are increasingly using other textual material to clarify statutes and regulations. These materials fall generally within two categories: preambles to rulemakings in the *Federal Register* and informal guidance documents.

As regulations are proposed and promulgated in the *Federal Register*, detailed explanatory material also is usually included. This explanatory material can be as important, and sometimes is more important, than the text of the regulation involved. The tendency of the government in recent years has been to make such preamble discussions more and more detailed, and environmental practitioners regularly practice using preamble research. These preamble discussions can often be found using the citations to the original promulgation of regulations that are included below the regulation, in very small print, within the Code of Federal Regulations. They also can be found using various indexes that accompany the Code of Federal Regulations and the *Federal Register*.

The second set of informal rules is sometimes more difficult to find. It comprises memoranda, letters, and other informal explanations issued by EPA from time-to-time. Various legal loose leaf services track these guidance documents, and advice concerning important guidance can also often be gathered from expert agency officials.

## 3.2 THE NATIONAL ENVIRONMENTAL POLICY ACT OF 1969

**by T. P. Erwin**

### 3.2.1 BACKGROUND

The National Environmental Policy Act (NEPA) became law on January 1, 1970 (*Pub. L. No. 91-190, 83 Stat. 852, codified as amended at 42 U.S.C.A. §§ 4321-4347 (West 1977 & Supp. 1992)*. It is one of the most important of the many federal laws intended to protect the environment. The regulations promulgated by the Council

**Citations to Selected Federal Statutes and Regulations**

| Popular name of statute | Statutory citation in the United States Code | Selected citations in the United States Code of Federal Regulations |
|---|---|---|
| Atomic Energy Act | 42 U.S.C. §§ 2011-2296 | 10 CFR Parts 0-171, 760-763, 962; (Nuclear Regulatory Commission); 40 CFR Parts 190-192 (U.S.E.P.A.) |
| Clean Air Act | 42 U.S.C. §§ 7401-7642 | 40 CFR Parts 50-87 |
| Clean Water Act | 33 U.S.C. §§ 1251-1387 | 40 CFR Parts 104-149, 401-471 |
| Comprehensive Environmental Response, Compensation, and Liability Act | 42 U.S.C. §§ 9601-9675 | 40 CFR Parts 300-311 |
| Emergency Planning and Community Right-to-Know Act | 42 U.S.C. §§ 11001-11050 | 40 CFR Parts 350-374 |
| Endangered Species Act | 16 U.S.C. §§ 1531-1544 | 7 CFR Parts 355-356; 50 CFR Parts 17, 20-23, 81, 217-227, 401-453 |
| Energy Supply and Environmental Coordination Act | 15 U.S.C. §§ 791-798 | |
| Environmental Taxes | 26 U.S.C. §§ 4611-4682 | 26 CFR Part 52 |
| Environmental Trust Funds | 26 U.S.C. §§ 9507-9509 | |
| Federal Land Policy and Management Act | 43 U.S.C. §§ 1701-1784 | 36 CFR Parts 200-297; 43 CFR passim |
| Forest and Range Land Renewable Resources Planning Act | 16 U.S.C. §§ 1600-1687 | 36 CFR Parts 200-251 |
| Geothermal Energy Research, Development, and Demonstration Act | 30 U.S.C. §§ 1101-1164 | 10 CFR Part 790 |
| Global Climate Protection Act | 15 U.S.C. § 2901 (note) | |
| Low-Level Radioactive Waste Policy Act | 42 U.S.C. §§ 2021b-2021j | |
| Marine Protection, Research, and Sanctuaries Act | 33 U.S.C. §§ 1401-1445 | 40 CFR Parts 220-229; 50 CFR 215-229 |
| Mining and Mineral Resources Research Institute Act | 30 U.S.C. §§ 1221-1230 | |
| Multiple-Use Sustained-Yield Act | 16 U.S.C. §§ 528-531 | 43 CFR 23, 3710-3740 |
| National Climate Program Act | 15 U.S.C. §§ 2901-2908 | |
| National Environmental Policy Act | 42 U.S.C. §§ 4321-4370b | 40 CFR Parts 1500-1517 (each agency of the federal government also has separate NEPA implementation regulations) |
| Noise Control Act | 42 U.S.C. §§ 4901-4918 | 40 CFR Parts 201-211 |
| Nuclear Waste Policy Act | 42 U.S.C. §§ 10101-10270 | 10 CFR Parts 51, 60, 72 |
| Oil Pollution Act | 33 U.S.C. §§ 2701-2761 | 33 CFR Parts 151-159 |
| Pollution Prevention Act | 42 U.S.C. §§ 13101-13109 | |
| Refuse Act of 1899 | 33 U.S.C. § 407 | |
| Resource Conservation and Recovery Act | 42 U.S.C. §§ 6901-6991i | 40 CFR Parts 240-279, 280-2 (underground storage tanks) |
| Safe Drinking Water Act | 42 U.S.C. §§ 300f-300j-11 | 40 CFR Parts 141-149 |
| Soil and Water Resources Conservation Act | 16 U.S.C. §§ 2001-2009 | |
| Surface Mining Control and Reclamation Act | 30 U.S.C. §§ 1201-1328 | 30 CFR Parts 700-955; 43 CFR Parts 3400-3480 |
| Uranium Mill Tailings Radiation Control Act | 42 U.S.C. §§ 7901-7942 | 40 CFR Part 192 |
| Toxic Substances Control Act | 15 U.S.C. §§ 2601-2654 | 40 CFR Parts 700-799, 761 (PCBs) |

on Environmental Quality (CEQ) to implement NEPA characterize NEPA as "our basic national charter for protection of the environment." (*40 C.F.R. § 1500.1 (1992).*) The law, which is not limited to specific environmental concerns or specific activities affecting the environment, applies to agency initiated activities and privately initiated activities that require federal action or approval.

This section discusses NEPA's procedures and policies, the regulations promulgated under NEPA, and, when appropriate, pertinent administrative and judicial decisions concerning implementation of and compliance with NEPA and the regulations. This section will focus on NEPA's effect on mineral exploration, extraction and processing activities.

### 3.2.1.1 The Statute

Generally, NEPA recites the federal government's commitment to environmental quality. (Caldwell, 1990.) Among NEPA's stated purposes is to encourage governmental actions that prevent or eliminate damage to the environment. Notwithstanding NEPA's statement of ideals, NEPA's critical impact results from its charge to all federal agencies to consider and report the environmental impacts of the agencies' activities. More specifically, NEPA requires each agency to include in every recommendation or report on proposals for legislation and other major federal actions significantly affecting the quality of the human environment a detailed statement on: (A) the environmental impact of the proposed action; (B) any adverse environmental effects that cannot be avoided if the proposal is implemented; (C) alternatives to the proposed action; (D) the relationship between short-term uses of the environment and the maintenance and enhancement of long-term productivity; and (E) any irreversible and irretrievable commitments of resources that will be involved in the action. (*42 U.S.C.A. § 4332(2)(C).*) The provisions have been characterized as "action-forcing," that is, if it is determined that the proposed agency action is major and will significantly affect the environment, the agency is compelled to undertake the burden of preparation of an environmental impact statement (EIS). Congress's goal when it enacted this requirement was to ensure that decisions about federal actions would be made only after responsible decision makers had fully considered the environmental consequences of the actions and had decided that the public benefits flowing from the actions outweighed their environmental costs. Judicial decisions construing the requirement for preparation of an EIS hold that these procedures are non-discretionary and require strict compliance with the law and regulations. (Yost, 1990.) The EIS requirement has been the most futile source of controversy and litigation under NEPA. (Coggins, 1990.)

Another major policy achieved by NEPA is multi-agency and public participation in the determination of the environmental impact of proposed federal actions. NEPA and the CEQ regulations require disclosure of the proposed federal action to the public and to federal, state and local agencies affected by or having jurisdiction of part of the proposed action. The proposing agency is obligated to solicit and consider comments from the public and, when appropriate, to hold public hearings concerning the proposed action.

An agency's failure to comply strictly with NEPA and the CEQ regulations is an invitation to litigation by action opponents who, although they may not be substantially affected by the proposed action if implemented, may nonetheless have standing to commence a legal action to compel compliance with NEPA procedures. (McCrum, 1986.) The efforts of project opponents to delay or obstruct project approvals have been most commonly successful when the agency or project proponent has failed to meet the NEPA procedural requirements, particularly in those instances when the agency decides not to prepare an EIS. (Coggins, 1990.) Opponents of proposed actions have been less successful when forced to address the substantive contents of an EIS. Among the remedies available to opponents of the proposed federal action are injunctive relief to compel agency compliance with NEPA and the CEQ regulations and to stay project activity pending completion of the NEPA process. Accordingly, the proponent of the proposed action, especially the developer of a mine or mineral processing facility, must carefully consider and ensure compliance with NEPA procedures at and from the earliest stages of project planning. (Herson, 1987.)

NEPA's impact has been dramatic. Before NEPA, federal agencies quietly implemented agency proposals and approved privately initiated actions with nominal public disclosure and little opportunity for public participation in the planning process. Federal agencies so acted in the absence of any intensive examination and analysis of the environmental consequences as now required under NEPA. Presently, because nearly any federal action may be characterized as "major" and as having a "significant impact" on the environment, NEPA's reach extends to nearly every aspect of industrial activity under federal control or subject to federal regulation, including mineral exploration and mining. In no case is this truer than in the conduct of mineral exploration and mining in the Western United States where substantial mining and mining-related activities are conducted on or near federal public lands under the management of federal agencies, particularly, the United States Bureau of Land Management (BLM) and the United States Forest Service (USFS). (Garver, 1992.)

## 3.2.2 NEPA IMPLEMENTATION

NEPA established the CEQ and charged it with the

responsibility to issue guidance to federal agencies regarding compliance with NEPA. President Nixon directed the CEQ to oversee the environmental responsibilities of federal agencies and to adopt guidelines for agency implementation of NEPA's EIS requirements. (*Exec. Order No. 11514 (1970).*) The CEQ issued its initial guidelines in 1970 and amended them in 1973 (*38 Fed. Reg. 20,550 (1973).*) In 1977, by Executive Order (Exec. Order No. 11991 (1977) President Carter directed the CEQ to issue binding regulations to replace the guidelines. The CEQ subsequently issued its regulations in 1978 (*43 Fed. Reg. 55,978 (1978)*). Since then, the CEQ has published an official explanation of certain provisions of the regulations (*46 Fed. Reg. 18,026 (1981*), *revised 51 Fed. Reg. 15,618 (1986)* and issued additional guidance (*48 Fed. Reg. 34,263 (1983); 49 Fed. Reg. 49,750 (1984).* Many federal agencies, including BLM, Department of Interior (DOI), USFS and the Environmental Protection Agency (EPA), have promulgated their own regulations for administration of their activities in compliance with NEPA.

The CEQ rules are considered a set of uniform regulations whose provisions are mandatory. The CEQ's interpretation of NEPA, as expressed in the CEQ regulations, is entitled to substantial deference by the courts. (*Andrus v. Sierra Club*, 442 U.S. 347, 358 (1979).) The CEQ regulations are intended to flesh out NEPA's provisions. They define the terms used in NEPA and prescribe fairly precise procedures for agency compliance with NEPA requirements.

Applicability of NEPA's EIS requirement, as prescribed in the CEQ regulations, requires the examination of three threshold issues identified in Section 102(2)(c) of NEPA. (*42 U.S.C.A. § 4332(2)(c)* (West 1977 and Supp. 1992).) First, is there a "proposal" for action? Second, is the proposed action a federal action within NEPA's scope? Finally, will consummation of the proposed action significantly affect the quality of the environment? Although after NEPA's enactment it was asserted that the proposed federal action must be a "major" federal action, that term has been construed by courts and the CEQ to modify the term "significantly" as used in NEPA Section 102(2)(c), and has been construed to not create another threshold issue.

The Supreme Court has held that the act that triggers the EIS requirement is an agency proposal for action. (*Kleppe v. Sierra Club*, 427 U.S. 390, 400-02 (1976).) A proposal is not the mere contemplation of action nor is it long-term policy planning. NEPA requires the actual proposal of a particular course of action, for example, the promulgation of regulations, the proposal of legislation, or the approval of a specific agency or privately-initiated project subject to federal control and responsibility. The CEQ regulations and judicial decisions construing NEPA provide that federal action under NEPA includes "nonaction" by the responsible official, if the official's failure to act is reviewable by the courts or administrative tribunals under the Administrative Procedural Act.

Once it has been determined that a proposal for action exists, it must be determined whether the action is "federal" as prescribed by NEPA. Recent cases that involve this issue regularly hold that even slight governmental involvement in the proposed action or project will carry it past the NEPA threshold. It is clear that the greater the magnitude of the project, the extent of the government's jurisdiction over project activities, and the government's participation in the permitting process, the more likely the action will be considered a federal action that will trigger the EIS requirement. In this regard, the EIS requirement has been applied to the issuance of rights-of-way, approval of construction of access roads on public lands, and approval of plans of operation for mining operations on public lands. (Hanson & Bush, 1987.)

The final issue in the determination of the applicability of the EIS requirement is whether the proposed federal action significantly affects the environment. The agency must identify the activity, its scope and its precise impact on the environment. The agency must then measure the magnitude of the impact. Concerning identification of the activity and its scope, the agency must measure the extent of federal involvement in the project development and approval process, whether the project activity is within the agency's regulatory or enforcement jurisdiction, and whether the proposed project affects lands or property of or under the control of the United States.

In determining the significance of the project's impact, the agency may allow only reasonable segmentation of the proposed action or project. This means that the project proponent may not segment or split the project into several, smaller parts each of that may have a relatively minimal impact on the environment such that, if considered alone, the part would not significantly affect the environment so as to trigger the EIS requirements. Segmentation will not be allowed if the proposed project has no substantial utility independent of likely future project stages or expansions. In certain cases, segmentation of mineral exploration activities from prospective and undecided mineral extraction and project development activities has been upheld. (*Cabinet Mountain Wilderness v. Peterson*, 510 F. Supp. 1186 (D.D.C. 1981), *aff'd*, 685 F. 2d 687 (D. Cir. 1982) (USFS approval of exploratory drilling near wilderness area); *Trout Unlimited v. Morton*, 509 F. 2d 1276, 1285 (9th Cir. 1974).)

In determining the significance of the environmental impact of the proposed action, the agency must analyze the significance of the action in social, regional, local terms. The agency must also measure the long and short-term impact of the proposed action. The agency must consider the intensity, or severity, of the impact, whether beneficial or adverse, including the impacts on public health or safety, cultural and ecological characteristics of the geographical area, the level of controversy engendered by the proposed action or project, the known and unknown

risks of the action or project, the cumulative effect of the impacts, and the degree to which the proposed action or project affects or will affect scientific, historical and cultural resources or the habitats of endangered or threatened species. (*40 C.F.R. § 1508.27.*)

Although the CEQ regulations and judicial decisions provide some guidance, the determination of the significance of any particular action must be made on a case-by-case basis; the process is particularly project specific. Judicial decisions on review of administrative approvals of mineral exploration and prospecting activities, particularly the casual use of existing access routes and facilities, hold that so long as such activities do not result in significant disturbances of the surface, water or biological resources, they do not significantly affect the environment so as to require an EIS. These cases imply, and others directly hold, that more extensive exploration activities, such as the drilling of tunnels, construction of adits and shafts, and the extraction of large bulk mineral samples, will require an EIS. It is safe to say that large scale mining activities, such as mine development, mining and the construction and operation of milling and processing facilities will require an EIS.

CEQ regulations authorize agencies to define categories of actions that individually accumulatively do not have a significant impact on the environment. The responsible officer need not prepare an EA or EIS concerning the exempt actions. Typically, the categorical exemptions include only minor or routine activities that generally do not have a significant impact on the environment.

There are few judicially created exemptions from NEPA. These exemptions include those instances in which the NEPA requirements conflict directly with other statutory requirements. Among the exemptions is the procedure for issuance of mineral patents. It has been held that because the right to patent on proof of satisfaction of the patent application requirements is not discretionary and the patent applicant's development of locatable minerals on public lands is a self-initiated, private action that does not require federal approval or permission, NEPA does not apply. (*South Dakota v. Andrus*, 614 F. 2d 1190, 1193-94 (8th Cir. 1980), *cert. denied*, 449 U.S. 822 (1980).)

### 3.2.3 ENVIRONMENTAL ASSESSMENT AND IMPACT STATEMENT PROCEDURES

The CEQ regulations prescribe the procedures for the environmental assessment and EIS processes. If the agency determines that the proposed action is one that only requires an EIS, the agency may proceed with its preparation. Conversely, if the proposed action is one that is categorically excluded from EIS requirements, the agency need not prepare the EIS. Proposed actions that are not covered by the foregoing rules require preparation of an environmental assessment (EA). The agency bases its decision whether to prepare an EIS on the EA.

An EA is a concise public document that serves to provide sufficient evidence and analysis for determining whether the agency must prepare an EIS and to measure the agency's compliance with NEPA if the EIS is deemed unnecessary. The EA is also intended to facilitate preparation of an EIS when necessary. The EA includes discussions of the need for the proposal, alternatives to the proposal, the environmental impacts of the proposal and its alternatives, and a listing of agencies and persons consulted in preparation of the EA. The CEQ regulations obligate the agency to involve environmental agencies, applicants and the public in the preparation of the EA.

The EA may be described as an abbreviated EIS. There are no regulations that specifically govern the format and content of an EA, and federal agencies have some flexibility in determining the structure and scope of an EA. Notwithstanding the absence of regulations concerning the required contents of an EA, it is the recommended and common practice that the EA address all potential environmental impacts raised by commenting agencies and the public and consider mitigation measures applicable to the proposal that support the determination that an EIS need not be prepared. (Pomeroy, 1984.)

If the agency determines on the basis of the EA not to prepare an EIS, the agency must prepare a finding of no significant impact (FONSI). The agency must make the FONSI available to the public. If the proposed action is the same as, or is closely similar to, an action that normally requires the preparation of an EIS or is an action without precedent, the agency may make the FONSI available for public review for 30 days before the agency makes its final determination whether to prepare an EIS and before the action may begin.

If the agency decides to prepare an EIS, it must prepare a notice of intent. The notice of intent must describe the proposed action and possible alternatives, describe the agency's proposed scoping process, and identify the person in the agency who will respond to inquiries concerning the proposed action and the EIS. The notice of intent must be published in the *Federal Register* and must be disclosed to the public in accordance with the CEQ disclosure procedures that provide for, among other methods of disclosure, mailed notice to persons who have requested notice concerning the proposed action and organizations reasonably expected to be interested in the proposed action, mailed notice to owners of nearby or affected properties, and publication in newspapers, newsletters and other media in the locality that will be affected by the proposed action.

Following preparation and publication of the notice of intent, the agency must complete the scoping process which is intended to address and identify the significant issues related to the proposed action. The CEQ regulations prescribe that as part of the scoping process the lead agency, which is the federal agency responsible for preparation of the EIS if more than one federal agency is

involved in the process, must invite participation of affected federal, state and local governments and Indian tribes, the proponent, and other interested persons, including persons who may assert opposition to the proposed action on environmental grounds. The lead agency must determine the significant issues to be analyzed in depth in the EIS, identify and eliminate from the study any insignificant issues or issues that have been covered by prior environmental review, allocate assignments for preparation of the EIS, identify other environmental and consultation requirements, establish the timing of preparation of the EIS and declare the planning and decision making schedule. Following completion of the scoping process, the agency begins preparation of the EIS.

The primary purpose of the EIS is to serve as a "action-forcing" device to ensure that NEPA's policies and goal are considered in the programs and actions of the federal government. The EIS is intended to provide the full and fair discussion of significant environmental impacts and to inform decision makers and the public of reasonable alternatives that will avoid or minimize adverse impacts or enhance the quality of the environment.

The CEQ regulations provide for preparation of the EIS in two stages; the EIS may also be supplemented. A draft EIS is prepared in accordance with the scope decided in the scoping process. The draft EIS must fulfill and satisfy to the fullest extent possible the requirements established for the final EIS. The lead agency is responsible to consult with cooperating agencies and to solicit and consider comments from government agencies, the public and of interested parties. The final EIS is prepared after receipt and consideration of comments; it must respond to substantive comments. If the agency makes substantial changes in the proposed action relevant to environmental concerns or significant new circumstances or information relevant to environmental concerns are developed, the agency must supplement either the draft or final EIS.

To satisfy NEPA's requirements, the EIS must address: (A) the environmental impacts of the proposed action; (B) any adverse environmental effects that cannot be avoided on implementation of the proposed actions; (C) alternatives to the proposed action; (D) the relationship between local short-term uses of the environment and maintenance and enhancement of long-term productivity; and (E) any irreversible and irretrievable commitments of resources involved in the proposed action if implemented. (*42 U.S.C.A. § 4332(2)(C).*) The most significant elements of the EIS are treatment of the environmental impacts of the proposed action and consideration of alternatives to the proposed action. It is these elements that receive the most stringent analysis and scrutiny. (Pomeroy, 1984.)

The format for an EIS is prescribed in the CEQ regulations. The formal or procedural requirements of EIS include a cover sheet, summary, list of the persons responsible for preparation of the EIS, and appendices. The first substantive requirement of the EIS is the specification of the purpose and need of the proposed action. (*40 C.F.R. § 1502.13.*) If the action or project is initiated by the agency, the agency must explain the purpose served by the proposed action and the need to which the proposed action is responsive. For a privately-initiated project, the statement of purpose and need must recite what the applicant seeks to achieve by the proposed action. The statement of purpose and need is significant because the description of the objectives of the proposed action will significantly influence the range of reasonable alternatives that the agency must consider. (Garver, 1992.)

The second substantive requirement of the EIS is presentation of the proposal and alternatives to the proposal in comparative form. This requirement is intended to sharply define the issues and to provide a clear basis for choice among the alternatives by decision makers and the public. As stated in the CEQ regulations, this requirement is "the heart of the EIS." (*40 C.F.R. § 1502.11.*) The EIS must consider only "reasonable" alternatives, that is, alternatives that contemplate economic and practical feasibility. The agency need not examine alternatives that are impractical, infeasible or speculative. (Garver, 1992.)

The third substantive element of the EIS is the description of the environment of the area or areas to be affected or created by the proposal and alternatives under consideration. (*40 C.F.R. § 1502.15.*) The CEQ regulations suggest that the data and analyses in the EIS be commensurate with the importance of the impact. Accordingly, the greater the potential severity of the impact, the more detailed and extensive must be the description of the affected environment.

The final substantive element of the EIS is the section that describes the environmental consequences of the proposed action and alternatives to the proposed action. (*40 C.F.R. § 1502.16.*) The discussion of environmental impacts must include: (A) consideration of direct effects and their significance; (B) the indirect effects and their significance; (C)possible conflicts between the proposed action and the objectives of federal, regional, state and local lands use plans, policies and controls for the area concerned; (D) the effects of alternatives, including the proposed action; (E) natural or depletable resource requirements and conservation potential of various alternatives, including mitigation measures; (F) urban quality, historic and cultural resources; and (G) means to mitigate adverse environmental impacts. The EIS must consider "connected actions," "cumulative actions," and "similar actions." (*40 C.F.R. § 1508.25.*)

The asserted cumulative impact of a proposed action is often a critical EIS issue. The CEQ regulations define "cumulative impact" as the impact on the environment that results from the "incremental" impact of the action when added to other past, present and recently foreseeable future actions regardless of what agency (federal or nonfederal) or person undertakes such other action. (*40 C.F.R. § 1508.7.*) The regulations expressly provide that cumulative impacts

can result from individually minor but collectively significant actions that occur over a period of time. The importance of this issue was recently illustrated in an action involving review of BLM's decision not to prepare an EIS that addressed the cumulative impact of placer mining operations in certain Alaskan watersheds. In the decision *Sierra Club v. Penfold*, 857 F. 2d 1307 (9th Cir. 1988), the Ninth Circuit Court of Appeals affirmed the district court's order to BLM to prepare an EIS that addressed the cumulative impact on water quality resulting from placer mines. The Court noted that although degradation of water quality resulting from individual mines may have been less significant so as not to warrant an EIS, the cumulative effect was sufficiently significant so as to require an EIS.
(857 F. 2d at 1320.)

When the EIS is completed, it must be circulated among federal agencies having jurisdiction or special expertise concerning the environmental impacts considered and among appropriate state and local agencies, the applicant, persons and organizations who have requested copies of the EIS, and, concerning the final EIS, any person who has submitted substantive comments on the draft EIS. The draft EIS must be filed with EPA; the act of filing commences the comment period prescribed in the CEQ regulations. The agency must solicit comments from the parties to whom the draft EIS is circulated, from the public, and from those persons or organizations who may be interested or affected by the proposed action. Under the CEQ regulations, each federal agency with jurisdiction by law or special expertise concerning the environmental impact involved in the proposed action is obligated to timely comment on the EIS.
(*40 C.F.R. § 1503.2.*)

The lead agency must assess and consider and respond to comments. Among the agency's authorized responses are modification of alternatives, including the proposed action, development and evaluation of new alternatives, supplementation or modification of the lead agency's analysis, factual corrections, and an explanation of why the comments do not warrant further agency response. (*40 C.F.R. § 1503.1.*) When the agency makes its decision, it must prepare a concise public record of decision (ROD) which states the decision, identifies all alternatives considered, specifies the alternative or alternatives that were considered to be environmentally preferable, and states whether all practical means to mitigate environmental impacts from the alternatives have been adopted, and, if not, why they were not adopted. The ROD must adopt and summarize a monitoring and enforcement program for mitigation measures. (*40 C.F.R. § 1505.2.*) The lead agency must include in grants, permits or other approvals all appropriate conditions necessary to implement the mitigation measures provided in the ROD. (*40 C.F.R. § 1505.3.*)

## 3.3 THE CLEAN AIR ACT

**by Z. C. Miller**

### 3.3.1 INTRODUCTION AND OVERVIEW

The Clean Air Act (*42 U.S.C. § 7401 et seq.*) (referred to in this subchapter as the "CAA" or the "Act") creates one of the most extensive and complex regulatory schemes in federal law. The Act contains a number of distinct, highly technical programs that are designed to protect or improve air quality throughout the country. Several of these programs can impose major restrictions and delays on mining activities.

### 3.3.2 KEY POLICIES AND THE CENTRAL ROLE OF THE STATES

The key general policies behind the Clean Air Act are to protect and enhance air quality nationwide in order to promote public health and welfare and the nation's productive capacity. The CAA places most of the responsibility on the states to carry out and enforce its goals and requirements. This has been accomplished primarily through separate "State Implementation Plans," often referred to as "SIPs," which outline each state's comprehensive program to meet the CAA's minimum requirements. State implementation plans may also include any additional restrictions imposed by that state.

Extensive amendments to the CAA in 1990 supplemented that traditional approach by mandating that each state adopt a comprehensive operating permit program. This permit program will require a renewable permit for each stationary air emission source subject to virtually any of the CAA's numerous requirements. EPA has concurrent authority, along with each state, to enforce the CAA and any issued permit, as well as any additional state requirements contained in an approved state implementation plan. As described below, the consequences of noncompliance with the CAA can be very severe.

#### 3.3.2.1 National Ambient Air Quality Standards: the Keystone of the CAA

The dominant strategy to improve air quality under the CAA centers around attempts to meet a basic set of National Ambient Air Quality Standards (usually referred to in shorthand as "NAAQS"). National standards have been set by EPA for six "criteria pollutants" believed to affect the public health and welfare adversely. As part of the state implementation plan development process, each state is divided into air quality control regions that are designated as "attainment" or "nonattainment" areas for each criteria pollutant, depending on whether the ambient air quality levels for that pollutant meet the established national standard. Elaborate regulatory programs designed to achieve or maintain compliance with the national ambient air quality standards are based on and triggered by these designations.

### 3.3.2.2 New Source Review Programs

Major new sources of air emissions and major modifications to existing major sources are required to undergo onerous permitting processes before beginning construction under one of two national ambient air quality standards-related programs. In attainment areas (where the national ambient air quality standards are being met and air quality is clean), such sources are subject to the Prevention of Significant Deterioration ("PSD") program, which is designed to prevent air quality from deteriorating to or below the national ambient air quality standards. This program works by placing a limit or "increment" on the extent of deterioration allowed for each pollutant and by requiring the use of the best available control technology ("BACT"). In nonattainment areas, the requirements are even more strict. Major new or modified sources must not only install controls reflecting the more stringent lowest achievable emission rate ("LAER") but also must demonstrate an "offset" representing at least a one-to-one emission reduction from another source(s).

As described below, what constitutes a regulated "major source" under these programs in some cases depends in part on the nature of the operation and, in certain nonattainment areas, on the extent to which a national ambient air quality standard is being exceeded. A single region often is in attainment for one pollutant and in nonattainment status for another, so it is possible that a source can be subject to both of these complex programs simultaneously.

The CAA also establishes new source performance standards ("NSPS") for air emission sources falling under one of more than 60 specified industrial source categories. These special standards require new or modified sources within a listed category to meet the best demonstrated technology for that category, as described in EPA rules. Mining operations are not currently subject to the new source performance standards program, but listed source categories include coal preparation plants and various mineral processing and smelting operations. (*See 40 C.F.R. Part 60.*)

### 3.3.2.3 Hazardous Air Pollutants

The CAA's historical focus on national ambient air quality standards compliance was broadened in the 1990 Amendments to include the comprehensive regulation for most stationary sources of a wide array of specified hazardous air pollutants ("HAPs"), including many substances common to the mining industry. Regulated hazardous air pollutant sources are generally required to obtain operating permits, use maximum achievable control technology ("MACT"), and also meet health-based "residual risk" requirements imposed by EPA for that source category. Relatively minimal emissions of one or more hazardous air pollutants can subject a source to this strict program.

### 3.3.2.4 Role of Technology-based Standards

A central strategy of the CAA is to protect air quality by requiring compliance with various technology-based standards. These are standards that require that a source adopt a particular level of air pollution control. In the new source performance standards program, the specific air quality control technology required for each listed source category is described in EPA's rules. (*40 C.F.R. Part 60.*) The 1990 Amendments similarly provide that EPA will identify applicable "maximum achievable control technology" requirements for each listed category of regulated hazardous air pollutant sources. For most other technology-based standards, however, such as best available control technology and lowest achievable emission rate, the type and extent of control technology required is established for each source on a case-by-case basis, by reference to currently available technologies and the varying criteria set for each standard.

The changing nature of these standards and the broad discretion of the implementing agencies can create substantial difficulties in planning and budgeting for a regulated source. EPA maintains a clearinghouse of information on control technologies used by permitted sources nationwide that is useful in evaluating potential controls that might be required under these standards.

### 3.3.2.5 Mobile vs. Stationary Source Regulation

While the central focus of the CAA has long been on stationary sources, the CAA also imposes stringent requirements on fuel producers and vehicle manufacturers to reduce emissions from mobile sources. The 1990 Amendments expanded the mobile source program to vehicle owners by requiring that owners or operators of car or truck "fleets" (10 or more) that are centrally fueled within certain ozone or carbon monoxide nonattainment areas must have a certain percentage of "clean-fueled" vehicles (e.g., fueled by ethanol). Under these phased-in requirements, by the year 2000, in affected areas 70% of new fleet cars and light trucks and 50% of heavy trucks must be clean-fueled. (*See 42 U.S.C. §§ 7581-7586.*) Mining operations near developed areas potentially could be covered by these fleet vehicle requirements.

## 3.3.3 HISTORICAL BACKGROUND

Following weak air quality laws passed in 1955, 1963, and 1967, Congress adopted the CAA of 1970. This incarnation of the CAA provides the basic framework for the current CAA. After minor changes to the CAA in 1974 and major revisions in 1977, Congress in 1990 passed extensive CAA Amendments which greatly expand and complicate an already very complex law. Some of the key changes made by the 1990 Amendments are described

below.

#### 3.3.3.1 New Operating Permit Program

Prior to the 1990 Amendments, the only permits required under the CAA were nonrenewable, pre-construction permits for major sources subject to the prevention of significant deterioration or nonattainment programs noted above. Once issued, such permits authorized operation for the life of the permitted source. New source performance standards facilities, sources subject to hazardous air pollutant standards, and other regulated entities were not required to obtain permits.

The lack of permits and monitoring for such sources was perceived to cause a major hurdle to enforcement of the CAA. As a result, the 1990 Amendments incorporated a comprehensive permit program into the CAA. Each state is now required to adopt a program requiring a limited-term, renewable operating permit for each source subject to virtually any of the numerous requirements under the CAA. Such permits are in addition to the pre-construction permits still required under the prevention of significant deterioration and nonattainment programs. General permitting requirements are described below.

#### 3.3.3.2 Expanded Regulation of Hazardous Air Pollutants

The 1970 CAA authorized EPA to regulate stationary source emissions of any hazardous air pollutant, which was broadly defined as any pollutant determined by EPA to contribute to an increase in death or serious illness. EPA was directed to set National Emission Standards for Hazardous Air Pollutants ("NESHAPs") for each identified hazardous air pollutant to protect public health with an "ample margin of safety." Due to controversy over applying those vague standards, by 1990 EPA had set national emission standards for hazardous air pollutants for only seven hazardous air pollutants.

The 1990 Amendments comprehensively revised the national emission standards for hazardous air pollutants program by expressly listing 189 specific substances that must be regulated as hazardous air pollutants. As more fully described below, both new and existing regulated hazardous air pollutant sources are now required, among other things, to obtain permits, monitor emissions, use specified control technology, and comply with supplemental, health-based restrictions. This expanded hazardous air pollutants program will regulate many more facilities, including mining-related operations, than the old national emission standards for hazardous air pollutants program.

The 1990 Amendments further created several new programs, also described below, for the prevention of accidental releases of certain extremely hazardous air pollutants. Operators subject to such programs must perform thorough site assessments and adopt comprehensive plans to prevent and respond to accidental emissions of listed substances.

#### 3.3.3.3 Other New or Modified Programs

The 1990 Amendments also substantially revised the nonattainment program to tailor many requirements to the severity of present pollution levels. In areas where a national ambient air quality standard is greatly exceeded, for example, in specified circumstances the emission levels necessary to become a regulated source are lowered, required emission offsets are higher, specified controls are more stringent, and compliance deadlines are longer. Accordingly, as described further below, in evaluating regulatory requirements for a particular site, a potential operator must determine not just whether the site is in a nonattainment area, but also the type and extent of the nonattainment.

In addition, the 1990 Amendments created an entirely new program to prevent "acid rain" by controlling sulfur dioxide ($SO_2$) and nitric oxide ($NO_x$) emissions from certain electric power plants. The program establishes an innovative process for creating and marketing "allowances" of $SO_2$ emissions. While principally directed to the utility industry, this program allows other $SO_2$ sources voluntarily to "opt in" to obtain and market these allowances. As discussed below, this program may provide a substantial opportunity for some mineral processors.

The 1990 Amendments also vastly expanded the monitoring and enforcement provisions of the CAA to equal or exceed those under other federal environmental laws. EPA's administrative enforcement authority was greatly enhanced, civil penalties were made more severe, even minor infractions were designated as felony criminal violations and, perhaps most significantly, individual personal exposure was greatly increased. As a result, at the same time that the CAA was made substantially more complicated, the consequences of noncompliance were made much more severe.

### 3.3.4 TYPICAL MINING ACTIVITIES REGULATED BY THE CAA

Air emissions from mining operations come chiefly from four different types of sources: 1) fugitive dust emissions from vehicles, mining activities, and stored or deposited materials; 2) point-source dust emissions from crushers, conveyors, and other equipment; 3) hydrocarbon emissions from industrial boilers and generators; and 4) emissions from milling and mineral processing operations. (Smelters and secondary mineral processing facilities have much larger emissions of $SO_2$ and various hazardous air pollutants but are beyond the scope of this Handbook.) Each of the above sources may be regulated under the CAA and is discussed below.

#### 3.3.4.1 Fugitive Dust Emissions

Fugitive dust emissions are any particulate emissions not emerging from a stack, vent, or other discrete opening, and generally are the greatest source of air emissions at a mine site. Fugitive dust commonly is generated by blasting, excavation, and loading activities, vehicles traveling on unpaved roads, and winds blowing on tailings piles and other stored, reclaimed, or disposed materials.

These types of emissions are difficult both to measure and to control. Typical control measures include revegetation and the use of water sprays or surfactants, such as magnesium chloride. Controls required under various CAA programs are likely to become increasingly stringent and require paving or "capping" and other interim revegetation measures in many cases.

As discussed in more detail below, fugitive emissions currently are not counted under federal rules in determining whether mining operations are major sources subject to the prevention of significant deterioration or nonattainment programs, but they are considered in determining whether an area is in attainment with the particulate matter national ambient air quality standards and whether various CAA requirements are being met. EPA and state policies on the consideration, measurement, and control of fugitive dust emissions are in an unsettled state and must be confirmed before proceeding with a major new or expanded project.

#### 3.3.4.2 Point-Source Dust Emissions

Dust also is typically generated in large amounts from crushers, conveyors, and similar equipment. In this type of equipment, dust is emitted, or is capable of being emitted, from a discrete opening, or an area that can be covered or controlled. These non-fugitive emissions are counted in determining whether an operation is a major source or modification subject to one or more of the CAA programs described below. In addition, state rules generally require permits and controls for these "point source" dust emissions even where the CAA does not. Typical controls required may range from a simple cover or "hood" to water sprays to bag houses to complete enclosure, depending on the basis for the requirement and the surrounding circumstances.

#### 3.3.4.3 Boilers and Generators

Many mines and mills have large boilers or generators to generate heat or power, typically fueled by coal, gas, or other hydrocarbons. The CO, hydrocarbon, and other emissions from these units often will trigger the permitting and possibly other CAA requirements described below. In particular, fossil fuel-fired boilers with over 250 million BTU heat input per hour are subject to the lower (100 tons per year) major source threshold under the prevention of significant deterioration program. Care should be taken, where possible, to avoid having boiler or generator emissions make an operation a major source subject to one or more of the various CAA programs.

#### 3.3.4.4 Mineral Processing-Related Emissions

Most mines and mills contain one or more mineral processing operations that cause air pollution emissions. These may include a roaster, bullion reduction oven, pressure oxidation autoclave, or other high temperature process, which may result in emissions of arsenic, mercury, sulfur, and other substances regulated under the CAA as hazardous air pollutants. Coal cleaning plants with thermal dryers and lime, phosphate rock, and taconite ore processing plants are subject to the lower (100 tons per year) prevention of significant deterioration major source threshold and also are among the 30 designated sources for which fugitive dust emissions will be counted in calculating whether a facility is a regulated major source under the prevention of significant deterioration and nonattainment programs. Other ore treatment and processing operations may also result in regulated air emissions. It is critical to keep in mind that all emission sources on the same or adjacent sites will be added together to determine whether an entire operation is a major source under one or more of the CAA programs described below.

#### 3.3.4.5 CAA Impacts on Mining Operations

Mining and mineral processing operations subject to CAA requirements generally will be required to obtain renewable operating permits, pay large annual permit fees, monitor and submit reports of air emissions, and install and implement various emission control devices and measures. In some cases, proposed projects or expansions may be precluded or limited by CAA restrictions, such as the consumption and current unavailability of allowable "increments" of air quality deterioration under the prevention of significant deterioration program. The greatest CAA impact, however, often can be major delays in construction or operation start-up due to the lengthy and complex processes for obtaining required CAA permits or authorizations. Accordingly, thorough air emission planning and analysis and, where necessary, long lead times are critical to avoid major, unexpected CAA-related delays and expenses.

### 3.3.5 DETAILED SUMMARY OF KEY CAA PROVISIONS

#### 3.3.5.1 National Ambient Air Quality Standards

Even after the 1990 Amendments, the National Ambient Air Quality Standards remain a central focus of the CAA. The national ambient air quality standards set by EPA

establish numerical criteria for listed pollutants to be applied uniformly across the country. The criteria consist of maximum average concentrations of a pollutant over a designated time period. EPA is required for each national ambient air quality standard to set a primary standard, to protect public health, and a secondary standard, to protect the public welfare. Several national ambient air quality standards also contain both long-term (1 year) and higher, short-term (1 hour or 8 hour) limits, in recognition that brief exposure to certain concentrations is acceptable if not prolonged or repeated.

National ambient air quality standards have been established for only six common, so-called "criteria pollutants": ozone, carbon monoxide, sulfur dioxide, nitrogen dioxide, lead, and particulate matter. (*See 40 C.F.R. Part 50.*) For four of these pollutants, the primary national standard is the same as the secondary standard. There is no secondary standard for carbon monoxide. Only the sulfur dioxide national ambient air quality standard has a separate secondary standard.

Of these standards, the national ambient air quality standard for particulate matter has by far the greatest direct impact on the mining industry. "Particulate matter" is a generic term for a broad class of diverse substances entrained in the atmosphere, both solid and liquid, that exist as discrete particles over a large range of sizes. The original national ambient air quality standard adopted by EPA for particulate matter broadly defined and regulated these substances as total suspended particulates or "TSP." In 1987, in recognition of the fact that smaller size particles constitute the primary risk to human health, EPA revised the particulate matter national ambient air quality standard and most related requirements to address only particles with an aerodynamic diameter of 10 microns or less, called "PM-10." In 1995, EPA reversed its earlier policy and concluded that only PM-10, and not other forms of particulate matter, will be quantified and regulated under the CAA "operating permit" program described in Section 3.3.5.9 below. Because of the large amounts of dust generated by mining operations, this shift from regulation of total suspended particulate matter to a more narrow focus on PM-10 is of critical importance to the mining industry. As discussed below, there has been and still remains considerable uncertainty and disagreement about whether and how fugitive dust emissions should be considered and regulated under the PM-10 standard.

Despite substantial disagreement generally over the propriety of EPA's established national standards, these few national ambient air quality standards still serve as the centerpiece for an elaborate set of requirements and programs.

### 3.3.5.2 Implementation by the States: The State Implementation Plan

As a matter of policy, the CAA places primary responsibility on the states both to achieve compliance with the national ambient air quality standards and to implement most other requirements of the CAA. The chief mechanism for this implementation is the state implementation plan, which consists of each state's comprehensive program to achieve national ambient air quality standards compliance and enforce the CAA's minimum requirements, as well as any additional restrictions voluntarily imposed by that state. The CAA provides strong incentives for states to submit acceptable state implementation plans and implement the CAA. It makes nonparticipating or unapproved states ineligible for federal funds for highways and air programs and requires increased nonattainment area "offsets" of 2-to-1 or more.

A state implementation plan must be approved by EPA to become effective under the CAA. A state implementation plan generally consists of the state's key air quality statute and related implementing regulations, but it also often encompasses a number of diverse sources of information such as correspondence with EPA, policy statements, and ordinances or rules of local governments or agencies with delegated authority. To complicate matters, EPA often only partially approves a proposed state implementation plan, in which case EPA retains exclusive authority to implement and enforce the CAA requirements for which the state does not have approved delegation. In those circumstances, it is critical to recognize that an adopted state statute or regulation generally is binding and enforceable as a matter of state law, even if the provision is rejected or not yet approved by EPA for purposes of CAA compliance. In such instances both state and federal law must be separately complied with, unless the state requirements are inconsistent with the controlling federal requirements.

After a state implementation plan or some portion of a state implementation plan has been approved by EPA, it is binding under both state and federal law and may be enforced by EPA or the responsible state or local agency. EPA rules describe the basis and source of each state's state implementation plan and the extent to which it has been approved. (*See 40 C.F.R. Part 52.*) Due to the phase-in of numerous requirements from the 1990 Amendments over the next 30 years, both EPA's and the states' codified rules are often out of date and must be double-checked carefully.

A key component of the state implementation plan is the division of each state into geographical air sheds called air quality control regions ("AQCRs"). Each air quality control region is then designated as "attainment" or "nonattainment" for each criteria pollutant, depending on whether the ambient air quality meets the national ambient air quality standards for that pollutant. An air quality control region often is an attainment area for one pollutant and a nonattainment area for another. Based on these designations, the state implementation plan imposes control requirements designed to attain, maintain, and enforce the national ambient air quality standards in each air

quality control region.

In addition to the provisions directed towards national ambient air quality standards compliance, each state implementation plan contains the state's requirements for obtaining operating permits, permit fees, regulation of hazardous air pollutants, visibility protection, and other CAA programs. Because the CAA generally sets minimum requirements, the states, with few exceptions, are free to adopt more stringent standards or achieve compliance by different means. As a result, requirements, restrictions, and the extent of state or local authority may vary considerably from state to state and must be checked carefully.

### 3.3.5.3 Nonattainment Program: Improvement of Dirty Air Areas

In areas where a national ambient air quality standard is being exceeded, new major sources of the pollutant(s) in question and major modifications to existing major sources are required to undergo onerous new source review ("NSR") procedures under the nonattainment area program. (*See 42 U.S.C. §§ 7502-7509a.*) The principal requirements of this program are that such sources 1) obtain a permit prior to commencing construction, after demonstrating 2) the use of the lowest achievable emission rate and 3) the achievement of an "offset" representing at least a one-to-one reduction in emissions of the nonattainment pollutant from some source(s).

The lowest achievable emissions rate is an onerous, technology-forcing standard that must reflect (a) the most stringent emission limitation in any state implementation plan for that source category (unless the applicant can show the limitation is not achievable) or (b) the most stringent limitation achieved in practice by any source within that category, whichever is stricter. (*42 U.S.C. § 7501(3).*) The lowest achievable emission rate must always be at least as strict as an applicable new source performance standard and often will be stricter than best available control technology requirements under the prevention of significant deterioration program, described below, since cost is not as great a factor in setting lowest achievable emission rate controls. The lowest achievable emission rate is established on a case-by-case basis, becoming more strict and generally more expensive with each improvement in technology.

Offsets required for regulated new or modified sources must be legally enforceable reductions in emissions of the nonattainment pollutant from the same or other sources within the same nonattainment area, with narrow exceptions. (*42 U.S.C. § 7503.*) Reductions can be achieved by the shutdown, curtailment, or stricter control of existing sources, or any combination of these approaches. Significantly, any emission reduction "otherwise required" by the CAA is not creditable to a nonattainment offset. Given the increasingly strict controls mandated by this and other CAA programs, offsets for all pollutants will become increasingly difficult to find by the use of controls beyond those already required by the CAA.

An offset generally must be equal to or greater than the anticipated emission increase from the new or modified source. The 1990 Amendments increased that requirement for ozone nonattainment areas, which are now separated into five classes based on the extent of nonattainment. Increased offsets required for these ozone areas range from 1.1-to-1 in marginal areas to 1.5-to-1 in extreme areas.

A "major source" subject to these new source review requirements generally includes any stationary source or group of such sources within a contiguous area and under common control that emits, or has the potential to emit, at least 100 tons per year of the nonattainment pollutant(s). A regulated "major modification" is any physical change to a major source that results in a significant net increase in emissions of the subject pollutant. What constitutes a "significant" increase is specified in EPA rules and varies for each criteria pollutant, ranging from 100 tons per year for carbon monoxide ("CO") to 0.6 tons per year for lead. (*See 40 C.F.R. § 51.165(a)(1).*)

As under the prevention of significant deterioration and hazardous air pollutants programs described below, "potential to emit" here means the maximum capacity of a source to emit a pollutant under its physical design, assuming full-time operation. Any limits on that potential, such as control equipment, hours of operation, or raw materials, may be considered only if they are required under an enforceable permit or state implementation plan. (*See C.F.R. § 51.165(a)(1).*) Historically, under all of these programs, such limiting factors had to be "*federally* enforceable" to be creditable. At the time of this writing, EPA is reconsidering and is likely to soften and expand that policy. Therefore, in evaluating whether a proposed operation might be a "major source," it is critical to assess its maximum theoretical emission potential and then ensure that any limiting factors considered are appropriately enforceable.

The 1990 Amendments lowered the "major source" threshold in certain PM-10, CO, and ozone nonattainment areas. For the three worst of the five ozone classifications noted above, for example, the threshold is reduced to 50, 25, and 10 tons per year, respectively. CO attainment areas are designated "moderate" or "serious" based on their ambient CO "design value" levels, with the major source threshold in serious areas reduced to 50 tons per year. Of particular importance to the mining industry, the 1990 Amendments also classify PM-10 nonattainment areas as either "moderate" or "serious," based on an evaluation of the area's likelihood of meeting either a six- or ten-year attainment deadline. The major source threshold for "serious" PM-10 nonattainment areas is then reduced to 70 tons per year. (*See 42 U.S.C. § 7513a(b)(3).*) Accordingly, it is critical in planning a facility to determine not just whether it is in a nonattainment area but

the nature and possible classification of the nonattainment.

In addition to meeting the above requirements, the owner or operator of a proposed new or modified major source in a nonattainment area must show that all other sources that it controls within the state are in full CAA compliance. The 1990 Amendments also now require a broad analysis of alternative sites, sizes, processes, and control techniques and a finding that the benefits of the proposed source "significantly outweigh" its environmental and social costs. (*See 42 U.S.C. § 7503(a).*) The implementation and impact of this sweeping requirement remain to be seen.

Existing sources in nonattainment areas can also be regulated. State implementation plans generally must provide for the implementation of reasonably available central measures ("RACM") in all nonattainment areas, specifically including the application of reasonably available control technology ("RACT") for all existing major sources. (*42 U.S.C. § 7503.*) Unlike most other technology-based standards, reasonably available control technology is not defined in the CAA, but EPA has issued a number of "control technique guidelines" intended to outline what constitutes reasonably available control technology for specified industrial categories. Although not issued or published as formal regulations, EPA has treated control technique guidelines as binding rules and will likely continue to do so. In practice, EPA has interpreted reasonably available control technology to be a strict standard of control but somewhat less onerous than best available control technology or lowest achievable emission rates. No control technique guidelines for mining operations have been issued to date, but future guidance is likely and must be closely consulted.

### 3.3.5.4 Special Requirements for PM-10 Non-Attainment Areas

In addition to the general nonattainment provisions described above, the 1990 Amendments established numerous requirements, deadlines, and procedures specific to nonattainment areas for particular pollutants. Ozone nonattainment areas, in particular, have a separate comprehensive scheme of detailed requirements and deadlines tailored to the severity of nonattainment and the resulting classifications noted above. (*42 U.S.C. §§ 7511-7511a.*) Carbon monoxide nonattainment areas also have special, more limited requirements. (*42 U.S.C. §§ 7512-7512a.*)

Several new requirements specific to PM-10 nonattainment areas, while minor compared to the ozone areas provisions, are the most likely to impact mining operations. All PM-10 nonattainment areas are now initially classified as "moderate" and required to achieve attainment within six years from designation. An area will be reclassified as "serious" if 1) it fails to reach attainment before the 6-year deadline or 2) before that time, EPA concludes that the area cannot practicably meet that deadline. (*42 U.S.C. § 7513.*)

As noted above, for "serious" PM-10 nonattainment areas, the threshold for "major sources" subject to new source review permitting requirements is reduced from 100 to 70 tons per year of potential PM-10 emissions. In both moderate and serious areas, the states must require new source review pre-construction permits for all new and modified major stationary sources of PM-10. Of critical importance to the mining industry, this and related new source review requirements now apply also to sources of PM-10 precursors (substances from which PM-10 may form), unless EPA finds that such sources do not significantly contribute to PM-10 nonattainment in the subject area. (*42 U.S.C. § 7513(a).*) Accordingly, some mining operations that do not directly generate fine particulates may still be regulated as sources of PM-10 precursors.

States must assure that reasonably available control measures to control PM-10 emissions, including the use of reasonably available control technology, are implemented by the end of 1993 or four years after designation for "moderate" PM-10 areas. For "serious" PM-10 nonattainment areas, states must require implementation of the best available control measures ("BACM") within four years of designation. (*42 U.S.C. § 7513a(b).*) Best available control measures are not defined in the CAA but apparently are intended to parallel and encompass the stringent best available control technology standard of the prevention of significant deterioration program, described below. Like reasonably available control measures, however, the control measures required by best available control measures are broader in scope than the control technologies primarily addressed by best available control technology and reasonably available control technology.

If EPA finds that "anthropogenic" (man-caused) sources of PM-10, such as naturally occurring windblown dust, do not significantly contribute to an area's violation of the national standard, it may waive any requirements applicable to "serious" PM-10 areas and also extend the deadline for attainment. (*42 U.S.C. § 7513.*) Moderate area control requirements, however, cannot be waived.

EPA is required to issue technical guidance on reasonably available control measures and best available control measures for certain categories of PM-10 sources. EPA guidance on mining activities is expected and, when issued or revised, should be carefully reviewed and followed, in conjunction with PM-10 area amendments to applicable state implementation plans. At a minimum, many existing mining operations will likely be required under these standards to implement or improve particulate emission controls on blasting, crushing, processing, and transportation activities and various materials handling, storage, and reclamation operations.

### 3.3.5.5 Prevention of Significant Deterioration Program: Protection of Clean Air Areas

The prevention of significant deterioration, or "PSD," program applies in areas designated either "attainment," where a national ambient air quality standard(s) is being met, or "unclassifiable." The program is designed to prevent the deterioration of this high quality clean air down to or below the national ambient air quality standards, while allowing for some measure of industrial growth. Unlike the nonattainment program described above, the prevention of significant deterioration program applies only to new major stationary emission sources and major modifications to those sources. New minor or existing unmodified sources are not directly affected. (*See 42 U.S.C. §§ 7470-7479.*)

The basic thrust of the prevention of significant deterioration program is to require covered sources 1) to obtain a permit before beginning construction, 2) to demonstrate the use of best available control technology ("BACT"), 3) to show that the national ambient air quality standards and certain allowable limits or "increments" of air quality deterioration will not be exceeded, and 4) to assure that various impact analyses have been performed. (*See 40 C.F.R. § 51.166.*) While simple in concept, this program in practice is one of the most complicated and cumbersome schemes of the CAA.

"Major sources" subject to prevention of significant deterioration requirements are defined somewhat differently than under the nonattainment program. Under prevention of significant deterioration rules, a "major source" is any stationary source that emits, or has the potential to emit, over 100 tons per year of any pollutant subject to regulation under the CAA for 28 designated source categories, and 250 tons per year for all other sources. The 28 listed sources include lime, taconite ore, and phosphate rock processing plants, several kinds of smelters, and fossil fuel-fired boilers with over 250 BTU per hour heat input, but they do not include mining activities. (*40 C.F.R. § 51.166(b)(1).*) Accordingly, mining operations generally are governed by the 250 tons per year limit.

As under the nonattainment program, a "major modification" subject to prevention of significant deterioration requirements is any modification to a major source that causes a "significant net increase" in emissions of any regulated pollutant. What constitutes a "significant" increase of a given pollutant is again specified in EPA's rules, ranging from 100 tons per year for carbon monoxide to 0.6 tons per year for lead. (*40 C.F.R. § 51.166(b)(2).*) Changes involving routine maintenance or repairs, use of certain alternative fuels, and increases in production not prohibited by an existing permit are not considered a regulated modification.

"Pollutants subject to regulation under the Act" that currently trigger prevention of significant deterioration requirements under EPA's rules include the six criteria pollutants, three pollutants covered by the new source performance standards program (fluorides, sulfuric acid mist, and total reduced sulfur compounds), and chlorofluorocarbons covered by the ozone protection program in *42 U.S.C. § 7671 et seq.* The prevention of significant deterioration program also formerly applied to the eight hazardous air pollutants listed under the old national emission standards for hazardous air pollutants program (including arsenic and asbestos), but the 1990 Amendments provided that prevention of significant deterioration requirements shall not apply to those or any other of the 189 pollutants listed under the current hazardous air pollutants program.

Despite this key exemption, state prevention of significant deterioration programs approved before 1990 generally covered the old national emission standards for hazardous air pollutants, and those state requirements continue in effect until revised. Accordingly, state prevention of significant deterioration rules should be carefully reviewed to confirm what pollutants may trigger or be regulated by prevention of significant deterioration requirements in a given state. Note also that some listed hazardous air pollutants that would otherwise be exempt from prevention of significant deterioration requirements may also be a criteria pollutant(s), such as particulates (e.g., asbestos) or volatile organic compounds ("VOCs"), and thus may still be regulated as a part of those constituents.

The CAA divides attainment areas into three classes, which each have separate prevention of significant deterioration "increments" of allowable pollutant increases. (*See 42 U.S.C. §§ 7471-7474.*) Class I areas have only minimal allowable increments and automatically include all national parks and wilderness areas over 5,000 acres that existed in 1977, including any later increases. All other areas are considered Class II but can be redesignated by the states to Class I or, in limited circumstances, to Class III, which allows for additional growth. No Class III areas yet exist. Increments have been set to date only for particulate matter, sulfur dioxide, and nitrogen dioxide.

Proving compliance with an applicable increment is a major cause of the complexity of this program. An increment is measured from an area's "baseline concentration," which is the ambient air quality that existed when the area's first prevention of significant deterioration permit application was filed. That difficult calculation is done by a combination of ambient air monitoring and computer modeling. The increment above this baseline is then "consumed" as additional new or modified sources, both major and minor, are constructed.

A prevention of significant deterioration permit application generally must be accompanied by continuous air quality monitoring data gathered for at least one year, and a "source impact analysis" confirming that the proposed source will not violate any allowable increment or national ambient air quality standard. This analysis must

also be done using a combination of monitoring data and computer models specified by EPA rules. Limited exceptions to the length of pre-application monitoring or type of modeling may apply. EPA and the states also have discretion to require post-construction monitoring to confirm preconstruction analyses. (*See 40 C.F.R. §§ 51.166(k)-(n).*)

A permit application must also include a separate analysis of "additional impacts" from the proposed source, including impairment to visibility, soils, or vegetation and projected resulting growth. In addition, if a federal Class I area may be affected, the responsible Federal Land Manager must review the application and request the state or EPA to deny a prevention of significant deterioration permit where the area's "air quality-related values" (including visibility) are adversely affected, even if the national ambient air quality standards and prevention of significant deterioration increments will be met. This broad restriction can be a major problem for sources near Class I areas. (*See 40 C.F.R. §§ 51.166(o)-(p).*)

A prevention of significant deterioration permit must require best available control technology to be applied for every regulated pollutant potentially emitted over a specified "significant" amount. The CAA defines best available control technology as the maximum degree of reduction achievable for the facility for each pollutant, considering "energy, environmental, and economic impacts and other costs." Best available control technology is determined on both a case-by-case and pollutant-by-pollutant basis and has been the subject of very considerable dispute. EPA generally places a heavy burden on an applicant to show why it should not use the best state-of-the-art controls available. Accordingly, close coordination with the state and EPA is advisable before concluding what constitutes best available control technology for a given source. (*See 40 C.F.R. §§ 51.166(b)(12) and (k).*)

A "completed" prevention of significant deterioration permit application must be denied or approved within one year. Due to the complexity of the best available control technology and impact analyses noted above, however, disputes over "completeness" alone can take a year or more. When combined with a year of pre-application monitoring, the prevention of significant deterioration permitting process commonly takes over two years to complete, and often takes substantially longer. As a result, potentially affected sources should plan for very long lead times or face possible lengthy delays to construction start-up.

### 3.3.5.6 Unsettled Status of Fugitive Dust Emissions

Perhaps the most critical CAA issue for mining operators is whether, how, and for what purposes fugitive dust emissions will be counted or regulated under the CAA. "Fugitive emissions" are defined as those that could not reasonably pass through a stack, vent, or other functionally equivalent opening. (*See 40 C.F.R. § 51.166(b)(20).*) At nearly all mines, fugitive dust from vehicles and stored materials constitutes by far the greatest source of air emissions. If such dust is counted as part of a mine's emissions, virtually every mine and mine expansion would be a regulated major source or modification under the prevention of significant deterioration and nonattainment programs. Problems both in quantifying and controlling fugitive dust emissions would also make compliance with those programs extremely difficult.

The seminal 1979 *Alabama Power* case (*636 F.2d 323, 369 (D.C. Cir. 1979)*) ruled that fugitive emissions could be considered in determining a source's potential to emit under the prevention of significant deterioration program, but only after EPA identifies appropriate source categories by rule. In response, EPA in 1980 passed rules identifying 30 categories of sources for which fugitive emissions can and must be counted in calculating the source's potential to emit. EPA created that list merely by repeating the prevention of significant deterioration statutory list of 28 designated (100 tons per year) "major sources" and then adding two more: source categories regulated in 1980 by the new source performance standards or national emission standards for hazardous air pollutants programs.

The new source performance standards program and the 28 listed prevention of significant deterioration sources include some smelters, coal cleaning plants, and lime, phosphate rock, and taconite ore processing plants, but they do not include mining operations. After extensive litigation, EPA's decision not to add surface coal mines to the above list was upheld in 1991. Therefore, at this time, fugitive dust emissions are not counted under EPA's rules in determining whether mining operations are a "major source" under the prevention of significant deterioration or nonattainment programs.

By comparison, EPA's rules under the hazardous air pollutant program (described in the following section) provide that fugitive emissions *will* be counted and included in determining whether a facility is a major source under that program. These rules were upheld by the courts in 1995 but may be revised in the future.

It should also be noted that EPA's rules arguably allow states, if they so choose, to count fugitive emissions in determining major sources under their state programs. (*See 40 C.F.R. §§ 51.165(a)(4) and 51.166(i)(4).*) EPA also is free to amend its rules at any time to include additional source categories for which fugitive emissions must be considered. Accordingly, for future projects, both EPA's and a given state's rules should be checked carefully to confirm that fugitive dust from mining is not included in any major source calculation.

Therefore, despite the exemption in the prevention of significant deterioration and nonattainment programs, fugitive dust emissions still have a present, critical impact

on CAA requirements for mining in at least four ways: 1) fugitive dust is counted in determining whether an area is in "attainment" with the national ambient air quality standards for PM-10 in the first place; 2) if a source is considered "major" without counting fugitive emissions, then those emissions will be considered in calculating prevention of significant deterioration compliance and related impacts; 3) fugitive emissions are counted in determining whether a facility is a major source of hazardous air pollutants; and 4) EPA counts fugitive dust in tracking prevention of significant deterioration "increment consumption." The latter practice, in particular, has a major impact in western states where dust from fugitive emissions can take up the entire allowable increment in prevention of significant deterioration areas and thus preclude any future emitting activities.

Attempts to exempt fugitive dust from the above calculations in the 1990 Amendments were unsuccessful. The Amendments did prohibit EPA from using its Industrial Source Complex ("ISC") Model to calculate the effects of fugitive dust from surface coal mines pending a study to adjust the ISC Model to mining operations. Operators should ensure that any improved model developed is also used for non-coal mines.

Current state and federal rules and policies on fugitive emissions should be carefully reviewed for possible future changes in this key area.

### 3.3.5.7 Regulation of Hazardous Air Pollutants

As revised by the 1990 Amendments, Section 112 of the CAA lists 189 specific substances as hazardous air pollutants that must be regulated under the CAA by EPA or the states. Many of these substances are common to the mining industry, such as asbestos, radionuclides, fine mineral fibers (average length less than 1 micron), and any compounds of lead, arsenic, cyanide, cadmium, mercury, nickel, and various other metals. (*See 42 U.S.C. § 7412(b)(1).*) EPA may add or delete a substance to or from the statutory list, on its own or by petition from any party, if it finds that cumulative emissions of the substance are (or are not) reasonably anticipated to cause adverse health or environmental impacts.

The chief components of the hazardous air pollutants program are 1) the EPA listing of source categories and subcategories of hazardous air pollutants emitting facilities; 2) the setting by EPA of separate emission control standards for each listed source category reflecting the use of the maximum achievable control technology; 3) strict timetables for EPA to set all maximum achievable control technology standards by the year 2000; 4) requirements for both new and existing major (and designated minor) sources to obtain permits and apply maximum achievable control technology controls; and 5) compliance by those sources with any supplemental, health-based "residual risk" standards later set by EPA. Each of these requirements is described below.

A "major source" subject to the hazardous air pollutants program is any new or existing stationary source, or group of sources in a contiguous area under common control, that emits or has the potential to emit 10 tons per year or more of a single listed hazardous air pollutant, or 25 tons per year or more of any combination of hazardous air pollutants. This is an extremely low threshold. EPA may set an even lower threshold for a particular hazardous air pollutant, based on its characteristics, and may also create completely different criteria for radionuclide sources. It has not done so to date. As noted above, under EPA's initial rules, fugitive emissions will be counted and included in determining whether a facility is a major source under this program.

Any hazardous air pollutant source that is not "major" is considered an "area source." EPA is obligated to regulate certain area sources in urban areas, but those sources are not expected to include mining-related operations. EPA has broad discretion, however, to list and regulate any other area sources, and many mining activities not considered major hazardous air pollutant sources are likely to be regulated as area sources under this authority.

EPA in July 1992 adopted its initial list of 174 regulated categories of major and area hazardous air pollutants sources. Under that initial EPA list, mining itself is not designated as a regulated source category, but various mineral processing operations and specific types of metal smelters and refiners are listed as separate categories. EPA's current source category list should be carefully reviewed when planning a new operation or process to determine which hazardous air pollutants source category the planned activities fall under.

By the year 2000, EPA must establish a specific maximum achievable control technology emission standard for each listed hazardous air pollutants source category. EPA is required to meet interim "milestones" by setting standards for a certain percentage of listed categories by the end of 1992, 1994, and 1997. Maximum achievable control technology standards for mining are likely to be a lower priority and may not be set until 1997 or 2000.

Maximum achievable control technology standards must reflect the maximum degree of reduction of hazardous air pollutants emissions that is achievable for each source category. EPA must consider costs, energy requirements, and any non-air-quality health and environmental impacts and has discretion to distinguish among classes, types, and sizes of operations in a source category when setting maximum achievable control technology. Unlike best available control technology, however, for new sources maximum achievable control technology must be no less stringent than the "best controlled similar source." For existing sources, maximum achievable control technology must be as stringent as the best performing 12% of other existing sources in the same category. (*See 42 U.S.C. § 7412(d).*)

Maximum achievable control technology standards take effect immediately upon issuance and must be updated at least once every eight years. Any national emission standards for hazardous air pollutants standard in existence before the 1990 CAA Amendments (*e.g.*, for asbestos) remains in effect until revised or replaced with a maximum achievable control technology standard.

If EPA finds an emission standard for a particular hazardous air pollutant or source category is not feasible, it may instead issue a design, equipment, work practice, or operational standard as maximum achievable control technology. These measures will often be better suited to mining-related activities than add-on control equipment. A particular source covered by a work practice or operational standard maximum achievable control technology may also employ an alternative site-specific means of hazardous air pollutants control, upon convincing EPA that the alternative is at least as effective as the published standard. (*See 42 U.S.C. § 7412(h).*) Mine operators should be alert to the potential for employing alternative hazardous air pollutants controls at a particular facility.

The Congressional Conference Report for the 1990 Amendments states that EPA is prohibited from considering the substitution or alteration of mineral-bearing ores or mineral processing feed stocks when setting maximum achievable control technology standards for hazardous air pollutants source categories engaged in mining and mineral processing. EPA is allowed to consider substitutions or changes of chemicals used in those activities if necessary to reduce hazardous air pollutants emissions, so long as a safe, effective substitute is reasonably available. EPA's setting or revision of mining-related maximum achievable control technology standards should be closely monitored for potential impacts on both new and existing operations.

EPA has the discretion to issue maximum achievable control technology standards for smaller "area sources." It is also authorized, in the alternative, to issue more lenient standards for such sources requiring use of "generally available control technologies or management practices" ("GACT"). It is expected that EPA will broadly issue generally available control technologies standards for area sources and that non-major mining activities, at a minimum, will be subject to such generally available control technologies measures.

Two key events trigger the beginning of regulation under the hazardous air pollutants program. First, once a maximum achievable control technology standard is set for a source category, no major hazardous air pollutant source may be constructed unless EPA (or a delegated state) finds it will comply with that standard. Second, after a state's new permit program has been approved (generally by 1995), no major source may be constructed or modified unless EPA or the state finds that maximum achievable control technology will be met. If a maximum achievable control technology standard has not been set after a permit program is in place, then the required maximum achievable control technology determination must be made for each regulated source on a case-by-case basis, a very difficult task.

A "modification" triggering maximum achievable control technology compliance after a state permit program is approved is any change to a major source that causes the emission, or increase in emissions, of a hazardous air pollutant by more than a *de minimis* amount. "*De minimis* amount" is not defined in the CAA but likely will be defined by rule to parallel the minimal "significant increase" levels in the prevention of significant deterioration rules. A change will not be considered a regulated modification if the resulting increase in hazardous air pollutants emissions is offset by at least as great a decrease from the same source of another hazardous air pollutant(s) that EPA finds is "more hazardous." EPA is required to rank the relative hazards of listed hazardous air pollutants to facilitate claims for these offsets. The potential for hazardous air pollutants offsets should be carefully considered to avoid unnecessarily creating any regulated modifications. (*See 42 U.S.C. § 7412(g).*) Unlike a new major source, a new modification to an existing major source need only meet the maximum achievable control technology standard for existing sources, not new sources. This is a key distinction from regulated modifications under the prevention of significant deterioration and nonattainment programs.

Existing major hazardous air pollutants sources must comply with maximum achievable control technology and any other applicable standards in accordance with a schedule to be published by EPA. (*See 42 U.S.C. § 7412(i).*) That schedule must require compliance no more than three years from the time a standard is set, with several helpful exceptions. Generally, EPA or an approved state may issue a permit granting a 1-year extension to an existing source, if needed to install controls. In addition, sources that have installed best available control technology or lowest achievable emission rate before issuance of a maximum achievable control technology standard are allowed five years from the date of installation to comply with maximum achievable control technology. Similarly, under the "early reduction" credit, a source will be granted an additional six years to comply with maximum achievable control technology if it achieves (or makes an "enforceable commitment" to achieve) a 90% reduction in hazardous air pollutants emissions (from a base year after 1986) before the otherwise applicable maximum achievable control technology standard is proposed.

A special exception for the mining industry provides that an additional extension (beyond the general 1-year extension) of up to three more years may be granted for "mining waste operations" if the 4-year compliance time is "insufficient to dry and cover mining waste in order to reduce emissions" of any listed hazardous air pollutants. (*See 42 U.S.C. § 7412(i)(3)(B).*) This effectively

authorizes EPA or a state to allow an existing source that can be characterized as a "mining waste operation" (which is undefined in the CAA) to take up to seven years to comply with an applicable hazardous air pollutants standard or rule.

Once a new state permit program required by the 1990 Amendments is approved, all major hazardous air pollutants sources and any regulated area sources must obtain operating permits. New sources and modifications need permits before beginning construction. Existing sources have 12 months after approval of the state permit program to submit a permit application and "compliance plan" on forms to be issued by each state.

After a state permit program is approved, the hazardous air pollutants "permit hammer" takes effect. Under that provision, if EPA fails to set a maximum achievable control technology standard according to its published schedule, then within 18 months after the missed deadline all major sources in the listed category must submit permit applications and establish maximum achievable control technology on a case-by-case basis. (*See 42 U.S.C. § 7412(j)(5).*) Again, this would be an onerous process.

By 1997, EPA must report to Congress on any "residual risks" to public health from hazardous air pollutants sources remaining after application of maximum achievable control technology. If Congress takes no action, within eight years after setting a maximum achievable control technology standard for a source category, EPA must issue supplemental "residual risk" emission standards for each category if needed to provide an "ample margin of safety" to protect public health or prevent adverse environmental effects. Residual risk standards must be set for certain carcinogenic hazardous air pollutants. Significantly, EPA is not required to review or set residual risk standards for listed area source categories for which EPA has set alternative generally available control technologies standards. (*See 42 U.S.C. § 7412(f).*)

These health-based standards would become effective immediately, with existing sources allowed only 90 days to comply. EPA may grant existing sources a "waiver" allowing up to two more years to comply if time is needed to install controls and interim measures are taken. Whether and to what extent these supplemental health-based hazardous air pollutants standards will be set and impact mining activities remains to been seen.

Mining operators must carefully consider means to minimize the application or impact of the hazardous air pollutants program by reducing a facility's potential to emit hazardous air pollutants below major source thresholds, obtaining deferrals of maximum achievable control technology compliance dates, evaluating the potential for early reduction credits, and ensuring proper delineation of hazardous air pollutants source categories for mining activities.

### 3.3.5.8 Prevention of Accidental Release of Air Toxics

The 1990 CAA Amendments also created two comprehensive programs to prevent and mitigate against accidental releases of air toxics. One program is administered under the CAA by EPA and a new independent Chemical Safety and Hazard Investigation Board (the "Chemical Safety Board") and regulates certain stationary sources of extremely hazardous substances and related accidental releases. The other, closely related program is administered by the U.S. Occupational Safety and Health Administration ("OSHA") to implement a work place safety standard to protect employees from accidental air emissions of highly hazardous chemicals.

Under the EPA program, operators of stationary sources that produce, process, handle, or store "extremely hazardous substances" over certain threshold quantities must perform a thorough hazard assessment of the facility and prepare a comprehensive risk management plan to prevent and provide prompt response to any air toxic release. (*42 U.S.C. § 7412(r).*) EPA issued its initial list of covered substances and threshold quantities in 1994. These lists include explosives and other materials common at mining operations but generally are considered narrower than the substances and quantities listed under the Emergency Planning and Community Right-to-Know Act ("EPCRA") (*42 U.S.C. § 11001*) and similar existing laws.

Covered operators are also deemed to have a "general duty," patterned on the general duty applied under OSHA's rules, to identify hazards, design and maintain a safe facility, and prevent and mitigate against accidental releases. This broad duty gives EPA wide latitude for enforcement in the event of an accidental release.

The Chemical Safety Board will issue separate rules or requirements for reporting accidental air toxic releases. The Board will investigate any such releases and, like the National Transportation Safety Board on which it is patterned, may gather evidence and hold hearings.

Under the OSHA program, OSHA has developed a "chemical safety standard" required by the CAA to protect employees from hazards from accidental releases of "highly hazardous chemicals" in the work place. Those chemicals also are listed by OSHA and closely parallel the list created under the above EPA program. The general OSHA program requirements also closely track those under the EPA program, requiring a hazard assessment and implementation of risk avoidance measures, as well as extensive employee notification and training. (*29 U.S.C. § 655 Note.*)

Mining and mineral processing operations that use, generate, or otherwise handle any materials covered by EPCRA or other extremely hazardous substances in more than *de minimis* amounts are likely to be covered by one or both of these CAA programs. EPA and OSHA lists and

rules under these programs should be carefully reviewed for applicability and future changes. Covered sources should coordinate programs to achieve and ensure complete, simultaneous compliance.

### 3.3.5.9 General Air Permitting Requirements

The 1990 CAA Amendments required each state to develop a comprehensive permit program for air emission sources by November 1993. EPA was required to approve or reject a proposed program within one year. If disapproved in whole or in part, a state must submit a revised program within 180 days. Most states had approved new permit programs in place by 1995. If a state did not have an approved permit program by November 1995, EPA was required to set up and run a program for that state. (*See 42 U.S.C. §§ 7661-7661f.*)

Under the new permit requirements, a limited-term, renewable operating permit is required for a very wide range of identified air emission sources, including the following:

i. "Major stationary sources" as defined anywhere in the CAA, including any source with a potential to emit of 100 tons per year and any smaller "major sources" as defined in the hazardous air pollutants and nonattainment programs;

ii. Certain $SO_2$ or $NO_x$ sources subject to the acid rain program (described below);

iii. Any source (including "area sources") subject to any hazardous air pollutants program requirements;

iv. Any source subject to new source performance standards requirements;

v. Any source requiring a pre-construction permit under the prevention of significant deterioration or nonattainment programs; and

vi. Any other source in a category later designated by EPA by rule.

(*See 42 U.S.C. § 7661a(a).*) This broad scope encompasses virtually every stationary air emission source that is subject to any requirement under the CAA. The hazardous air pollutants program alone will make hundreds of mining and industrial activities with more than minimal emissions of hazardous air pollutants subject to onerous permitting requirements. In addition, the states are free to make air permit requirements applicable to an even wider range of sources.

The CAA generally requires a regulated source to have a permit to operate. It is important to note, however, that major sources and modifications subject to the prevention of significant deterioration or nonattainment programs must still obtain permits prior to commencing construction. Major sources and modifications subject to the hazardous air pollutants program also require a demonstration that maximum achievable control technology will be met before beginning construction or reconstruction, which as a practical matter means that a permit must first be obtained. (*See 42 U.S.C. § 7412(g)(2).*) Accordingly, these three types of sources must obtain permits before beginning construction, but these pre-construction permits will also now either be in addition to or, in most cases, be a part of and consolidated with the same type of limited-term, renewable operating permit required for all other regulated sources. This distinction should be kept in mind when planning and scheduling the construction or modification of a potentially regulated source.

While the states have considerable flexibility under the CAA to tailor their own permit programs, they are subject to certain minimum statutory requirements. Each permit must contain enforceable emission limitations and standards specifying all applicable CAA requirements. A permit must have a fixed term, not to exceed five years, after which it must be renewed and reissued to remain in effect. Significantly, permits for major sources with remaining terms longer than three years must be "reopened" and revised within 18 months to add and reflect any new CAA requirements that will become effective before the permit expires. This reopening process can be a potential source of substantial unexpected costs, restrictions, or delays for sources that qualify as major.

Permits must also contain emission monitoring, reporting, and compliance certification requirements and agency access and inspection provisions to assure compliance with permit terms and conditions. States must require monitoring reports to be filed at least every six months. These reports must be signed and their accuracy certified by a "responsible corporate official," not just a rank-and-file employee. At least once a year such an official is also required to certify generally that a facility is in compliance with all permit and CAA requirements. Any deviations from permit requirements must be reported promptly to the permitting authority. As discussed below, the consequences of a false report or certification or an improper failure to report can be extremely severe.

If a source will not be in complete compliance at the time a permit will be issued, it must file a compliance plan along with its permit application. The plan must include an enforceable schedule of compliance. If a compliance plan is required, progress reports must be filed at least every six months to confirm that the plan is being followed.

Large annual permits fees must be collected by the states to assure adequate funding for state permit programs. The standard annual fee for each permitted source is $25 per ton of each regulated pollutant emitted, up to 4,000 tons per year. "Regulated pollutants" include virtually any substance regulated under the CAA, except that carbon

monoxide is expressly excluded for purposes of calculating fees. This standard fee amount can be increased, if necessary to fund the program, or decreased, if a state can convince EPA that some lesser amount will fully fund its state program. A source's failure to pay a fee can be penalized by a fine of 50% of the fee plus interest, in addition to the general enforcement mechanisms described below. Particularly if a state chooses to count fugitive dust in calculating a source's total chargeable emissions, many permitted mining operations could have very high annual permit fees.

As noted in Section 3.3.5.1, above, in 1995 EPA issued a Guidance Memorandum stating that only PM-10 (particulates under 10 microns), and not larger forms of particulate matter, will be considered a "regulated pollutant" and will be counted and included for purposes both of assessing fees and of determining "major source" status under this operating permit program. This was a critical ruling for the mining industry, since many mining operations have only minor PM-10 emissions but would be considered "major" (and be subject to substantial annual fees) if all particulate emissions were counted. It should be noted, however, that EPA could change this informal ruling at any time and that this policy is not binding on, and in some cases has not been followed by, the states. Operators should confirm that EPA has not changed its position (and that the pertinent state has also adopted such position) before relying on this "PM-10 only" policy.

Once a state permit program is approved by EPA, existing regulated sources have 12 months to submit a permit application, including a compliance plan where necessary. So long as the application is complete and timely (and later information requests are timely complied with), an existing source will be deemed to be in compliance with the CAA, regardless of how long the state takes to issue the permit. New sources are subject to permitting requirements immediately upon approval of a state program. (*See 42 U.S.C. § 7661b.*)

States have three years to act on permit applications filed within one year after its program is first approved by EPA. One-third of those applications must be processed within each of those three years. Applications filed after the first year of a state program must be acted on within 18 months. Due to the backlog caused by issuing complete, new permits for all regulated sources, it is expected that air permitting throughout the 1990s will be a very slow, cumbersome process.

EPA retains a major role in overseeing state permit programs. The public and neighboring states may also have a substantial impact. All permit applications and draft proposed permits must be provided for review both to EPA and to all other states that either are contiguous and might be adversely affected or are within 50 miles of the source. Public notice, including the opportunity for a public hearing, must also be given of each draft permit. These multiple review procedures further complicate and delay the permit process.

EPA in effect has a "veto" power over a proposed permit. EPA has 45 days from receipt of a draft permit to object to all or part of it as not complying with the CAA or the state's state implementation plan. The state then must resubmit a revised draft permit within 90 days, or else EPA will either issue a suitably revised permit or deny it altogether. If EPA does not object within 45 days, the state may issue the permit. In addition, even after a permit has been issued, EPA at any time can notify the state that some cause exists for a permit to be terminated, modified, or revoked and reissued. If the state does not resolve its differences with EPA within 90 to 180 days after such notice, EPA itself may terminate, modify, or revoke and reissue the permit. The CAA does not define what constitutes "cause" justifying these actions.

If a neighboring state gives written recommendations regarding a proposed permit, the permitting state must either follow the recommendations or explain in writing to EPA and the other state why it chose not to do so. In practice the states are very deferential to each other, so coordination with neighboring state agencies is advisable where appropriate, to avoid any adverse recommendations.

The public may affect the permit process in three ways. After issuance of the public notice of a draft proposed permit, any person may submit comments on the draft. Anyone may also request and make comments at a hearing on the proposal. In addition, if EPA fails to object to a draft permit by the end of its 45-day review period, any person may petition EPA within 60 days to request an EPA objection or "veto." The latter petition may only be based on issues raised during the comment period, unless the petitioner can show it was impracticable to have done so. Where possible, objections from the public to proposed projects requiring air permits should be identified and resolved, or at least thoroughly addressed in the administrative record, to minimize disruptions and delays from this public review process.

The 1990 Amendments also added several favorable provisions relating to air permitting. A single, "aggregate" permit may now be issued for a facility that has multiple air emission sources, as is typical of mining operations. Obtaining a single, consolidated permit usually will greatly simplify reporting and compliance and may also reduce permit fees.

The CAA also directs that permits be written to provide for operational flexibility by allowing minor changes without triggering the need for a new permit, so long as the change is not a regulated "modification." Seven days' prior notice is required for these minor authorized changes. What constitutes a minor, permissible operational change is subject to changing EPA policy and may also differ from state to state. Great care should be taken by an operator in developing an air permit for a facility to provide for the maximum possible degree of operational flexibility.

The 1990 Amendments also created a favorable "permit

shield," which provides that compliance with an issued air permit constitutes compliance not only with all CAA requirements specified in the permit, but also with all other CAA provisions that the permit states are not applicable to the permittee. Operators should invoke this protection as extensively as possible and attempt to obtain comprehensive statements in issued permits that other CAA requirements are not applicable.

As noted above, despite these extensive minimum requirements, state permitting rules often vary considerably from state to state. In particular, many states require all air permits to be obtained prior to beginning construction, rather than just operation. That difference may have a significant impact on projects with long construction lead times. Accordingly, state permitting rules should be carefully reviewed for possible additional or more strict requirements.

### 3.3.5.10 CAA Enforcement

EPA and the states generally have concurrent authority to enforce all CAA requirements for which a state has an approved state implementation plan or other formal delegation. EPA has exclusive enforcement authority for any undelegated CAA programs and requirements. Private citizens and entities also have broad authority to sue to stop, prevent, or penalize some alleged violation of the CAA or related state implementation plan or permit.

States have great latitude under the CAA to develop their own enforcement schemes, subject to the minimum CAA requirements for source monitoring and reporting noted above and for the provision of "appropriate criminal penalties" and civil penalties up to at least $10,000 per day for each violation. Accordingly, the rules of a given state should be reviewed to evaluate the state's applicable enforcement mechanisms and any potential noncompliance penalties and procedures.

The CAA provides a number of powerful alternative mechanisms for EPA to enforce the CAA and creates extremely stringent federal civil and criminal penalties for violators. These mechanisms include several administrative actions (compliance orders, civil penalty orders, and field citations) and several judicial actions (suit for civil penalties, criminal prosecution, and citizen suits). (*See 42 U.S.C. § 7413.*) Each of these measures and related penalties are described below.

The 1990 Amendments greatly expanded EPA's authority to enforce the CAA by various administrative actions without filing a lawsuit. EPA may issue "administrative compliance orders" requiring an operator to take certain actions to come into compliance with the CAA or an applicable state implementation plan or permit in accordance with a specified schedule. These orders may now last up to one year and are not subject to court review before they are enforced. As a result, a source must comply even with an order it believes is erroneous before it seeks judicial review, or else run the risk of potential civil or criminal liability for knowingly disobeying the order itself. Issuance of an EPA compliance order does not preclude EPA or a state from pursuing other administrative or judicial remedies, including civil penalties. (*See 42 U.S.C. § 7413(a)(1).*)

EPA must give 30 days' notice before issuing a compliance order. An order may not take effect until the recipient has had an opportunity to confer with EPA. Accordingly, a "noncompliance conference" with EPA, at a minimum, will defer the effectiveness of a compliance order and is usually requested. EPA may also issue general administrative orders prohibiting the construction or modification of any major source in areas where EPA concludes the state is not properly implementing the CAA's requirements. This provision, in effect, causes private sources to be penalized and delayed due to disputes between EPA and a particular state. In states considered by EPA to be out of compliance with the CAA in some pertinent respect, a source should consult with EPA to confirm proper authorization and avoid a potential construction ban order.

EPA may also issue "administrative penalty orders" for monetary fines up to $25,000 per day, with a maximum total limit of $200,000. These penalty orders generally must be issued within 12 months after the first alleged date of violation. EPA and the U.S. Attorney General together have the nonreviewable discretion to enlarge both the above penalty ceiling and the 12-month time limitation. They have not done so to date.

EPA again must give 30 days' prior notice for these penalty assessments and must also provide the recipient an opportunity to request and have a formal administrative hearing. In setting a penalty, EPA must look at a broad range of factors, such as the size of the business, the seriousness of the violation, any economic benefit, the good faith and compliance history of the operation, and so forth. EPA's assessed penalty can be challenged in federal court but must be upheld unless there is no "substantial evidence" in the record to support it. This is a very difficult standard for an alleged violator to overcome.

The CAA also now creates a presumption of a continuing violation where EPA has shown violations at two different times and believes it is "likely" that the violation occurred continuously between those times. This "guilty-until-proven-innocent" presumption in effect forces the operator to prove the absence of a violation during that interim period to avoid liability. If an assessed administrative penalty is not timely paid, EPA can sue and collect all its costs of recovery, including attorneys' fees and a 10% penalty.

EPA may now also issue "field citations," sometimes called "toxic tickets," for minor CAA violations. Designated EPA officers can issue these administrative citations with fines up to $5,000 per day. A recipient can either pay the fine or request an informal administrative

hearing. If a fine is upheld after such a hearing, it is then subject to judicial review in federal court under the same difficult "substantial evidence" standard noted above for general administrative penalties. The CAA provides that payment of a field citation fine will not bar further enforcement action, including additional penalties, "if the violation continues." (*See 42 U.S.C. § 7413(d)(3).*) Arguably, if the violation is discontinued, payment of a field citation penalty would bar further enforcement action.

Section 120 of the CAA creates a separate, complex system for EPA to assess administrative "noncompliance penalties." Under a detailed set of rules, these penalties are designed to calculate and recover the economic benefit received by a noncomplying source. (*42 U.S.C. § 7420.*) With the much simpler administrative orders available after the 1990 Amendments, it is very unlikely that EPA will resort to this much more cumbersome process.

In addition to these administrative actions, EPA may bring a civil lawsuit for penalties and injunctive relief in federal district court. This was the prevalent form of CAA enforcement until 1990 but should decrease in prominence given the expansion of EPA's administrative powers. A civil judicial action has a broader reach than an administrative order in at least two critical respects. First, EPA can seek civil penalties for past violations occurring within the last five years, instead of just 12 months. Second, maximum penalties are expanded to $25,000 per day for each violation, with no total upper ceiling. The same broad range of penalty factors and the presumption of continuing violations noted for administrative penalty assessments also apply to judicial civil penalty actions. In the unlikely event that the court finds that EPA's civil action was "unreasonable," it has discretion to award the defendant all its costs of defending the action. (*42 U.S.C. § 7413(b).*)

"Knowing" violations of the CAA are subject to possible federal criminal prosecution. The 1990 Amendments increased virtually all criminal violations under the CAA from misdemeanors to felonies. Any person who knowingly violates a permit, state implementation plan, EPA administrative order, or other specified CAA requirements can be prosecuted for a felony crime and imprisoned up to five years and fined up to $250,000 for individuals and $500,000 for organizations. Knowingly making a false statement in a report or certification or failing to report when required can be a felony punishable by two years in jail with the same monetary penalties noted above. Even the knowing failure to pay a CAA fee can be a felony resulting in a 1-year imprisonment and the above maximum fines. These maximum penalties are all doubled for any repeat violations. (*See 42 U.S.C. § 7413(c).*)

The 1990 Amendments also created two new crimes for the knowing or negligent release into the air of extremely hazardous substances, which are the substances listed under Section 302 of EPCRA (*42 U.S.C. § 11001*) or any hazardous air pollutants listed under the CAA. Any release of these substances that negligently causes an imminent endangerment to any person is a misdemeanor punishable by up to one year imprisonment and the same monetary penalties described above. Any release that knowingly causes such endangerment is a major felony punishable by imprisonment up to 15 years and fines up to $250,000 for individuals and up to $1,000,000 for each violation for any organization. (*42 U.S.C. § 7413(c)(3).*)

A "knowing" violation under these criminal provisions means only that the person or entity knew what it was (or was not) doing, not that it was aware that the act or omission was a violation of the CAA. Accordingly, many violations will be "knowing" in this broad sense, and ignorance or misunderstanding of some obscure or complex CAA provision generally will not be a defense to a criminal violation under the CAA.

The CAA also highly personalizes these enforcement mechanisms to reach to individuals as well as entities. An "operator" subject to civil penalties and orders is defined to include any person who is "senior management personnel or a corporate officer." A "person" subject to criminal prosecution is similarly defined to include "any responsible corporate officer." With several specific exceptions, liable "operators" or "persons" generally will not include non-management, non-officer employees, unless they are alleged to have committed a knowing and willful violation. "Knowing and willful" here means that they both knew what they were doing and knew that it was unlawful, but they need not have known they were violating the CAA specifically. (*See 42 U.S.C. § 7413(h).*) Accordingly, EPA has broad discretion in a given case to choose to bring an enforcement action or criminal prosecution against various individual officers, managers, or even employees, instead of or in addition to the responsible company or organization. This potential personal liability greatly increases the stakes of ensuring CAA compliance.

The "citizen suit" provisions of the CAA broadly authorize "any person" to bring a civil action in federal district court against any person or entity claimed to be in violation of a permit, state implementation plan, administrative order, or other CAA requirement. EPA and a state can also be sued by any person to compel some mandatory agency action that has been unreasonably delayed or unlawfully withheld.

A citizen suit may be brought only where a violation can be shown to have been "repeated." More than a single violation is sufficient to satisfy this requirement. A plaintiff must give EPA, the state, and the claimed violator 60 days' notice before filing suit. Suits against EPA or a state to compel delayed agency action require 180 days' prior notice. The complaint and any proposed settlement consent decree must be sent to EPA, which may intervene in the action at any time. Unless EPA joins the action as a party, however, it is not bound by any judgment or settlement entered in the case.

Citizen suit plaintiffs can now sue for civil penalties, as well as for injunctive relief. The monetary limits are the same as for EPA judicial penalty actions. Penalties assessed generally go into the U.S. Treasury, not to the plaintiff, but up to $100,000 may be applied by the court or by settlement to "beneficial mitigation projects" to enhance public health or the environment. The court, if "appropriate," may also award the plaintiff its costs and attorneys' fees. These expansive provisions are certain to make CAA citizen suits increasingly more frequent and successful. (*See 42 U.S.C. § 7604.*)

EPA may also award "bounties" up to $10,000 for information leading to any CAA criminal conviction or civil penalties. In addition, no federal agency may enter into any contract with persons criminally convicted under the CAA relating to the violating facility, and EPA has the discretion to extend this contract ban to any other facilities owned or operated by the convicted person. This "contractor ban" could have a substantial adverse impact on mining operators who have or plan to have federal mineral leases or other federal contracts.

#### 3.3.5.11 Acid Rain Program

Title IV to the 1990 CAA Amendments created a special new program to control atmospheric acid deposition, or "acid rain," by regulating $SO_2$ and $NO_x$ emissions from certain specified utility power plants. This program creates marketable "allowances" authorizing affected sources to emit one ton of $SO_2$ per allowance per year. EPA is required to allocate annual $SO_2$ allowances to existing affected power plant sources so that, by the year 2000, total annual $SO_2$ emissions will not exceed 8.9 million tons. Once allowances are fully allocated, new or expanded power plants must obtain allowances on the open market from another source(s) to authorize any new $SO_2$ emissions. (*See 42 U.S.C. §§ 7651-7651o.*)

While directed primarily at power plants, Title IV authorizes other sources of $SO_2$ voluntarily to "opt in" to be treated as an "affected source" and become subject to the allowance program. (*42 U.S.C. § 7651i.*) A source that can then achieve a substantial reduction in its $SO_2$ emissions will have valuable excess allowances to sell on the open market to electric utilities seeking to construct or expand their facilities. An election to become an affected source must be submitted to EPA along with a permit application, compliance plan, baseline emission data, and other information specified in extensive EPA rules. Significantly, $SO_2$ allowances produced as a result of "reduced utilization or shutdown" may not be transferred or banked. (*42 U.S.C. § 7651i(f).*) This restriction may limit the potential usefulness of this program to mining activities.

Mining and mineral processing operations that have appreciable $SO_2$ emissions should strongly consider the cost-benefit of opting into this acid rain program and marketing excess $SO_2$ allowances. Detailed guidance on establishing baseline $SO_2$ emissions and procedures for making voluntary elections is available from EPA.

## 3.4 THE CLEAN WATER ACT

**by R. L. Griffith**

### 3.4.1 INTRODUCTION TO THE ACT AND OVERVIEW OF MAJOR PROGRAMS

#### 3.4.1.1 Purpose of the Act

Congress adopted the Federal Water Pollution Control Act in 1972 to implement a nationwide program for the control of surface water pollution. (*33 U.S.C. §§ 1251 et seq.*) The stated goals of the Federal Water Pollution Control Act, now known as the Clean Water Act ("CWA" or "Act"), are to restore and maintain the integrity of the nation's waters and to achieve and protect fish, wildlife, and recreation uses. (The latter is often referred to as the "fishable, swimmable" goal.) The discharge of pollutants into surface waters was to be eliminated by 1985. While the "no-discharge" goal has not been achieved, it has been relied upon to support the adoption of stringent water pollution standards.

Prior to the adoption of the CWA, federal law had relied on states to adopt instream water quality standards and to enforce the standards through permits. The Act strengthened the water quality standards program by making the U.S. Environmental Protection Agency responsible for setting pollutant discharge standards for each industry, which are applicable nationwide.

EPA was also given permitting authority over discharges of pollutants and supervisory responsibility for state permit programs. Most states have been delegated EPA's permitting authority and, as a result, enforce the Act's permit program. States continue to have the primary responsibility for setting instream water quality standards, which EPA must approve. The U.S. Army Corps of Engineers has permitting authority for dredge and fill permits under Section 404 of the Act, although EPA retains a role in the granting and enforcement of such permits.

#### 3.4.1.2 The NPDES Permit Program

The primary enforcement mechanism of the Act is the National Pollutant Discharge Elimination System ("NPDES") permit program. An NPDES permit must be obtained for any discharge of pollutants from a point source to waters of the United States. The permit sets limits on the pollutant discharges and requires self monitoring of compliance. The permitting agencies and the courts have interpreted an NPDES permit to be required for a wide range of discharges. For example, an overflowing sump in

a gold leaching operation has been construed to be a point source. Most activities that result in a discharge of pollutants to surface water are potentially subject to the NPDES program.

#### 3.4.1.3 Technology-Based Standards and Instream Water Quality Standards

The discharge limits ("effluent limitations") set by NPDES permits are derived from two sources: (a) the nationally applicable technology-based effluent limitations adopted in regulations by EPA for each industry and (b) the water quality standards adopted by the states, which set maximum allowable concentrations of pollutants for streams and other water bodies. Technology-based limitations are based on the capabilities and costs of technologies to control the discharge of pollutants. Technology-based effluent limitations have been set for discharges of mine water and mill or processing water for mineral mining and processing, ore mining and dressing, and coal mining.

Water quality standards for stream segments and other bodies of water have been adopted by the states at levels sufficient to protect existing uses, such as public water supply, aquatic life, recreation, and agriculture, and to improve water quality to support aquatic life and recreation uses, where degradation has occurred. Discharge limitations in NPDES permits are set to comply with the more stringent of the instream water quality standards and the technology-based effluent limitations that apply to the source involved.

#### 3.4.1.4 The Dredge and Fill Permit

Section 404 of the Act authorizes the U.S. Army Corps of Engineers ("Corps") to issue permits for the discharge of dredge or fill material into the navigable waters. "Navigable waters" has been construed broadly to include the surface waters of the United States, including wetlands. "Discharge of dredge or fill material" is defined to encompass a wide range of construction and fill activities in surface waters and wetlands.

In recent years, dredging and filling activities in wetlands have become a highly politicized issue because of the ecological importance of wetlands for vegetation and wildlife. The focus of this issue has been whether to narrow or broaden the definition of the types of wetlands included as "waters of the United States" requiring a dredge and fill material permit. As a result of the politicization of this issue, it is becoming increasingly difficult to obtain such permits for projects disturbing significant areas of wetlands.

### 3.4.2 TYPICAL MINING PROBLEMS ADDRESSED BY THE CWA

#### 3.4.2.1 Discharges of Mine Water/Acid Drainage

Acid mine drainage is the typical discharge of concern from underground mining operations, though it also occurs at surface operations. (It is described in detail in other portions of this Handbook.) Acid drainage from a mine occurs where sulfitic rock has been exposed to oxygen and water as a result of mining activities, although it may also occur naturally. Acid drainage water quality typically has a low pH, is high in sulfate, and contains significant concentrations of metals.

Underground mines likely to result in acid drainage are those where substantial amounts of sulfide minerals are left in the ground during mining and are located above a water table, which has been lowered by the mining activities. The mining can contribute to the fracturing of the rock, exposing additional surface area to oxidation.

#### 3.4.2.2 Flows From Mineral Wastes

Discharges of acid drainage from tailings ponds, waste rock management units, and ore stockpiles may require an NPDES permit. Acid drainage discharges from waste rock management units and ore stockpiles may occur when they are exposed to precipitation or runoff. Tailings ponds, of course, may also include chemical reagents, such as cyanide, which are pollutants under the Act.

Seepage flow from tailings ponds into groundwater are not regulated under the Act, although many states that enforce the NPDES program regulate discharges to groundwater under their state programs. In addition, such seepage may result in liability under the federal Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA" or "Superfund") or similar state statutes.

#### 3.4.2.3 Storm Water Runoff

Storm water runoff from mining operations is not generally regulated under the CWA unless it is collected and discharged from a conveyance, such as a pipe or ditch ("point source"). Even point source discharges of runoff have only been erratically regulated in the past under the Act. At least one court has held that runoff from spoil piles discharged to a stream by means of gullies created by the runoff was a point source requiring an NPDES permit. (*Sierra Club v. Abston Construction Co.*, 620 F.2d 41 (5th Cir. 1980).) The uncertainty of whether runoff is regulated has been resolved by the 1987 amendments to the Act, which require storm water discharges from industrial activities, including mining activities, to obtain NPDES permits. The new storm water discharge requirements are discussed in Section 3.h, below.

### 3.4.3 OUTLINE OF THE STATUTORY SCHEME: THE GENERAL WATER QUALITY PROTECTION PROGRAM

#### 3.4.3.1 Scope of Federal CWA Controls over Surface Waters

The CWA regulates discharges to "waters of the United

States" which has been interpreted to include surface waters but not groundwater. The types of surface waters protected by the Act include: 1) navigable waters; 2) interstate waters; 3) intrastate lakes, rivers, and streams which are (a) used by interstate travelers for recreation and other purposes, or (b) which are a source of fish or shellfish sold in interstate commerce, or (c) which are utilized for industrial purposes by industries engaged in interstate commerce; 4) impoundments of the other types of waters defined as waters of the United States; 5) tributaries of the foregoing; and 6) wetlands adjacent to the other types of waters defined as waters of the United States. (*40 C.F.R. § 122.2.*) "Wetlands" are defined by rule as areas inundated or saturated by surface or groundwater sufficient to support a prevalence of vegetation adapted for saturated soil conditions.

The courts have upheld the Act's applicability to a wide range of surface waters. Arroyos and dry creek beds have been held to be waters of the United States because of the potential flow to navigable streams after an intense rainfall. (*Quivira Mining Co. v. EPA*, 765 F.2d 126 (10th Cir. 1985).) The Act's jurisdiction has also been held to extend to isolated, seasonal, and man-made bodies of water. (*Leslie Salt Co. v. United States*, 896 F.2d 354 (9th Cir. 1990).) Thus, virtually all surface water bodies and even areas of saturated soils (*i.e.*, wetlands) are subject to the Act's provisions. One exception that the agencies generally recognize is a man-made waterway confined to the property of the discharger which is part of an industrial process, such as a pond used for internal recirculation purposes.

### 3.4.3.2 The NPDES Permit Program

The NPDES permit program is the primary means by which the Act controls the discharge of pollutants. (The regulations for this program are found at *40 C.F.R. Parts 121-125.*) Any person responsible for the discharge from a point source of a pollutant or pollutants into waters of the United States must obtain an NPDES permit. As discussed above, "waters of the United States" include most surface water bodies and wetlands. Similarly, discharges of "pollutants" from "point sources" include most discharges from mining activities.

"Pollutants" regulated by the Act include virtually any type of chemical at any concentration in discharges to surface water. At present, there is no single list of pollutants regulated by the Act. Many of the states' programs rely on general prohibitions against the discharge of toxic or hazardous pollutants as a means of limiting the discharge of any chemical considered to be deleterious. As a result, even the discharge of natural groundwater from a mine that contains trace metals and solids may require an NPDES permit. The new requirements related to toxic pollutants (see below) should result in more certainty in the future as to regulated pollutants.

"Point source" is defined to mean "any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged." (*33 U.S.C. § 1362(14).*) This definition is given an expansive interpretation by the enforcement agencies. An unplanned overflow from a reserve sump used in a gold leaching operation has been determined to require an NPDES permit because the "escape of liquid from the confined system is from a point source." (*United States v. Earth Sciences, Inc.*, 599 F.2d 368 (10th Cir. 1979).) The "may be discharged" language has been interpreted to include the overflow from tailings impoundments which occurs only infrequently under excessive precipitation conditions.

An NPDES permit must be obtained from the state or EPA prior to any discharge from the facility. Most states have received authorization from EPA to issues NPDES permits. EPA may issue its own permit if a permit issued by a state does not comply with federal effluent limitations or protect water quality standards.

New sources in states where EPA is the permitting authority must prepare an environmental assessment for EPA's use in determining whether an environmental impact statement is required by the National Environmental Policy Act ("NEPA"). Where the state is the issuing authority, compliance with NEPA is not required for new or existing sources.

Prior to issuance of a permit by EPA, Section 401 of the Act requires a state to certify compliance with specified requirements of the Act, including state-adopted water quality standards ("401 Certification"). The state may propose conditions for the permit which, if incorporated, will meet the requirement for the 401 Certification.

The conditions imposed in an NPDES permit fall into three general categories: "effluent limitations," which are numeric limits on the quantity of pollutants allowed to be discharged; self-monitoring requirements to measure compliance with the effluent limitations; and biological monitoring for toxic pollutants for which numeric limits have not been set (see Section 3.e., below). Effluent limitations are usually stated in terms of concentrations of the pollutant in the waste water (*e.g.*, cyanide = 0.01 mg/l). Effluent limitations are based on the more stringent of the technology-based limits for mining operations or compliance with the instream water quality standards.

### 3.4.3.3 Technology-Based Effluent Standards

As required by the Act, EPA has adopted regulations setting technology-based effluent limitations for three categories of mining discharge sources: ore mining and dressing (*40 C.F.R. Part 440*), mineral mining and processing (*40 C.F.R. Part 436*), and coal mining (*40 C.F.R. Part 434*). The effluent limitations set the allowable discharge concentrations of metals, pH, and total

suspended solids. They are standards which impose mandatory levels of treatment, depending on the industry regulated, regardless of the quality of receiving waters.

The ore mining and dressing effluent limitations have been set for gold placer mines and the following ores: iron, aluminum, uranium, radium, vanadium, mercury, titanium, tungsten, nickel, antimony, copper, lead, zinc, gold, silver, molybdenum, and platinum.

Effluent limitations for the mining and processing of the following minerals have been adopted: crushed stone, construction sand and gravel, industrial sand, gypsum, asphaltic mineral, asbestos, wollastonite, barite, fluorspar, salines from brine lakes, borax, potash, sodium sulfate, phosphate rock, Frasch sulfur, bentonite, diatomite, jade, novaculite, tripoli, and graphite.

Effluent limitations for coal mining are applicable to discharges from coal preparation plants, acid mine drainage, alkaline mine drainage, and inactive mines that are subject to reclamation bond requirements.

The Act establishes three different sets of technology-based effluent limitations: 1) "best practicable control technology currently available" ("BPT"), which became applicable to existing and new dischargers as of July 1, 1977, or if adopted after January 1, 1982, must have been complied with no later than three years after adoption but no later than March 31, 1989; 2) "best available technology economically achievable," ("BAT") which became applicable to existing and new dischargers no later than three years after adoption but no later than March 31, 1989; and 3) "new source performance standards" ("NSPS"), which are applicable to any new discharge source which commences construction after the publication of a proposed new source performance standard. EPA has adopted BPT, BAT, and NSPS discharge limits for ore mining and dressing and coal mine operations. To date, EPA has adopted only BPT limitations for the mineral mining and processing category.

New dischargers for which new source performance standards have not been adopted are subject to the applicable BPT and BAT effluent limitations. For those discharges for which BPT and BAT have not been adopted by EPA, the permitting authority will set the BPT and BAT effluent limitations on a case-by-case basis based on engineering judgment and specified criteria.

BPT effluent limitations are intended to reflect the average of the discharges achieved by the best existing mines of various ages, sizes, processes, and other common characteristics of mines of the particular type. The Act required EPA to consider the cost of the technology in relation to the effluent reduction benefits, the age of the equipment and facilities involved, the process employed, and non-water quality environmental impacts (such as energy requirements) in setting BPT.

BAT is supposed to represent the best existing performance of mining discharges in the relevant category. EPA is required to consider only the cost of achieving effluent reduction in setting BAT. In many instances, BAT is more stringent than BPT.

New source performance standards are intended to be based on the "best available demonstrated control technology, processes, operating methods, or other alternatives." The assumption underlying new source performance standards is that new sources have a greater ability to incorporate the best available processing and waste water treatment technology than do existing sources.

Dischargers may also qualify for a variance from the foregoing technology-based effluent limitations. A "fundamentally different factors" variance from the BPT and BAT limitations is available for facilities that are fundamentally different from the assumptions that EPA relied upon to set the effluent limitations. An applicant for such a variance must show that it raised the fundamentally different factors during EPA's adoption of the applicable effluent limitations or why it did not have a reasonable opportunity to raise such factors. Several other variances to BAT are available under specified circumstances.

### 3.4.3.4 Water Quality Standards

The CWA authorizes the states to adopt "water quality standards" for stream segments, lakes, reservoirs and other water bodies. These are standards designed to protect the uses and ambient quality of the waters to which they apply.

The first step in adopting water quality standards is normally to designate water uses to be achieved or protected for each stream segment or water body. Typical designated uses are public water supplies, protection of fish, shellfish, and wildlife, recreation in and on the water, agricultural, industrial, and navigation. The designated uses must include existing uses and the Act's goals of fishable, swimmable waters, if not already achieved. For example, a stream segment that currently supports a thriving bass population and is used for boating and swimming may be designated for "aquatic life" and "recreation" uses.

The next step is to set numeric concentrations of pollutants for the stream segment which will protect the designated uses. EPA has adopted water quality "criteria" guidelines for states in setting the numeric standards. These criteria transform use protection goals into specific numeric criteria.

EPA must review and approve water quality standards adopted by the states. If EPA decides that the state's standards do not meet the Act's criteria, it is authorized to adopt standards for the state.

Discharge limitations in NPDES permits must be set at levels which will protect against exceeding the water quality standards. Mathematical models are used to relate water quality standards to discharge limits. The assumptions used in the modeling may vary from state to state. Critical assumptions relate to the volume of flow of the receiving waters and the background concentrations of the discharged pollutants. The area immediately

surrounding the point of discharge may be considered to be a "mixing zone" in which the water quality standard is not applicable.

Water quality standards may not be exceeded even if their protection requires greater limits on a discharge than required by the technology-based effluent limitations. Effluent limitations derived from water quality standards are likely to set NPDES discharge limits for streams with numerous dischargers, water bodies with stringent water quality standards to prevent degradation or to achieve new uses, and water bodies with limited assimilative capacity because of size or limited inflow of fresh water supplies. No variances are allowed to most water quality standards.

EPA's "anti-degradation policy" prohibits a state from allowing the discharge of pollutants into waters in national and state parks and wildlife refuges, and severely limits the discharge of pollutants into any body of water having existing quality better than necessary to support aquatic life and recreation uses. (*40 C.F.R. § 131.12.*) This policy can lead to extensive waste water treatment by mining operations located in pristine areas.

### 3.4.3.5 The Control of Toxic Pollutants

The initial effort to control toxic pollutants under the Act was in Section 304(e) adopted in 1977. Section 304(e) authorizes EPA to require NPDES permittees to adopt "best management practices" ("BMPs") for plant runoff, spillage or leaks, sludge or waste disposal, and drainage from raw material storage. EPA adopted regulations of a general nature applicable to all dischargers who use, store, handle or discharge any toxic pollutant, including the authority to incorporate best management practices in permits on a case-by-case basis. (*40 C.F.R. Part 125, Subpart K.*) In addition, a permittee must develop and implement a best management practice program which prevents or minimizes the release of toxic pollutants. The program must address a number of ancillary activities, such as materials inventory and compatibility, employee training, visual inspections, preventive maintenance, housekeeping, and security.

The 1987 amendments to the CWA greatly strengthen the control of toxic pollutants. The states were required by Section 304(l) of the Act to identify waters within the state where water quality standards for toxic pollutants were not being met. Where the failure to meet the water quality standards was due primarily to point source discharges, the states were required to develop individual control strategies for those point sources to achieve compliance with the water quality standards. This program appears to have been implemented on schedule.

The Act was also revised in 1987 to require the states to adopt water quality standards for toxic pollutants if they have not already done so. (Section 303(c)(2)(B).) Many states have since adopted additional toxic criteria or adopted toxic criteria for the first time. Nevertheless, EPA in December 1992 promulgated criteria for toxic pollutants for 14 states.

If numeric water quality standards for toxic pollutants are unavailable, the states must set standards based on biological monitoring methods. EPA has issued guidance for biological monitoring. (*54 Fed. Reg. § 50216 (Dec. 4, 1989).*) The concept of biological monitoring is to test the toxicity of a discharger's "whole effluent" on specified aquatic species at various levels of dilution. The results of the test may be used to set permit discharge limits. Alternatively, an NPDES permit may impose whole effluent testing of this type at specified intervals (*e.g.*, monthly), and if toxicity is found, may require steps to identify and abate the source of the toxicity. Most states and EPA regions are implementing various approaches to biological monitoring.

### 3.4.3.6 Self-Monitoring Requirements

NPDES permits impose substantial monitoring, record keeping, and reporting requirements on permittees. Monitoring is generally required at the point of discharge unless infeasible. At a minimum, monitoring is required to determine compliance with permit conditions setting amounts and concentrations of pollutants and volume of effluent discharged. Monitoring of internal waste streams may only be required in limited circumstances, such as where the final discharge point is inaccessible or where monitoring at the point of discharge causes analytical interference.

The NPDES permit specifies maintenance and proper installation of the monitoring equipment, monitoring methods, frequency of sampling, and the laboratory analytical methodology. The results of this self-monitoring will be the basis for enforcement actions by permitting agencies and citizens groups, so careful consideration should be given to selecting the most appropriate monitoring equipment and procedures. In an enforcement action alleging violations of discharge limitations based on the permittee's self-monitoring results, it may be difficult to contend that the equipment or procedures were faulty.

Mining dischargers must notify the permitting agency as soon as they know of the discharge of toxic pollutants not addressed in the permit which will exceed discharge levels specified in EPA's regulations. Any noncompliance with the NPDES permit which will endanger health or the environment must be reported orally within 24 hours and in writing within five days.

Monitoring records must be maintained for a minimum period of three years. The monitoring results must be submitted periodically to the permitting authority as provided in the permit.

### 3.4.3.7 Enforcement and Citizen Suits

EPA may bring a civil lawsuit or issue an administrative

order against any person in violation of the Act, the implementing regulations, or NPDES permit conditions. EPA may also give the state the option of bringing an enforcement action by notifying the state and discharger that it will take enforcement action if the state does not do so in 30 days.

In a civil lawsuit, EPA may seek civil penalties of up to $25,000 per day of violation. EPA may also assess civil penalties by issuing an administrative order. When EPA issues an administrative order for penalties that do not exceed $10,000 per violation nor $25,000 total (regardless of the number of days of violation or the number of violations), the discharger is allowed only an informal hearing at which evidence may be presented. If the total of the administrative penalties is between $10,000 and $125,000, the discharger has a right to a formal evidentiary hearing.

The Act also creates a wide range of potential criminal violations. Negligent violations are subject to criminal penalties of between $2,500 and $25,000 per day of violation and imprisonment of up to one year. Knowing violations are subject to penalties of not less than $5,000 per day and imprisonment of up to three years. Knowingly making false statements or tampering with monitoring devices is punishable by up to a $10,000 fine and imprisonment of up to two years. Violations by persons who knowingly place another person in imminent danger of death or serious bodily injury are punishable by fines of not more than $250,000 ($1,000,000 for organizations) or imprisonment for not more than two years, or both.

The trend in recent years has been to bring criminal charges for violations of the Act, including against responsible corporate officers. The threat of criminal enforcement reinforces the need for diligence in compliance with the Act's requirements.

State enforcement programs are generally patterned after EPA's and are subject to certain minimum requirements. For example, states must be able to seek court injunctions restraining violations of the Act's requirements and permit conditions and be able to recover at least $5,000 per day in civil penalties and $10,000 per day in criminal fines.

To supplement the government agencies' enforcement authorities, the Act provides for citizen suits. Any person having an interest which is adversely affected may bring a civil action against a discharger for violation of an effluent limitation or other requirement of the Act. Citizen suits may seek injunctive relief ordering a discharger to comply with applicable NPDES permit conditions and seek civil penalties which are payable to the federal government. Attorneys' fees are payable to the citizen plaintiffs, which has encouraged the bringing of such suits.

Typically, a citizen suit is brought based on a discharger's own discharge monitoring reports showing the violations of effluent limitations. Such suits cannot be maintained for past violations but only for violations that are continuing or intermittent. (*Gwaltney v. Chesapeake Bay Foundation*, 484 U.S. 49 (1987).) Prior to bringing a citizen suit, the citizen must give 60 days notice to the discharger, the EPA, and to the state. A citizen suit may not be filed if EPA or a state is diligently prosecuting an action concerning the violation.

#### 3.4.3.8 Storm Water NPDES Permits

NPDES permits for storm water discharges associated with industrial activity are required by the 1987 amendments to the Act. (*40 C.F.R. § 122.26.*) "Storm water discharge associated with industrial activity" means the discharge from any conveyance which is used for collecting and conveying storm water and which is directly related to manufacturing, processing or raw materials storage areas at an industrial plant. Active and inactive mining operations that do not already have NPDES permits for their storm water discharges must obtain an NPDES permit for storm water discharges.

An exception to the permit requirement is made for storm water runoff from mining operations composed entirely of flows which are from conveyances or systems of conveyances (including but not limited to pipes, conduits, ditches, and channels) used for collecting and conveying precipitation runoff and which are not contaminated by contact with or that has not come into contact with, any overburden, raw material, intermediate products, finished product, byproduct or waste products located on the site of such operations. Also, no permit is required for discharges to a municipal sanitary system or a combined storm sewer/sanitary sewer system.

Although the states have some flexibility in the procedures for implementing this program, EPA has established three types of permits for industrial activities: 1) individual permit applications; 2) group applications; and 3) general permits. Group applications would be done in two parts. Part one is a group application by facilities from the same effluent guideline subcategory establishing the similar characteristics of the group members. Part two would require at least 10% of the group to submit detailed quantitative data about discharges.

General permit requirements to be adopted by EPA (and already adopted by some states, such as California) would impose conditions applicable to all industrial dischargers or specified subgroups without requiring detailed permit approval procedures.

An individual permit application is the most burdensome as it requires extensive quantitative data, based on samples of storm water discharges from all storm water out falls associated with the industrial activity.

### 3.4.4 DREDGE AND FILL MATERIAL PERMIT PROGRAM/WETLANDS

#### 3.4.4.1 Agency Jurisdiction

The responsibility for issuing dredge and fill material permits under Section 404 of the Act ("404 Permit") is

shared among the U.S. Army Corps of Engineers ("Corps"), EPA, and the states. The Corps has the primary responsibility to review the permit application and to grant or deny the permit. In deciding to grant or deny the permit, the Corps applies its own regulations (*33 C.F.R. Parts 320-330*), as well as mandatory guidelines promulgated by EPA pursuant to Section 404(b)(1) of the Act (the "404(b)(1) Guidelines" published at *40 C.F.R. Part 230*).

In the event of a disagreement between the Corps and EPA as to whether a dredge or fill activity is within "waters of the United States" subject to a Section 404 Permit, EPA has authority to make the final decision. (*Memorandum of Agreement Between the Department of the Army and the Environmental Protection Agency Concerning the Determination of the Geographic Jurisdiction of the Section 404 Program and the Application of the Exemptions under Section 404(f) of the CWA* (January 19, 1989).) Section 404(c) authorizes EPA to prohibit or restrict a proposed discharge and, in effect, to veto a 404 Permit proposed to be issued by the Corps. Although states may be delegated the authority to issue 404 Permits, only two states (Michigan and New Jersey) have received such delegations. Under Section 401 of the Act, a 404 Permit may not issue unless the state in which the discharge will originate certifies that the proposed discharge will not result in the violation of applicable state water quality standards.

### 3.4.4.2 Scope and Purpose of the Program and Its Technical Politicization

The Act prohibits all discharges of dredge and fill material into navigable waters unless authorized by a 404 Permit. "Discharge of dredge and fill material" is defined to include the addition of any material that has been excavated or dredge from a regulated water body and any material used to replace an aquatic area with dry land or of changing the bottom elevation of a water body. Activities that may come within this definition include any mill or mine site development in streams or wetlands, such as the construction of roads or tailings impoundments.

"Navigable waters" has been broadly defined to include most surface waters and wetlands. The United States Supreme Court has affirmed that 404 Permits can be required for wetlands. (*United States v. Riverside Bayview Homes*, Inc., 474 U.S. 121 (1985).)

In recent years, the issue of how to characterize a wetland subject to Section 404 has become controversial and politicized. The issue of the extent to which wetlands should be protected from development results from their ecological significance, including habitat functions which wetlands provide for migratory birds and other plants and wildlife. The controversy intensified with the adoption in February 1989 of the "Federal Manual for Identifying and Delineating Jurisdictional Wetlands" by EPA, the Corps, the U.S. Fish and Wildlife Service, and the Soil Conservation Service ("1989 Manual") replacing the Corps 1987 Manual ("1987 Manual"). Some parties contended that the 1989 Manual was too inclusive by, for example, defining wetlands to include areas in which the water level rose to 18 inches below the surface for a minimum of seven consecutive days during the growing season. In response, in August 1991 a federal task force released proposed revisions to the 1989 Manual (referred to as the "proposed 1991 Federal Manual"), which was opposed by other parties as proposing a too narrow view of those wetlands deserving protection. Congressional legislation in 1991 ordered the Corps to stop using the 1989 Manual and to use the 1987 Manual. In 1992, Congress commissioned a study of the wetland delineation issue but no further action has occurred at the federal level. In the meantime, state and local governments have taken different approaches to using the 1987 Manual and the 1989 Manual. Given the millions of acres of wetlands at stake, this promises to be a continuing political issue.

### 3.4.4.3 Permit Requirements and Mitigation

Two types of permits have been established: individual permits and general or "nationwide" permits. The nationwide permits apply to types of activities that cause only minimal adverse environmental effects and minimal cumulative adverse effects. Activities qualifying for a nationwide permit must follow specified best management practices and are not required to submit permit applications, although notification of the Corps may be required. For example, surface coal mining activities qualify for a nationwide permit if they have received a surface mining permit from the U.S. Office of Surface Mining or an approved state. Some states have denied or imposed conditions on use of the surface coal mining permits pursuant to state authority to issue water quality certifications under Section 401 of the Act and state authority to issue consistency determinations under Section 307 of the Coastal Zone Management Act. The list of activities qualifying for nationwide permits should be examined prior to applying for a Section 404 Permit for a mining-related dredge or fill operation. Nationwide permits are valid only for five years from the initial date of promulgation by the Corps and ongoing mining operations may need to reestablish coverage upon reissuance by the Corps.

Dredge and fill activities above the headwaters or in waters that are not part of a surface tributary system connecting to interstate waters or traditionally navigable waters qualify for a nationwide permit. "Headwaters" is defined as that point on a stream above which the average annual flow is less than 5 cu ft/sec. This nationwide permit applies only if the activity will not adversely modify ten acres or more of wetlands. If between one and ten acres will be adversely modified or lost, the Corps must be notified and has discretion to require an individual permit. Some

states have further limited use of this nationwide permit through denial or imposition of conditions on water quality certification under Section 401 of the Act.

The criteria for issuance of an individual permit give considerable discretion to the Corps and EPA in setting conditions or in denying the permit. The 404(b)(1) Guidelines require the Corps to consider whether there are practicable alternatives which would have less adverse impact on the aquatic ecosystem. If "practicable" alternatives exist which do not involve dredging or filling a wetland or other waters of the United States, the Corps will deny the permit. Inevitably, this raises the issue of which alternatives are practicable. For example, courts have held that in some circumstances sites not owned by the applicant must be considered as practicable alternatives. (*Bersani v. EPA*, 850 F.2d 36 (2d Cir. 1988).)

The 404(b)(1) Guidelines further require permit conditions to mitigate potential adverse impacts. Mitigation may include changing the location of the discharge, controlling the material discharged, and steps to protect plants, animals, and human uses. In a Memorandum of Agreement ("MOA") entered into between the Corps and EPA in February 1990 concerning mitigation, the priority for mitigation was stated to be: (1) avoidance (through the use of practicable alternatives); (2) minimization (through the imposition of mitigation measures); and (3) compensation by the creation of new wetlands to replace lost wetlands. The latter policy is referred to as the "no net loss" policy. The MOA provides that the replacement wetlands should provide at least the equivalent value and function of the lost wetland, which requires a minimum of a one for one acreage replacement.

The Corps also conducts a "public interest review" which weighs, among other factors, "the needs and welfare of the people." The Corps may impose any conditions necessary to protect the public interest.

#### 3.4.4.4 Exemptions from the 404 Permit Requirement

The Act creates several exemptions from the 404 Permit requirement that may be applicable to mining operations. Construction or maintenance of temporary roads for moving mining equipment is exempt if best management practices intended to minimize adverse effects on the aquatic environment are followed. Maintenance, including emergency reconstruction of recently damaged parts of currently serviceable structures, such as dikes and dams, is exempt. Construction of temporary sedimentation basins on a construction site, which does not require placement of fill material into the navigable waters, is also exempt. "Construction" site is defined to include quarrying and mining activities. (The foregoing exemptions are inapplicable in certain limited circumstances.)

#### 3.4.4.5 Enforcement

EPA has the same enforcement authority for failure to obtain a Section 404 Permit as for failure to obtain an NPDES Permit. Likewise, the same criminal penalties apply to dischargers who fail to obtain 404 Permits or who are in noncompliance with the permit conditions.

The Corps has separate authority to issue orders requiring compliance with 404 Permit conditions or may file civil lawsuits seeking penalties of up to $25,000 per day per violation and restoration of areas that have been dredge and filled without a permit or in violation of permit conditions. Finally, the Corps has authority identical to EPA's to assess civil penalties administratively.

## 3.5 THE COMPREHENSIVE ENVIRONMENTAL RESPONSE, COMPENSATION, AND LIABILITY ACT

**by J. Cowan**

### 3.5.1 INTRODUCTION

By 1976, Congress had enacted most of the modern environmental statutes. The Clean Air, the Clean Water, and the Safe Drinking Water Acts were already in place to protect air, surface water, and drinking water. The Resource Conservation and Recovery Act had been enacted to regulate the present and future treatment, storage, and disposal of hazardous waste. But the discovery of widespread contamination at Love Canal and in other parts of the country convinced Congress that yet another statute was necessary, one which would address cleanup of the past disposal of hazardous substances, and pollutants and contaminants. In 1980, Congress enacted the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA") to deal with this problem.

CERCLA was enacted with two broad goals: first, to rapidly and permanently clean up polluted sites, and, second, to allocate the associated costs widely to the parties responsible for the pollution. To reach these goals, Congress drafted CERCLA to be an adversarial, "litigation" statute, rather than a regulatory statute. CERCLA is found at *42 U.S.C. § 9601 et seq.*, and was amended extensively in 1986 by the Superfund Amendments and Reauthorization Act ("SARA"). (Formal citations to CERCLA and its regulations are not extensively used in this chapter, but language has been borrowed liberally from each in the text below.)

CERCLA is also referred to as "Superfund." The latter is the name of the government account created by the statute to finance the cleanup of sites where private parties cannot be found to pay for the cleanup. The Superfund is funded primarily by a tax on chemical manufacturers. CERCLA is an expensive program: Congress appropriated

$1.6 billion to the Superfund when CERCLA was enacted in 1980, and $8.6 billion when CERCLA was amended by SARA in 1986.

The statute is very broad and can be applied generally, to active and inactive mining facilities, for example. Nevertheless, the sites to which CERCLA addresses itself principally can be described as "uncontrolled landfills," where pollutants were disposed of by placement on the ground. The primary concerns here are migration of pollutants to groundwater and soil contamination. Accordingly, CERCLA requires an analytical process designed to characterize pollutants, track migration, and treat pollutants to eliminate the threat to human health or the environment.

The regulations that guide EPA's procedural response to CERCLA sites are complicated and confusing, but an understanding of that process is essential for the parties involved. That understanding is necessary for the CERCLA respondent to maintain some control over the response, and to challenge unauthorized expenses when EPA, state, or private parties sue the responsible parties to recover cleanup costs.

An understanding of CERCLA is critically important to the mining community because of the enormous costs involved with site cleanups. In 1990, for example, an EPA official testified to a congressional committee that the average construction cost per site had increased to $29 million, exclusive of the large enforcement costs and other transaction costs related to the sites. (*See* the case study of the Iron Mountain site in California, which appears in Chapter 18 of this Handbook.)

## 3.5.2 TYPICAL CERCLA MINING PROBLEMS

Many mining activities have caused releases of hazardous substances into the environment that are sufficient to trigger CERCLA jurisdiction. Examples include acid mine drainage, releases of hazardous substances from tailings, soil contamination, and leakage or disposal of polychlorinated biphenyls ("PCBs") from transformers and other electrical equipment.

Acid mine drainage is common, of course, and has caused several sites to be placed on CERCLA's National Priorities List ("NPL") of cleanup sites. The problem with acid mine water is twofold: low pH, and dissolved metals. The acid water and the dissolved metals it contains are primarily responsible for killing plant and animal life in the upper reach of the receiving stream, and the metals that precipitate as the pH of the discharge eventually increases can be responsible for environmental damage to sediments further downstream and can add to metals content in fish flesh.

Tailings may contain a variety of hazardous substances (such as, for example, lead or arsenic). CERCLA jurisdiction is triggered by the possibility of exposure to human, animal, or plant populations when these materials are placed in the environment through wind or water erosion, or direct contact.

Soil contamination comes from a variety of sources, including improper disposal of hazardous substances, wind deposition, metals contamination from disposal of acid mine water or process water, and the like. The risks of soil contamination are compounded when the site is near a city or town, because contaminated soils (and tailings) have sometimes been used as fill in connection with building and road construction, and the fill must be included in the cleanup.

PCBs were historically used as cooling and dielectric fluid in oil-filled transformers and condensers. Such equipment is common at electrical storage areas at older mining sites, and is prone to leak with age. Also, transformers were sometimes drained at the site, and the PCB contaminated oil used for dust suppression or disposed of with other oil.

Some examples of releases of hazardous substances from mining operations that have triggered CERCLA action include:

1. Lead contaminated tailings
   (Smuggler Mountain, Aspen, Colo.)

2. Acid mine water drainage into surface stream
   (California Gulch, Leadville, Colo.)

3. Uranium tailings
   (Uravan, Colo.)

4. Chromium mill tailings
   (Moat Industries, Columbus County, Mont.)

## 3.5.3 BRIEF SUMMARY OF THE STATUTORY SCHEME

### 3.5.3.1 Jurisdiction

CERCLA liability arises when there is a release or threat of release into the environment of any hazardous substance, or the release or threat of release into the environment of any pollutant or contaminant which may present an imminent and substantial danger to the public health or welfare. The actions then authorized by the statute are removal actions which are short term, partial cleanups, remedial actions, which are permanent, remedies, or any other response measure consistent with CERCLA regulations set out in *40 C.F.R. Part 300*, which are referred to as the National Contingency Plan.

CERCLA then gives EPA, states, and private parties broad authority to deal with sites that pose a hazard to human health or welfare. In order to describe the breadth of this authority, a number of terms must be defined:

- A *release* is broadly defined as any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment (including the abandonment or discarding of barrels, containers and other closed receptacles containing any hazardous substance or pollutant or contaminant). (*42 U.S.C. § 9601(22).*)
- A *hazardous substance* is generally any of the substances listed in *40 C.F.R. Table 302.4.* This is a list of more than seven hundred substances, including metals, solvents and other materials. The universe of hazardous substances also includes all hazardous wastes which fail the characteristic and other tests under the Resource Conservation and Recovery Act.
- *Petroleum exclusion.* The term "hazardous substance" does not include petroleum, including crude oil or any fraction thereof, which is not otherwise specifically listed or designated as a hazardous substance (for example, benzene). Natural gas, natural gas liquids, liquefied natural gas, and synthetic gas used for fuel (or mixtures of natural gas and such synthetic gas) are specifically excluded from the definition of hazardous substance. (*42 U.S.C. § 9601(14).*)
- A *facility* is any building, structure, installation, equipment, pipe or pipeline, well, pit, pond, lagoon, impoundment, ditch, landfill, storage container, motor vehicle, rolling stock, or aircraft, or any site or area where a hazardous substance has been deposited, stored, disposed of, or placed, or otherwise come to be located. (*42 U.S.C. § 9601(9).*)
- *Pollutant* or *contaminant* means any substance which after release into the environment and upon exposure to any organism in any manner will, or may reasonably be anticipated to cause death, disease, behavioral abnormalities, cancer, genetic mutation, physiological malfunctions, or physical deformation, in such organisms or their offspring; except that the term pollutant or contaminant does not include substances included within the petroleum exclusion. (*42 U.S.C. § 9601(33).*)
- A *response action* is generally a cleanup action under CERCLA. It may be comprised of a short term, abbreviated cleanup, called a "removal action." It may also be a permanent, long-term cleanup, called a "remedial action."
- The *national priorities list* is the list of sites with the most urgent requirement for remedial action. While not of great legal significance, placement on the national priorities list is of practical importance. Listing means that EPA will target the site for permanent cleanup.
- The *Hazard Ranking System* ("HRS") is the principal mechanism used by the EPA to place sites on the national priorities list. The hazard ranking system is a screening device to evaluate the potential for releases of hazardous substances to cause human health or environmental damage.

### 3.5.3.2 Types of Liability and Cleanup Alternatives

One of CERCLA's primary purposes is to compel the parties who are responsible for the release of hazardous substances to pay for the cleanup. The statutory mechanism establishes four categories of potentially responsible parties (usually referred to in jargon as "PRPs") in an instance where statutory liability is triggered otherwise:

- The current owner or operator of a facility from which there is a release, or threat of release of a hazardous substance which causes the incurrence of response costs;
- Any person (often referred to as a "former owner or operator") who, at the time of disposal of any hazardous substance, owned or operated any facility at which such hazardous substance were released;
- Any person (often referred to informally as a "generator") who arranged for disposal or treatment or arranged with a transporter for disposal of a hazardous substance that comes to be located at a facility from which there is a release;
- Any person (often referred to as a "transporter") who accepted any hazardous substance for transport to disposal or treatment facilities or sites selected by such person, from which there is a release.

These four groups of liable parties often overlap at a CERCLA site, meaning that one person can be liable in several categories. The breadth of these classes also means that several parties usually are responsible for the same site. The expense of cleanup and other damages ultimately is shared among these parties.

Liability under CERCLA is "strict." Strict liability is liability without proof of fault. Thus, in order to prevail, EPA (or any other party seeking to recover response costs) need only prove that a potentially responsible party disposed of a hazardous substance at a facility from which there was a release. No evidence of wrongdoing is required, and, significantly, it is not a defense to CERCLA liability that the disposal was legal when it occurred.

"Joint and several" liability means that any individual potentially responsible party is liable in the first instance for the entire cost of cleanup. EPA is generally not required to allocate the cleanup cost among several potentially responsible parties; it is authorized to proceed against a single potentially responsible party, who may then sue the remaining potentially responsible parties for their respective shares of the cleanup costs. It is up to the responsible parties, in later proceedings, to allocate liability.

The courts have expanded CERCLA liability by broadly interpreting the language of the statute. Thus, as described, the legal thresholds for liability are very low. In addition,

defenses to liability are virtually nonexistent. Settlement is thus a prudent alternative for potentially responsible parties, and CERCLA provides a mechanism to facilitate settlement without litigation.

EPA initiates the settlement process by mailing a "special notice" letter to the potentially responsible parties. CERCLA provides that the issuance of special notice triggers a moratorium during which EPA may not commence a response action, study, or an enforcement action, pending the outcome of settlement negotiations. Settlement will result in an administrative order on consent that sets out the terms of settlement, as well as a provision for payment of monetary penalties if the potentially responsible parties in the settlement fail to perform. Settlement also protects the settling parties from suits by other potentially responsible parties at the site.

EPA has authority to conduct remedial activities in three ways: by doing the work at its own expense and recovering its costs from the potentially responsible parties, by ordering one or more potentially responsible parties to finance the remedial action, or by settling with one or more of the potentially responsible parties as described above.

### 3.5.3.3 The Parties: Government Plaintiffs and Private Plaintiffs

CERCLA authorizes activities (and cost recovery litigation) by both public and private entities, but imposes more restrictions on the ability of private parties to recover their response costs. The EPA, a state, or an Indian tribe is allowed to recover all costs of removal or remedial action incurred which are "not inconsistent with the National Contingency Plan." Anyone other than the EPA, a state, or an Indian tribe is allowed to recover any other necessary costs of response which are "consistent with the National Contingency Plan."

The phrase "not inconsistent with" affords to EPA, state, and tribal plaintiffs an enormous advantage in a cost recovery action against a potentially responsible party. In order to successfully challenge the validity of a particular cost or action, the potentially responsible party defendant must prove that the cost or action contradicts a provision of the national contingency plan. Conversely with respect to cost recovery actions by private parties, it is much more difficult for a plaintiff to prevail. The potentially responsible party plaintiff in a private cost recovery action must prove that its actions meet the dictates of the national contingency plan.

### 3.5.3.4 The National Contingency Plan and the CERCLA Process

The heart of CERCLA is the national contingency plan. The stated purpose of the national contingency plan (*40 C.F.R. Part 300*) is "to provide the organizational structure and procedures for preparing for and responding to . . . releases of hazardous substances, pollutants, and contaminants." (*40 C.F.R. 300.1.*) The following is a summary of the portions of the national contingency plan that address releases of hazardous substances.

CERCLA generally authorizes the federal government, through EPA, to undertake a response action when there is a release of a hazardous substance into the environment or when there is a release into the environment of a pollutant or contaminant that may present an imminent and substantial danger to the public health or welfare. But, unless an emergency exists, EPA will not respond to the following releases: 1) a release of a naturally occurring substance in its unaltered state due to the actions of nature; 2) a release of asbestos or other building materials that occurs inside a building; or 3) a release of asbestos or other substances into a public drinking water supply due to deterioration of the system through ordinary use. (Section 104(a).)

Response actions usually involve construction activity that would normally require federal, state, or local permits. Such permits are not required when the response action is conducted on-site. An on-site remedy is one that is confined, or in very close proximity, to the area contaminated by the release. This no-permit-required rule also applies to the provisions of the National Environmental Policy Act regarding environmental impact statements.

Upon discovery of a release, a decision must be made regarding the urgency for remedial action. If an emergency exists, an emergency removal action may be authorized. In the absence of an emergency, the more usual circumstance, a more detailed study of the site is conducted.

The decision to conduct a removal action, or short term, partial cleanup, is based on a removal site evaluation (*40 C.F.R. § 300.410*), which includes a removal preliminary assessment and, if necessary, a removal site inspection. A removal preliminary assessment generally includes: 1) identification of the source and nature of the release or threat of release; 2) evaluation of the threat to public health; 3) evaluation of the magnitude of the threat; 4) evaluation of the factors necessary to make the determination of whether a removal is necessary; and 5) determination of whether a private party is undertaking proper response. Following the removal site evaluation, a removal site inspection may be conducted if more information is needed.

The final decision to conduct a removal action is based on the following criteria: 1) actual or potential exposure to nearby human populations, animals, or the food chain from hazardous substances or pollutants or contaminants; 2) actual or potential contamination of drinking water supplies or sensitive ecosystems; 3) hazardous substances or pollutants or contaminants in drums, barrels, tanks, or other bulk storage containers, that may pose a threat of release; 4) high levels of hazardous substances or pollutants

or contaminants in soils largely at or near the surface, that may migrate; 5) weather conditions that may cause hazardous substances or pollutants or contaminants to migrate or be released; 6) threat of fire or explosion; 7) the availability of other appropriate federal or state response mechanisms to respond to the release; 8) other situations or factors that may pose threats to public health or welfare or the environment. If appropriate, the removal action is commenced as soon as possible to eliminate the threat posed by the release.

If planning for a removal action will take six months, EPA is required to conduct an engineering evaluation/cost analysis ("EE/CA") prior to beginning a removal action. An EE/CA is an analysis of removal action alternatives.

Removal actions that are financed by the Superfund must generally be terminated after two million dollars has been spent or twelve months have elapsed from the time that removal activities begin, unless EPA determines that: 1) the immediate threat to public health or welfare or the environment still exists, and response action must continue in order to mitigate the emergency; or 2) continued response action is otherwise appropriate and consistent with the remedial action to be taken. Removal actions consist of activities such as: 1) fences, warning signs, or other site security to exclude people or animals; 2) drainage controls to reduce migration caused by run-on or run-off; 3) stabilization of berms, dikes, or impoundments to maintain the integrity of the structures; 4) capping of contaminated soils or sludges to reduce migration; 5) use of chemicals or other methods to retard the migration of contaminants; 6) excavation, consolidation, or removal of highly contaminated soils from drainage or other areas in order to reduce the migration of contaminants; 7) removal of drums, barrels, tanks, or other bulk containers in order to reduce the likelihood of spillage or explosion; 8) containment, treatment, disposal or incineration of contaminants in order to reduce the threat to human health or the environment; 9) provision of an alternate water supply if the primary supply is contaminated; 10) temporary relocation of persons as necessary to protect public health or welfare.

Many sites that require remedial action, or long term permanent cleanup, do not pose an immediate threat to human health or welfare, so a removal action is inappropriate. In such cases, the national contingency plan requires the remedial action to follow a more analytical, and much more lengthy, approach, as set forth below. Remedial actions can take more than ten years to complete.

EPA maintains a computer data base consisting of all sites where releases are suspected to have occurred. This data base, called the Comprehensive Environmental Response, Compensation, and Liability Information System ("CERCLIS"), identifies each site in a particular state, together with the current status of the site in the CERCLA process. Anyone seeking information about the environmental condition of a site should refer to the current CERCLIS list for the state where the site is located.

After a site has been placed on the CERCLIS list, an investigation is begun by conducting a preliminary assessment ("PA"). A preliminary assessment consists of a review of existing information about a release, such as pathways of exposure, exposure targets, and source and nature of the release. If the preliminary assessment indicates that further action is necessary, EPA will conduct a site inspection ("SI").

The purposes of a site inspection are 1) to eliminate from further consideration those releases that pose no significant threat; 2) to determine the need for removal action; 3) to collect additional data, as appropriate, to evaluate the release under the hazard ranking system; and 4) to collect such additional data as are necessary to facilitate the remedial investigation/feasibility study ("RI/FS").

The site inspection is the first point in the remedial action process where field samples are collected. Since the results of analysis of samples are critically important to the remedial action process, great care is required in sample collection and in laboratory procedure. Hence, prior to conducting field sampling, EPA develops a sampling and analysis plan that consists of; (1) a field sampling plan describing the number, type, and location of samples, and the type of analysis; and (2) a quality assurance project plan ("QAPP") that describes policy, organization, and functional activities, and the data quality objectives and measures necessary to achieve adequate data for site evaluation and hazard ranking.

At the conclusion of the site investigation, EPA prepares a site investigation report that identifies the contaminants known to be located at the site, the population at risk, and a recommendation as to whether further remedial action is required. Remedial action priorities are established by evaluating the eligibility of a site for placement on the national priorities list.

The national priorities list is the list of sites which EPA believes pose the greatest threat to human health or the environment. Sites qualify for listing by achieving a high score in the hazard ranking system. Only those sites listed on the national priorities list are eligible for Superfund financing (but removal actions up to two million dollars are authorized before a site is placed on the national priorities list). The inclusion of a site on the national priorities list does not guarantee that Superfund money will be spent there, but, as a practical matter, EPA focuses most of its attention upon these sites.

If the site investigation report recommends further remedial action at a site, a remedial investigation/feasibility study will likely be required. The purposes of a remedial investigation and feasibility study are to assess site conditions and evaluate alternatives to the extent necessary to select a remedy. A remedial investigation and feasibility study usually includes the following activities: 1) project scoping; 2) data collection; 3) risk assessment; 4) treatability studies, and analysis of remedial alternatives.

Project "scoping" sets the initial tone for the remedial

investigation and feasibility study and consists of the following tasks: 1) assembly and evaluation of existing data, with an emphasis on its quality and adequacy; 2) identification of discrete areas, known as operable units, that can be dealt with separately; 3) identification of the type, quality, and quantity of data required to support decisions regarding the remedial action; 4) preparation of a site health and safety plan ("HASP") that sets out specific safety requirements for all areas within the site; 5) development of a sampling and analysis plan ("SAP") which consists of the field sampling plan, as well as the quality assurance project plan, which describes data quality objectives and measures necessary to achieve adequate data for use in selecting the appropriate remedy; 6) initial identification of the cleanup standards, which are referred to as applicable or relevant and appropriate requirements ("ARARs"). Upon approval of the scoping document, the remedial investigation is commenced.

The purpose of the remedial investigation is to collect data necessary to adequately characterize the site for the purpose of developing and evaluating effective remedial alternatives. The process consists of a field investigation, treatability studies as appropriate, and a baseline risk assessment. The remedial investigation provides information necessary to assess risks to human health and the environment, and to support the development, evaluation, and selection of appropriate response alternatives. A complete remedial investigation should contain the following: 1) a physical description of the site, including surface features, soils, geology, hydrology, meteorology, and ecology; 2) characteristics of air, surface water, and ground water; 3) a waste characterization, including quantities, physical state, concentration, toxicity, tendency to bioaccumulate, persistence in the environment, and mobility; 4) identification and characterization of the source of the release (for example, a tailings pond might be the source of the release of acid process water); 5) actual and potential exposure pathways through air, water, or other environmental media; 6) actual and potential exposure routes such as ingestion or inhalation; 7) other factors that pertain to the site characterization or support the analysis of potential remedial action alternatives. A complete remedial investigation should enable EPA to select an appropriate remedy.

Selection of a remedy is based on the feasibility study. The purpose of a feasibility study is to ensure that appropriate remedial alternatives are developed and evaluated so that relevant information concerning the remedial action options can be presented to a decision maker and an appropriate remedy selected.(*40 C.F.R. § 300.430(e)(1)*) The feasibility study thus identifies several remedial action options, then analyzes each option using the following criteria: 1) short and long term protection of human health and the environment; 2) compliance with applicable and relevant and appropriate requirements (see the discussion of applicable and relevant and appropriate requirements elsewhere in this section); 3) long term effectiveness and permanence of the remedy; 4) reduction of toxicity, mobility, or volume through treatment; 5) short term effectiveness; 6) implementability; 7) cost; 8) state acceptance; and 9) community acceptance. (*40 C.F.R. 300.430(e)(9)(iii)*.) The remedy selection is made in a document called a record of decision ("ROD").

The record of decision is described by EPA as the "legal document that . . . demonstrates that the lead and support agency decision making has been carried out in accordance with statutory and regulatory requirements and that explains the rationale by which remedies were selected." (*55 Fed. Reg. § 8731.*) Following the record of decision, the remedy is implemented through a remedial design/remedial action ("RD/RA").

Remedial design and remedial action include the development of the actual design of the selected remedy and implementation of the remedy through construction. An operation and maintenance period may follow the remedial action.

### 3.5.3.5 Cleanup Standards

CERCLA requires that remedial actions "attain a degree of cleanup...which assures protection of human health and the environment." (*42 U.S.C. § 9621(d).*) Cleanup standards established to accomplish this mandate can either be "applicable or relevant and appropriate requirements" or action levels based upon a risk analysis. The choice of cleanup standards is at the heart of the CERCLA process, because it defines how clean the site will be and how much the cleanup will cost.

As the name implies, there are two categories of applicable and relevant and appropriate requirements: applicable, and relevant and appropriate. Applicable requirements are federal or identified state standards, requirements, criteria, or limitations under any environmental law that specifically address the hazardous substances or circumstances at the site. For example, if the remedy at a CERCLA site consists of construction of an on site landfill to dispose of substances that are hazardous wastes under RCRA, the landfill must meet RCRA standards. This category is necessary because permitting and other requirements are not directly used at a CERCLA site.

In order for a federal or state standard, requirement, criteria, or limitation to meet the second criteria, and to be both relevant and appropriate to the circumstances of the release, the standard must meet two criteria: 1) a relevant standard, while not directly applicable, addresses problems sufficiently similar to those existing at the site that their use is well suited to that particular site; and 2) the standard is appropriate in view of the goals and objectives at the site. For example, drinking water quality standards might be relevant to contaminated ground water at a site, but not appropriate because the water will never be used for

drinking.

There are three subcategories of applicable and relevant and appropriate requirements: action specific, chemical specific, and location specific. Action specific applicable and relevant and appropriate requirements are triggered by the remedial action taken, rather than by the type of hazardous substance involved. For example, compliance with the RCRA standards for hazardous waste landfills would be applicable and relevant and appropriate if the remedy specifies land disposal of hazardous substances that qualify as RCRA hazardous waste.

Chemical specific applicable and relevant and appropriate requirements are used when the particular hazardous substance involved is subject to treatment standards or effluent limitations under a statute or regulation. For example, the applicable and relevant and appropriate requirements for the discharge of water from a mine site with lead contaminated soils would be the effluent limitation for lead under the Clean Water Act discharge permit requirements (NPDES permit).

Location specific applicable and relevant and appropriate requirements set out restrictions on remedial actions based on the geographic, cultural, or ecological characteristics of the area where the site is located. For example, the National Historic Preservation Act might be applicable and relevant and appropriate at a mine site located within an historic district.

EPA has the authority to waive applicable and relevant and appropriate requirements at a particular site under any of the following circumstances: 1) the remedial action is an interim remedy that will be followed in time by a permanent remedy that meets applicable and relevant and appropriate requirements; 2) compliance with applicable and relevant and appropriate requirements will result in greater risk to human health and the environment; 3) compliance with applicable and relevant and appropriate requirements is technically unachievable; 4) an equivalent level of protection can be achieved using another method; 5) the state where the site is located is not consistently applying a state applicable and relevant and appropriate requirement under similar circumstances at another site; and 6) in the case of a Superfund financed remedial action, the cost of compliance with applicable and relevant and appropriate requirements would require an inordinate proportion of the fund.

#### 3.5.3.6 Natural Resources Damages

The release of a hazardous substance into the environment may cause injury to natural resources that remains after the cleanup is complete. For example, the release of acid mine drainage from an abandoned mine may kill a wetland into which it drains. A remedial action that treats the mine water will eliminate the source of the contamination, but will not necessarily bring back the wetland. In order to provide for restoration of such damage, CERCLA provides that the responsible parties are liable for damages for injury to, destruction of, or loss of, natural resources, including the reasonable costs of assessing such injury. (*42 U.S.C. § 9607(a)(4)(C).*)

When natural resources damages exist, a natural resources trustee is appointed to act on behalf of the public. In the case of federal land, a federal agency is the trustee; the affected state is trustee over state land. CERCLA requires that sums recovered by the trustee may be used "only to restore, replace, or acquire the equivalent of such natural resources...". (*42 U.S.C. § 9607(f).*)

## 3.6 THE RESOURCE CONSERVATION AND RECOVERY ACT

**by A. Babich**

Congress enacted the Resource Conservation and Recovery Act ("RCRA") in 1976 as an amendment to the Solid Waste Disposal Act. RCRA requires the U.S. Environmental Protection Agency ("EPA") to regulate management of hazardous waste from generation to disposal, *i.e.*, from cradle to grave. Congress has amended RCRA several times, most notably with the Hazardous and Solid Waste Amendments of 1984 (known as "HSWA"). HSWA changed RCRA considerably by adding liability provisions and requirements for cleanup of past contamination that are analogous to provisions of the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA" or "the Superfund Act.") RCRA again is due for amendment and reauthorization.

RCRA contains at least four distinct programs, regulating solid waste (Subtitle D), hazardous waste (Subtitle C), underground storage tanks (Subtitle I), and medical wastes (Subtitle J). This subchapter will focus on Subtitle C (also known as Subchapter III) — the hazardous waste management program.

RCRA is codified at *42 U.S.C. §§ 6901 - 6992k.* The details of RCRA's requirements, however, are found in hundreds of pages of implementing regulations. (*40 C.F.R. Parts 260-270.*) Voluminous *Federal Register* preambles and EPA guidance documents explain and interpret those regulations. Court decisions and EPA Administrative Law Judge decisions provide important precedent concerning interpretation of RCRA.

### 3.6.1 STATE IMPLEMENTATION

Like many federal environmental laws, RCRA allows states to replace EPA as the primary enforcement and permitting authority. Such state implementation of federal law generally is referred to as "cooperative federalism." To obtain authority to implement RCRA, states must enact hazardous waste laws that are consistent with and equivalent to RCRA. This means that substantive state regulations in states with authorized programs generally

will be no less stringent than federal regulations. State regulations may, however, be more stringent than federal law. Most authorized state hazardous waste regulatory programs track EPA's substantive RCRA regulations closely, although procedural and enforcement provisions may vary.

Generally, RCRA does not preempt, or invalidate, state hazardous waste laws. Thus, states need no approval from EPA to regulate hazardous waste, even if state regulation effectively duplicates RCRA. Rather, EPA authorization of a state program has the effect of withdrawing the effectiveness of most federal RCRA regulations in favor of the state's regulations. Since the state and federal RCRA regulations are usually very similar, the practical result of EPA's authorization of a state program is that the state takes the lead on permitting and enforcement. EPA, however, retains authority to step in.

EPA often changes and supplements federal RCRA regulations. Authorized states usually cannot follow suit immediately, but must enact conforming changes in state laws, or promulgate conforming regulations in order for state programs to remain consistent with RCRA. In responding to this lag between EPA and state changes to RCRA regulations, RCRA imposes an extremely confusing twist on the concept of cooperative federalism. It is necessary to understand these provisions, however, for regulated entities such as mining companies to know who implements the regulations that govern various facets of their operations.

For some regulatory changes, authorized states have a grace period to adopt conforming changes and submit those changes to EPA for authorization. In the meantime, the changes simply do not apply in the authorized state. When EPA makes regulatory changes to implement the 1984 RCRA amendments (HSWA), however, those changes take effect immediately in *all* states. EPA implements those regulations, even in states that have authorized programs, until the states obtain EPA approval of conforming changes to their own regulations. Thus, regulated entities often must submit permit applications to *both* EPA and an authorized state. When EPA promulgates a new RCRA regulation, the Agency specifies whether the regulation is effective immediately in authorized states or only upon authorization of a change to the state program. In other words, EPA specifies whether the regulation was promulgated pursuant to HSWA or pursuant to other pre-HSWA provisions of RCRA.

To further complicate this already murky situation, many states enforce their own versions of EPA-implemented RCRA regulations even before EPA authorizes those states' programs. Thus, for example, EPA may have authorized State X to implement the basic RCRA program. Since the date of that authorization, EPA may have added an expanded waste definition (for example, "toxic" waste) to the RCRA regulations pursuant to HSWA. State X may add regulations to its program to regulate toxic waste and may enforce those regulations while awaiting EPA approval. Thus, pending EPA's approval of State X's regulations for toxic waste, State X has primary authority to regulate most RCRA waste within its borders under both federal and state law. EPA has primary authority to regulate toxic waste in State X under federal law. But State X retains authority under state law to regulate toxic waste and the regulated entity must answer to both State X and EPA authority.

In the example presented above, if EPA has added a waste to its regulations pursuant to a part of RCRA that HSWA did not change, the regulation would not be effective in State X as a matter of federal law until EPA approved a change to State X's program. As a matter of state law, State X could regulate the new waste at any time consistent with its own laws.

### 3.6.2 DEFINITIONS OF SOLID AND HAZARDOUS WASTE

RCRA has two sets of definitions of "hazardous waste" and "solid waste": Statutory and regulatory. The broad statutory definitions primarily govern RCRA corrective action (*i.e.*, cleanup) under *42 U.S.C. §§ 6924(u) & (v), 6928(h)*, inspections (*42 U.S.C. § 6927*), and actions to abate substantial risks to the public and the environment under *42 U.S.C. §§ 6972(a)(1)(B) & 6973*. The regulatory definitions apply to most other RCRA Subtitle C regulations.

Generally, when RCRA addresses hazardous waste as defined by the regulations, the statute refers to "hazardous waste *identified or listed under this subchapter*" or similar language. *E.g., 42 U.S.C. §§ 6925(a); 6930(a)*. When RCRA simply refers to "hazardous" or "solid waste," *e.g.*, in *42 U.S.C. § 6973*, it is the statutory definitions that apply. (*45 Fed. Reg. §§ 33084, 33090 (May 19, 1980)*).

### 3.6.3 STATUTORY DEFINITIONS

Subject to narrow exceptions (for waste in domestic sewage, irrigation return flows, discharges regulated by Clean Water Act permits, and radioactive constituents regulated under the Atomic Energy Act), the RCRA statute defines all "discarded" material as solid waste, regardless of whether the material is solid or liquid. (*42 U.S.C. § 6903(27)*). The exact scope of "discarded" in this context is subject to continuing controversy and litigation. Nonetheless, for many regulated entities and in many situations, it is relatively easy to determine whether a waste stream qualifies as "solid waste" using common sense.

Subject to specific exceptions, the RCRA statute defines "hazardous waste" to include essentially any solid waste that may pose a hazard to the public or the environment. (*42 U.S.C. § 6903(5)*).

*The Regulatory Definitions*

For EPA to have authority to classify material as "hazardous waste" under Subtitle C regulations, that material must fall also within the statutory definitions of "hazardous waste" and "solid waste," explained above. (*American Mining Congress v. EPA*, 824 F.2d 1177 (D.C. Cir. 1987)). EPA's regulatory definition of "solid waste" includes materials that are "abandoned," "recycled," or "inherently waste-like," all of which are defined terms.

The definitions of "recycled" and "inherently waste-like" are used to determine which materials, under which circumstances, remain subject to RCRA Subtitle C regulation when reused. Abandoned materials include materials that are disposed of, incinerated or stored in lieu of being disposed of or incinerated. Materials are disposed of when placed on land or water in such a way that they may enter the environment. Thus, EPA's definition of "solid waste" easily encompasses almost any material that would normally be classified as waste, in the everyday use of that term, and may include additional materials that the regulated entity may not consider to be waste.

EPA's regulatory definition of "hazardous waste" includes solid waste that:

- Appears on an EPA list of hazardous wastes; or
- Exhibits a characteristic of hazardous waste; or
- Is a mixture of a listed hazardous waste and a solid waste or is a solid waste that has been derived from a hazardous waste, subject to exceptions; and
- Is not exempt.

EPA's hazardous waste regulations list certain wastes as hazardous at *40 C.F.R. Part 261, Subpart D*. The regulations contain three lists: "nonspecific source wastes," "wastes from specific sources" and "commercial chemical products."

Use of EPA's hazardous waste lists is somewhat more complex than simply finding a chemical name on a list. For example, chemicals on the list of "commercial chemical products," are hazardous wastes if found in discarded commercial products, residues, or environmental "media," (*e.g.*, soil) contaminated from spills of such products. Such chemicals are not necessarily hazardous wastes if *produced* as a waste by a facility's process.

EPA's regulations also set forth characteristics that identify non-listed wastes as hazardous wastes at *40 C.F.R. Part 261, Subpart C*. Those characteristics, determined by tests set forth in the regulations, are:

- Ignitability
- Corrosivity
- Reactivity
- Toxicity

A hazardous waste generally remains regulated as hazardous waste, despite changes to its makeup. Thus, under the "mixture rule," any solid waste mixed with listed hazardous waste is hazardous waste, subject to exceptions. *(40 C.F.R. § 261.3(a)(2)(iv))*. Under the "derived-from rule," any solid waste generated from treatment of a hazardous waste generally is a hazardous waste. *(40 C.F.R. § 261.3(c)(2)(i))*.

A federal court recently invalidated the mixture and derived-from rules because of EPA's failure to follow proper administrative procedures when promulgating the rules. EPA, however, has reinstituted the rules on a temporary (but indefinite) basis while the Agency considers alternatives. Regardless of the mixture and derived-from rules, EPA generally insists that any material that contains hazardous waste (for example, contaminated soil) be managed as hazardous waste.

RCRA and its regulations set forth many exceptions to the definitions of solid and hazardous waste. For example, the list of exempt wastes include: household wastes, agricultural wastes, certain oil and gas production wastes, and cement kiln waste. An important exception applies to wastes that are disposed of in publicly owned waste-water plants under the terms of the Clean Water Act. Another important exception, pursuant to a statutory provision known as the "Bevill Amendment," exempts many mining and milling wastes. It is important to remember, however, that exempt waste that is mixed with non-exempt hazardous waste may be regulated as hazardous waste under the mixture rule.

EPA may de-list (*i.e.*, exempt from regulation) wastes on a case-by-case, facility-specific basis in response to petitions by regulated entities. Moreover, certain types of recycling can exempt hazardous waste from Subtitle C regulation. Also, EPA has proposed a "Hazardous Waste Identification Rule" (known as HWIR") that would allow waste to "exit" much of the hazardous waste regulatory system if hazardous waste constituents in the waste fell below published levels.

### 3.6.4 REGULATION OF HAZARDOUS WASTE PRODUCERS

A generator is the entity that first causes a hazardous waste to become subject to regulation, whether by creating the waste, importing it or taking another action that causes RCRA to apply to the waste. Although generators are the first link in RCRA's cradle-to-grave regulation of hazardous waste, RCRA does not require generators to obtain permits. Generators, however, must comply with regulations found at *40 C.F.R. Part 262*.

It is the generator's responsibility to determine whether he or she generates hazardous waste, *i.e.*, to perform a waste determination. Generators determine whether their waste is hazardous through chemical analyses, process knowledge or a combination of the two. Generators who fail to make such a determination carefully can easily

violate a whole panoply of regulations that flow from the hazardous waste determination.

A waste determination generally must be a regular or continuing process, since changes in a facility's operations may easily change the nature of the waste produced. Generators should be careful to consider all waste streams produced at their facilities, including maintenance (*e.g.*, cleaning, pest control, lawn chemicals), shipping and receiving ( *e.g.*, spills, truck cleaning) and waste produced by contractors. Generators that intend to send their wastes to off-site treatment or disposal facilities should consider the type of information required by the off-site facility when performing the waste determination.

There are three categories of generators under RCRA:

- Large quantity generators;
- Small quantity generators; and
- Conditionally exempt small quantity generators.

Large quantity generators produce over 1000 kilograms per month of hazardous waste or over 1 kilogram of acutely hazardous waste per month. They are subject to all of the requirements of *40 C.F.R. Part 262*. They must:

- Obtain an EPA ID number;
- Determine whether their waste is hazardous or nonhazardous;
- Prepare their waste for transportation, consistent with DOT requirements for packaging and placarding;
- Meet RCRA's storage, training, planning, record keeping and reporting regulations; and
- Comply with manifesting requirements.

If large quantity generators accumulate waste for over 90 days, they must obtain permits to "store" hazardous waste or obtain an extension from the applicable regulatory agency.

Small quantity generators produce between 100 and 1000 kilograms per month of hazardous waste and accumulate less than 6000 kilograms at any one time, and they generate less than 1 kilogram of acutely hazardous waste per month and accumulate less that 1 kilogram at any one time. They must comply with most provisions of *40 C.F.R. Part 262*, but may accumulate waste for up to 180 days.

Conditionally exempt small quantity generators produce less than 100 kilograms of hazardous waste per month and less than 1 kilogram of acutely hazardous waste. They are exempt from Subtitle C regulation as long as they (1) determine that their waste is hazardous, (2) do not accumulate more that 1000 kilograms of hazardous waste, and (3) treat or dispose of their waste on site or send it to an appropriate hazardous or solid waste facility.

The linchpin of RCRA's cradle-to-grave regulatory scheme is the Uniform Hazardous Waste Manifest (the manifest). The manifest contains:

- The names and EPA ID numbers of the generator, the transporter and the treatment, storage or disposal facility;
- The DOT description of the waste to be transported;
- The quantities of the waste;
- The address of the facility to receive the waste (the designated facility);
- Certification that the generator has a program to minimize the volumee and toxicity of its waste; and
- Certification that the treatment, storage or disposal of the waste is the most practical method of minimizing risk to health and the environment.

Each time the waste is transferred (*i.e.*, from generator to transporter or from transporter to designated facility) the manifest must be signed to prove receipt. After the transporter delivers the waste to the designated facility, the owner or operator of that facility sends a copy of the manifest back to the generator, closing the circle. If the generator does not receive this manifest within 35 days after transport, he or she must investigate. Generators who do not receive a copy of the manifest within 45 days must submit an exception report to EPA or the state. Large quantity generators also submit biennial reports to regulators detailing quantities and natures of hazardous wastes, and providing EPA ID numbers of transporters and designated facilities. Generators must keep copies of biennial reports, exception reports and other records for three years.

RCRA's goal of waste minimization currently is implemented by requiring certification on the manifest that the generator has a waste minimization program in place. A false certification may subject generators to severe civil or criminal sanctions.

### 3.6.5 REGULATION OF TRANSPORTERS

Hazardous waste transporters also generally do not receive permits under RCRA but must obtain EPA ID numbers and comply with the manifest system discussed above. (*40 C.F.R. Part 263.*) They must also meet DOT transportation requirements (*49 C.F.R. § 171-179*) and must react appropriately to spills or other accidents. Transporters must report serious accidents and spills to the National Response Center (1-800-424-8802) and DOT. Any transporter who accumulates waste for over 10 days must obtain permits to "store" hazardous waste.

### 3.6.6 RCRA PERMITTING REQUIREMENTS FOR TREATMENT, STORAGE OR DISPOSAL FACILITIES

"Treatment," "storage," and "disposal" are all defined terms under RCRA. (*40 C.F.R. § 260.10.*) Treatment is a process, such as incineration, that changes the physical, chemical, or biological character of the waste. Storage is

the holding of waste for a temporary period. Disposal is discharge, deposit, dumping, spilling, leaking, or placing of waste into or on land or water so that the waste (or any waste constituent) may enter the environment. Treatment, storage or disposal facilities often are referred to as "TSD" facilities. These facilities are subject to RCRA's Subtitle C permitting requirements.

As noted above, generators and transporters of hazardous waste generally do *not* require RCRA permits. However, a generator or transporter may only accumulate hazardous waste for a limited time before becoming a storage facility, and a permit *is* required for hazardous waste storage.

RCRA prohibits the treatment, storage or disposal of Subtitle C hazardous waste without a permit issued by EPA or an authorized state. RCRA also prohibits the construction of an unpermitted facility for treatment, storage or disposal of hazardous waste. Because Congress considered it impractical to halt all hazardous waste activity pending the issuance of permits, however, RCRA allows existing facilities which have met certain requirements to operate under "interim status," a grandfathering provision.

*Interim status facilities.* Interim status facilities are "treated as having been issued [a] permit" pending issuance or denial of an actual permit. (*42 U.S.C. § 6925(e)(1).*) To obtain interim status under RCRA, an owner or operator of a facility that treats, stores or disposes of hazardous waste must apply for a RCRA permit within six months after publication of changes in the law which first subject that facility to regulation. (*42 U.S.C. § 6925(e); 40 C.F.R. § 270.10(e).*) Interim status is available only with respect to a facility that: (i) has complied with the notification requirements of *42 U.S.C. § 6930(a)*; (ii) has submitted the first part (Part A) of its permit application; and (iii) was in existence when statutory or regulatory changes first rendered the facility subject to the requirement to have a permit. (*42 U.S.C. § 6925(e)(1).*) The RCRA regulations provide for limited changes to interim status operations. Changes in processes are permitted to prevent emergencies and threats to public health and welfare, and to comply with the law. (*40 C.F.R. § 270.72(a)(2) & (3).*) *40 C.F.R. § 270.72(a)(1)* authorizes "treatment, storage, or disposal of new hazardous wastes not previously identified in Part A of the permit application ... if the owner or operator submits a revised Part A."

Interim status is lost when: (1) the regulatory agency grants or denies a permit; (2) the regulatory agency terminates interim status for failure to submit a timely and complete Part B application; or (3) the facility misses a deadline set forth under RCRA's loss of interim status provisions, *e.g.*, for submitting a Part B permit application or for certifying compliance with RCRA provisions. (*40 C.F.R. § 270.3.*) EPA may also revoke interim status when issuing an order to respond to a release of hazardous waste into the environment. (*40 U.S.C. § 6928(h).*)

*The RCRA permit.* A RCRA permit application consists of two parts: Parts A and B. The Part A permit application includes a description of the processes to be used for treatment, storage and disposal, and a specification of the hazardous wastes to be treated, stored and disposed. (*40 C.F.R. § 270.13.*) The Part A permit application is due by the statutory and regulatory deadlines set forth in the discussion of interim status above.

The Part B application is significantly more detailed and is due when requested by the regulatory agency or by deadlines set forth in the regulations. When issuing a permit, the regulatory agency first issues a draft for public comment along with a statement of the agency's basis for issuing the permit. If there is opposition to issuance of the permit, the agency must provide for a public hearing. The agency then takes final agency action, issuing, modifying or denying a permit and responding to public comments. The agency's action is effective thirty days later. When EPA issues a permit, an administrative appeal of the Agency action automatically stays the effective date of the permit pending the Agency's resolution of the appeal.

All RCRA permits contain duties, requirements and conditions, including a duty to comply and an acknowledgment that failure to comply is not excused even if compliance would have required cessation of activities at the facility. Permits impose specific conditions necessary to comply with the RCRA regulations and other conditions, not necessarily required by the regulations but imposed for protection of the public and environment. Permits may be terminated for cause and do not convey property rights. RCRA permits may include compliance schedules to bring portions of the facility up to standards.

*Standards for TSD facilities.* The RCRA regulations set forth operating requirements for TSD units, *e.g.*, containers, tanks, surface impoundments, waste piles, land treatment, landfills, and incinerators. Interim status TSD facilities must meet generic requirements set forth at *40 C.F.R. Part 265*. Permitted facilities must meet permit requirements based on the regulations set forth in *40 C.F.R. Part 264*. Generally, TSD facilities must analyze incoming waste, meet security requirements, inspect their facilities, meet record keeping requirements, train their employees and comply with siting requirements. They must, as appropriate, meet groundwater monitoring and reporting requirements, closure and post-closure requirements (discussed below), requirements for control of air emissions, and financial assurance requirements (discussed below).

RCRA provides for closure of permitted units and, for disposal facilities, for post-closure care. Closure is a process by which a hazardous waste management unit is either decontaminated or isolated from the public and the environment. Closure must occur after a unit has stopped accepting wastes for treatment, storage or disposal. Post-closure care is a thirty-year period of monitoring and

maintenance after closure of a disposal facility. Closure and post-closure care occur pursuant to a plan that is part of each TSD's permit.

RCRA also contain provisions for financial responsibility. These provisions are designed to insure that the owner or operator will have the resources to accomplish closure and post closure care and to cover liabilities to third persons. Financial responsibility provisions adopt one or more financial instruments such as a trust fund, a surety bond, a letter of credit, insurance policy, or financial worth test. (*See* additional discussion of this topic in Chapter 16 of this Handbook.)

### 3.6.7 LAND DISPOSAL RESTRICTIONS

The 1984 RCRA amendments (HSWA) impose stringent controls on land disposal of hazardous wastes. Congress phased in requirements that hazardous waste meet treatment standards before land disposal. (*42 U.S.C. § 6924(c) - (h); 40 C.F.R. Part 268.*) The practical effect of these standards is that TSD facilities strictly limit the kinds of waste they will accept and the cost of disposing of hazardous waste in landfills has increased dramatically. Moreover, RCRA forbids storage of land disposal restricted waste except for the purpose of accumulating enough waste to treat or dispose of properly. (*42 U.S.C. § 6924(j).*)

### 3.6.8 RCRA CORRECTIVE ACTION

After 1984, RCRA mandates that, as a condition of issuing a RCRA permit, EPA and authorized states require corrective action to clean up effects of past releases of hazardous waste or constituents. (*42 U.S.C. §§ 6924(u) & (v).*) Regulators may also require corrective action at interim status facilities. (*42 U.S.C. § 6928(h).*) Corrective action is in many ways similar to CERCLA (*i.e.*, Superfund) cleanups. RCRA's corrective action provisions apply to hazardous waste, as defined by the RCRA statute, and hazardous constituents. Thus, RCRA corrective action is *not* limited to Subtitle C (regulatory) hazardous waste.

The corrective action process involves preparation of a RCRA Facility Assessment to determine the need for further action. This step is analogous to the preliminary assessment and site investigation provided for in the Superfund regulations. If warranted, the next step is a RCRA Facility Investigation ("RFI") which is intended to determine the nature and extent of the contamination. Possible remedial steps are then considered in the RCRA Corrective Measures Study ("CMS"). Thus, the RFI and CMS are analogous to the Remedial Investigation and Feasibility Study of the Superfund process. A corrective action remedy is then selected to attain cleanup standards, provide for long term reliability, reduce toxicity, mobility or volume, provide for short-term improvements and minimize short-term risks. Cost and ease of implementation are also considered.

Since RCRA corrective action is intended to accomplish the same basic objectives as the Superfund program, it is important to note how the programs differ and overlap. Although Superfund applies to "hazardous substances" and RCRA applies to "hazardous waste and constituents" often both programs are potentially applicable at one site. EPA has adopted a preference for cleaning up sites under the RCRA corrective action program rather than Superfund. Often, however, the regulated entity may influence the decision of which program applies, *e.g.*, by determining whether to contest RCRA jurisdiction. Thus, it may be important to analyze the differences between the Superfund and RCRA programs as they apply at a particular site.

The RCRA corrective action program generally is funded and accomplished by the regulated entity, subject to regulatory oversight, often as part of a permit application. Thus, the regulated entity may have more ability to ensure that the scope of studies, the remedy and costs are appropriate. Often, under RCRA, the regulator is a state rather than EPA. In contrast, EPA usually acts as the lead agency under the Superfund program and often directs and funds site investigations so that significant decisions are made in the first instance by the regulator.

On the other hand, Superfund cleanups are often exempt from federal, state and local permitting requirements. RCRA corrective action offers no similar exemption. Additionally, RCRA, unlike Superfund, can require cleanup of releases that are contained within a work place.

### 3.6.9 ENFORCEMENT

*Civil enforcement.* Regulators may respond to violations with administrative orders and court action. Violations of RCRA are punishable with fines of up to twenty-five thousand dollar per violation per day and Courts may issue injunctions that usually contain a detailed schedule for compliance. As a practical matter, the twenty-five thousand dollar per violation per day limit may have little effect; regulators generally have the option of treating most incidents of noncompliance as multiple violations. For example, if a violator has disposed of hazardous waste without a permit, that same entity probably is also liable for failure to make an appropriate hazardous waste determination, and for a panoply of violations of inspection, training, labeling and preparedness requirements. Administrative penalty calculations are generally based on an EPA penalty policy that considers the extent of deviation from the requirement at issue and the resulting potential for harm.

Under *42 U.S.C. § 6973*, EPA may bring an action in court against any person whose past or present conduct has caused or contributed to handling, treatment, storage or disposal of hazardous or solid waste that may present an

imminent and substantial endangerment to health or the environment. EPA has clarified that it is the broad, statutory definitions of hazardous and solid waste that apply to such actions. (*42 U.S.C. § 261(b)(2)(ii).*) EPA has occasionally used this enforcement authority to address mining wastes that, under the Bevill Amendment, are exempt from RCRA Subtitle C regulations.

Under *42 U.S.C. § 6973* the Court is authorized to restrain such person and to take such other action as may be necessary. Some courts have awarded EPA cleanup costs under this provision.

An endangerment (*i.e.*,threat) may be "imminent" even if the harm may not occur for many years. The situation need not present an emergency. In a recent decision, under an analogous RCRA citizen suit provision, a Court ruled:

> First, it is significant that the word "may" precedes the standard of liability: '[t]his is 'expansive language,' which is 'intended to confer upon the courts the authority to grant affirmative equitable relief to the extent necessary to eliminate *any risk* posed by toxic wastes.' ... Second, 'endangerment' means a threatened or potential harm and does not require proof of actual harm.

*Lincoln Properties, Ltd v. Norman Higgins*, Civ. No. S-91-760 DFL/GGH (E.D. Cal. Jan.21, 1993) Slip op. at 29 (citations omitted). The Court issued "[a]n injunction [that] will determine the existence and extent of the endangerment through further investigation, monitoring and testing." (*Id.* at 39.)

Thus, any potentially significant risk of eventual harm may qualify as a situation that may present an imminent and substantial endangerment. The scope of any injunctive relief, of course, is within the equitable discretion of the court. (*See e.g., Amoco Production Co. v. Gambell*, 480 U.S. 531 (1987).)

Regulators also have the power to inspect the premises and records of any person who manages hazardous waste. For purposes of its inspection authority, EPA uses the broad, statutory definition of hazardous waste.

*Criminal enforcement.* As with many federal environmental laws, knowing violation of most RCRA provisions is a federal crime. (*42 U.S.C. § 6928(d). See United States v. Hoflin*, 880 F.2d 1033 (9th Cir. 1989), *cert. denied* 107 S. Ct. 1047 (1990).) RCRA also provides for up to 15 years in prison and a fine of up to $250,000 ($1,000,000 for an organization) for knowingly transporting, treating, disposing or exporting hazardous waste or used oil and thereby knowingly placing another person in imminent danger of death or serious bodily injury. (*42 U.S.C. § 6928(e).*) *See United States v. Protex Industries, Inc.*, 874 F.2d 740 (10th Cir. 1989).) Depending on the circumstances, regulators may conduct simultaneous civil and criminal investigations and prosecutions. (*See, e.g., Securities and Exchange Comm'n v. Dresser Ind.*, 628 F.2d 1368 (D.C. Cir.) *cert. denied*, 449 U.S. 993 (1980).)

*Citizen enforcement.* RCRA, like most federal environmental laws, provides for citizen enforcement by "private attorney generals." (*See, e.g., Middlesex County Sewerage Authority v. National Sea Clammers Ass'n*, 453 U.S. 1, 11 (1981).) Any person may bring such a suit. In general, Congress intended citizen enforcement to supplement enforcement by government agencies and to: (1) abate pollution (2) encourage voluntary compliance and (3) prod government enforcers into action.

Environmental laws generally provide for only two kinds of citizen enforcement suits: Suits against persons who have violated statutory provisions, regulations, or permits and suits against EPA for failing to discharge a duty that is not discretionary with the agency (*e.g.*, failing to promulgate regulations by statutory deadlines). RCRA provides these causes of action in *42 U.S.C. §§ 6972(a)(1)(A)* and *6972(2)*, respectively. RCRA — as amended in by HSWA 1984 — is unique, however, because it *also* allows a third type of citizen suit.

Under RCRA § 7002, *42 U.S.C. § 6972(a)(1)(B)*, citizens may seek injunctions when waste handling "may present an imminent and substantial endangerment" *regardless* of whether there is any underlying regulatory violation. This cause of action is substantially identical to *42 U.S.C. § 6973*, described above. The difference is that "any person," rather than just EPA, may bring the action. Thus, even owners and operators that are in full compliance with RCRA regulations face potential liability to citizen enforcers for activities that "may" create an imminent hazard. *42 U.S.C. § 6972(a)(1)(B).* In *Meghrig v. KFC Western, Inc.*, 116 S.Ct. 1251 (1996), the U.S. Supreme Court ruled that this provision does not authorize courts to reimburse plaintiffs for cleanup costs that were incurred before invocation of RCRA's statutory process.

### 3.6.10 BEVILL AMENDMENT

One portion of RCRA is of particular importance to the mining community, because it exempts some mining wastes from RCRA's hazardous waste programs. This portion of the statute is known as the "Bevill Amendment," and is found in *42 U.S.C. §§ 6921(b)(3)* and *6982(p)*, as well as in *40 C.F.R. § 261.4(b)(7).*

The Bevill Amendment places certain solid wastes outside the universe of hazardous wastes. The exemption includes solid waste from the extraction, beneficiation, and processing of ores and minerals, limited in regulations to particular types of mining operations.

The Bevill Amendment provisions of RCRA have been interpreted by the courts (*Environmental Defense Fund v. EPA*, 852 F.2d 1316 (D.C. Cir. 1988)) to apply only to high volume, low hazard wastes. Thus, not every type of solid waste associated with the mining industry is exempt from RCRA, and miners must be careful to ascertain which

of their solid wastes continue to fall within the universe of regulated hazardous waste.

## 3.7 PUBLIC LAND LAWS

**by S. Blackstone**

### 3.7.1 DEFINITION OF THE PUBLIC LAND LAWS

The public land laws are statutes enacted by the U.S. Congress that deal with acquisition, disposal, use, protection, and management of the public lands. Under Article IV of the U.S. Constitution, Congress has the power "to dispose of and make needful rules and regulations" regarding the public lands. Federal agencies charged with administering these statutes, such as the Bureau of Land Management or the Forest Service, promulgate federal regulations that detail, interpret, and apply the general principles and requirements of the statute. When authorized and validly promulgated, these regulations are as legally binding as the statutes. Administrative decisions by the various agencies and cases decided in federal and state courts also serve to "flesh out" and refine the meaning of the statutes and regulations. Together, these statutes, regulations, agency decisions, and court cases comprise the body of public land law.

### 3.7.2 DEFINITION OF THE PUBLIC LANDS

The term public lands generally refers to federal public lands, although lands owned by state and local governments are sometimes included in the general term public lands. The term federal public lands, or simply federal lands, refers to any lands owned by the federal government. However, certain statutes may use a specific definition of public lands for purposes of that statute, so it is often helpful to check the definitions section of a statute or regulation. Federal lands do not include Indian lands, most of which are held in trust by the United States for the benefit of Indians. Also, in the context of mining, the terms federal lands or public lands generally do not include offshore or submerged lands.

Federal lands may be either "public domain" or "acquired lands." The term public domain is a term of art, referring only to those lands which have remained in federal ownership since first obtained by the U.S. either from a sovereign nation (through treaty, purchase, or conquest) or from one of the original thirteen states (through cession of public lands previously claimed by the state). Over 90% of federal lands are public domain lands. By contrast, the term acquired lands refers to lands that were once in private or other nonfederal ownership and later acquired by the U.S. through purchase, condemnation or gift. Examples of acquired lands include many of the National Forest lands in the eastern seaboard states, while National Forest lands in most western states were simply carved out of existing public domain lands. It is particularly important to distinguish between public domain lands and acquired lands for mining purposes because they are subject to different mineral disposal laws.

### 3.7.3 THEORY BEHIND THE PUBLIC LAND LAWS

#### 3.7.3.1 Historical Development

Much of today's public land law makes little sense without some understanding of its historical development. For example, anyone looking at a map of federal public lands might wonder why most of the public lands are concentrated in the eleven contiguous western states and Alaska. This results more from historical accident than from any policy determination by Congress (much less by the states themselves!). It simply happened that these states were left with vast areas of land unsuitable for agricultural settlement -- and thus largely unavailable for private ownership under the various homestead laws -- both when the states were admitted to the Union and when federal policy later changed officially from one that favored disposal of all public lands to one that mandated retention of public lands.

In forming the United States, the thirteen original states eventually relinquished their claims to vast areas of "unoccupied" western lands stretching from the Alleghenies to the Mississippi River. The cession of these lands by the states to the federal government formed the original public domain. It grew dramatically, however, as a result of subsequent conquests, purchases and treaties by the U.S. These included the 1803 Louisiana Purchase, the acquisition of Florida in 1819 by treaty with Spain, the addition of the Pacific Northwest with the Oregon Compromise of 1846, the addition of the Southwest by cession from Mexico in 1848, the purchase of certain lands from Texas in 1850, the Gadsen Purchase from Mexico in 1853, and finally the 1867 purchase of Alaska from Russia.

From this vast public domain, new states were formed, beginning with Ohio in 1802. Other than the thirteen original states, Kentucky, Tennessee, Vermont, Maine, West Virginia, Texas, and Hawaii, the remaining 30 states were carved from the public domain. Meanwhile, settlers were pushing westward, and much of the habitable land was passing into private ownership under federal homestead and other land disposal laws. This general policy of disposing of public lands into private ownership persisted into the 1930s, although starting in the 1890s large tracts were withdrawn from disposal under the public land laws and reserved as national parks, national monuments, national forests and national wildlife refuges. The policy of retaining public lands in federal ownership was officially adopted in the 1976 Federal Land Policy and Management Act.

Federal public lands today comprise approximately 660 million acres, or nearly 30% of the total land area of the United States. (U.S. Department of the Interior, Public Land Statistics, 1990.) In addition, the federal government owns reserved mineral rights to over 56 million acres, the surface of which is privately owned. Federal lands are located primarily in the western states and Alaska. The percentage of federal land is particularly significant in mining states such as Nevada (82%), Utah (64%), Idaho (63%), California (61%), Wyoming (49%), Arizona (43%), Colorado (34%). More importantly, large areas of federal lands are considered among the most geologically favorable areas for new mineral discoveries.

The bulk of the federal public lands of interest to miners is managed by two agencies: the Bureau of Land Management in the Department of the Interior and the Forest Service in the Department of Agriculture. Other major land-managing agencies include the National Park Service, the Fish and Wildlife Service, the Bureau of Reclamation, and the Department of Defense.

The BLM is technically responsible for administering the U.S. mining and mineral leasing laws on all federal lands. However, the surface managing agency is responsible for both land use planning and environmental regulation of activities that affect the land surface, including mining, and thus a federal phosphate lease is issued and administered by the BLM. However, if the leased lands are within a National Forest, the Forest Service will provide environmental requirements for both the lease and the mine permit. If a lease has not yet been issued, the Forest Service land use planning process will determine whether the lands should be made available for leasing, and under what conditions or stipulations.

Exploration and mining activities on federal lands are subject to different environmental regulatory programs depending on the type of land and on the type of mineral involved. This is partly due to the fact that the statutes prescribe different standards for different land-managing agencies. It is also partly due to the different laws that govern disposal of different minerals. For example, environmental regulation of gold mining is somewhat different for Forest Service public domain lands than it is for BLM public domain lands because the two agencies operate under different enabling statutes. Different types of minerals are subject to different legal regimes for disposal (i.e., by lease, sale, or location of a mining claim), each of which involve different statutes and environmental regulatory programs. Furthermore, the same mineral may be subject to different disposal laws depending on whether it is found on public domain or acquired lands. (This means that regulation of gold mining on acquired public lands is even more different than gold mining on public domain lands managed by either agency, since gold on acquired lands is only obtainable by lease, rather than location of a mining claim, and a lease allows an agency much broader discretion to impose environmental requirements.)

### 3.7.3.2 Acquiring Rights to Minerals on Public Lands

Minerals on federal lands generally are not discovered or produced by the federal government, but by private entities which obtain rights to federal minerals under one of three mutually exclusive systems: 1) the location system, 2) the leasing system, or 3) the direct sale system.

*Location system.* The location system is governed by the 1872 Mining Law, as amended over the years by Congress. *30 U.S.C. § 21, et seq.* It is called the location system because prospectors who discover a valuable mineral deposit under the Mining Law may appropriate that deposit by "locating" a mining claim (or claims) in accordance with federal and state requirements. Upon fulfilling certain other requirements, owners of valid mining claims may be entitled to a patent (fee title) to the deposit and the lands containing it. However, valid mining claims need not be patented for the owner to mine and market the mineral deposit, so long as the claim is properly maintained.

The Mining Law applies only to public domain lands, including the federal reserved mineral estate where the surface was originally patented under various federal homestead acts. The Mining Law originally applied to all valuable mineral deposits on federal lands except coal. Over the years, Congress removed various minerals from operation of the Mining Law, making them either leasable or salable. Today, "locatable minerals" include valuable mineral deposits of gold, silver, mercury, lead, tin, copper and other so-called "hard-rock" mineral deposits. Minerals that would be locatable on public domain lands are leasable when found on acquired lands.

*Leasing system.* The leasing system applies to coal, oil, gas, oil shale, tar sands, sodium, phosphate, potassium, and sulfur in Louisiana and New Mexico under the 1920 Mineral Leasing Act. *30 U.S.C. § 181 et seq.* The Acquired Lands Leasing Act of 1947 extended the leasing system to all minerals on acquired lands. *30 U.S.C. § 351 et seq.* Under the leasing system, the government generally has much more discretion to determine what lands will be made available for lease and to establish restrictions and limitations on mining. Unlike a mining claim, a lease has a specified term within which certain mineral production requirements, or specified substitutes for production, must be met.

*Direct sale system.* The direct sale system applies to mineral materials such as clay and to so-called "common varieties" of sand, stone, gravel, pumice, and similar materials. Materials Act of 1947, *30 U.S.C. §§ 601-604.* Surface Resources Act of 1955, *30 U.S.C. §§ 611-612.* Mineral materials are disposed of by contract to private entities or by free use permit to governmental entities or nonprofit organizations.

#### 3.7.3.3 How Environmental Protection Fits In

First and perhaps foremost, environmental protection is a major factor in the land use planning processes mandated by Congress for land-managing agencies such as the Bureau of Land Management and the Forest Service. The land use planning process determines both the availability of lands for mineral exploration/discovery and the initial environmental restrictions or stipulations that may affect development of any minerals that are found.

Once mineral rights are obtained under one of the three systems described above, numerous environmental permits and approvals are required prior to mining activities, and often prior to exploration, depending on the amount of surface disturbance involved. Furthermore, both federal and state environmental regulations apply to mineral development on federal lands. In some states, overlapping federal and state environmental reviews are minimized by interagency agreements that allow a state agency to take the lead role in environmental permitting.

### 3.7.4 TYPICAL MINING PROBLEMS ENCOUNTERED ON PUBLIC LANDS

Environmental regulation of mining on public lands is arguably more pervasive than that for mining on private lands since even the process of acquiring mineral rights on public lands is often subject to numerous environmental reviews. For example, the process may begin with development and adoption of a land use plan, which involves preparation of an environmental impact statement by the agency. The plan may identify certain lands that are particularly environmentally sensitive. Such lands may be either formally withdrawn from location or leasing, or burdened with such restrictive use stipulations that mineral exploration and development would be effectively precluded. Lands may also be categorized or classified during the land use planning process in ways that trigger other environmental laws, such as stringent visibility standards under the Clean Air Act. Such classifications can effectively preclude mining without even mentioning mining in the plan. Even once mineral rights to public lands have been acquired by private firms or individuals, obtaining access for mining and mining-related activities may require separate and additional environmental reviews and regulations.

Mineral exploration and development activities, of course, are subject to extensive environmental regulations and permit requirements by both federal and state agencies. These include all air, water, and hazardous material regulations, as well as reclamation and surface use regulations directed at mining activity.

### 3.7.5 ENVIRONMENTAL REGULATION OF BLM LANDS

#### 3.7.5.1 Land Use Planning

The Federal Land Policy and Management Act of 1976 (FLPMA) is referred to as the "organic act" or "enabling act" for the Bureau of Land Management. While the BLM also administers and is subject to many other statutes, FLPMA provides the agency with its basic policy guidance. Among other things, FLPMA requires the BLM to conduct comprehensive land use planning, to manage the public lands based on principles of multiple use and sustained yield, to balance the need for environmental protection against the need for domestic sources of minerals, food, timber and fiber, while giving priority to protecting areas of critical environmental concern. *43 U.S.C. §§ 1701-1784.*

Congress in fact provided very little useful guidance for the BLM in carrying out these mandates. To appreciate the difficulty of the agency's task, one need only look to the statute's definition of "multiple use" - which Congress illumined as:

> "...the management of the public lands and their various resource values so that they are utilized in the combination that will best meet the present and future needs of the American people: making the most judicious use of the land for some or all of these resources or related services over areas large enough to provide sufficient latitude for periodic adjustments in use to conform to changing needs and conditions; the use of some land for less than all of the resources; a combination of balanced and diverse resource uses that takes into account the long-term needs of future generations for renewable and nonrenewable resources, including, but not limited to, recreation, range, timber, minerals, watershed, wildlife and fish, and natural scenic, scientific and historical values; and harmonious and coordinated management of the various resources without permanent impairment of the productivity of the land and the quality of the environment with consideration being given to the relative values of the resources and not necessarily to the combination of uses that will give the greatest economic return or the greatest unit output." *43 U.S.C. § 1702(c).*

In spite of such language, the BLM has adopted detailed planning regulations (*43 C.F.R. Part 1600*) for preparation of resource management plans. Once a plan is approved, all subsequent actions in that resource area must be consistent with the plan.

Although a detailed description of the planning process is beyond the scope of this chapter, it is worth emphasizing that the process is extremely critical in determining environmental restrictions on mining activity. More importantly, the broad language of FLPMA makes it very difficult to challenge agency decisions once a land use plan is properly adopted, assuming the decision is reasonably consistent with the plan.

#### 3.7.5.2 Locatable Minerals

Under FLPMA, the BLM is authorized to regulate mining

activities under the 1872 Mining Law to prevent unnecessary or undue degradation of federal lands. *43 U.S.C. § 1732(b).* BLM regulations provide for three levels of surface-disturbing activities:

1. Casual use involving only "negligible" surface disturbance — which does not require either agency notification or approval;

2. Activities not qualifying as casual use that disturb five acres or less per year (including access) — which require at least 15 days prior written notice to the BLM and may require consultation on access, and

3. Activities that disturb more than five acres per year, or any activity in certain specially protected areas (such as wilderness areas or areas of critical environmental concern) — which require an approved plan of operations. *43 C.F.R. § 3809.*

Approval of a plan of operations may require preparation of an environmental impact statement by the agency. Even activities conducted under the notice provisions must comply with specific performance and reclamation standards. For example, operators must limit access routes and perform reclamation at the earliest possible time, which must include measures to preserve topsoil, control erosion, etc. All operations, including casual use, must comply with all applicable state and federal environmental laws and standards. Most activities now require posting of a bond to ensure compliance with reclamation requirements. BLM lands designated as "wilderness study areas" are subject to separate, more stringent regulations. *43 C.F.R. § 3802.*

#### 3.7.5.3 Leasable Minerals

For non-coal leasable minerals, BLM regulations require approval of exploration or mining plans prior to any surface-disturbing activity. *43 C.F.R. Part 23.* Performance bonds sufficient to cover reclamation requirements are required for both exploration or mining plan approval.

### 3.7.6 ENVIRONMENTAL REGULATION ON FOREST SERVICE LANDS

#### 3.7.6.1 Land Use Planning

Forest Service land use plans are governed by the Forest and Rangeland Renewable Resources Planning Act of 1974, as amended by the National Forest Management Act of 1976 (codified in scattered sections of *16 U.S.C.*). The Forest Service planning process is substantively similar to that of the BLM, although procedurally quite different *36 C.F.R. § 219.*

#### 3.7.6.2 Locatable Minerals

The Forest Service manages surface-disturbing activities related to mining claims under the authority of its 1891 Organic Act. *16 U.S.C. § 471.* Forest Service regulations require the filing of a "notice of intent" for any activities that might cause disturbance of surface resources. *36 C.F.R. § 228.* If the District Ranger determines that such operations will likely cause "significant disturbance" of surface resources, the operator must submit a proposed plan of operations for approval. As with a BLM plan of operations, approval of a plan of operations may require preparation of an environmental impact statement.

#### 3.7.6.3 Leasable Minerals

The Forest Service has not promulgated regulations for non-coal leasable minerals. However, the BLM incorporates environmental requirements or stipulations recommended by the Forest Service in approving exploration or mining plans.

### 3.7.7 DESIGNATION OF FEDERAL LANDS AS UNSUITABLE FOR MINING

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) provides for designation of federal lands as unsuitable for either coal mining (*30 U.S.C. § 1272*) or for non-coal mining (*30 U.S.C. § 1281*). For non-coal mining, federal reserved minerals (i.e., the federal severed mineral estate) is subject to such designation if the overlying surface is of a predominantly urban or suburban character and is being used primarily for residential purposes. Other federal lands may be designated as unsuitable for non-coal mining if mining operations would have an adverse impact on residential lands. An unsuitability designation may be initiated by either the agency or by any person having an interest which is or may be adversely affected by non-coal mining on federal lands.

### 3.7.8 PROTECTION OF ARCHAEOLOGICAL AND PALEONTOLOGICAL RESOURCES ON FEDERAL LANDS

Archaeological resources found on federal lands are protected under several statutes, including the Antiquities Act of 1906 (*16 U.S.C. §§ 431-433*), the Historic Sites Act of 1935 (*16 U.S.C. §§ 461-467*), the National Historic Preservation Act of 1966 (*16 U.S.C. § 470*), and the Archaeological Resources Protection Act of 1979 (ARPA) (*16 U.S.C. §§ 470aa -470ll*), ARPA establishes a permit system for excavation or removal of archaeological resources and provides for both civil and criminal penalties. Removal of arrowheads located on the surface of the ground is exempt from both criminal and civil penalties. ARPA is

directed primarily at commercial exploitation of archaeological resources on public lands. Under the Surface Mining Control and Reclamation Act of 1977 (SMCRA), coal mine operators must identify and protect all known archaeological resources.

Both the BLM and the Forest Service have authority to manage and protect paleontological resources on federal lands under their jurisdiction. BLM surface management regulations for locatable minerals specifically protect both archaeological and paleontological resources. *43 C.F.R. § 3808.2-2*. Forest Service regulations require a permit for collecting of any vertebrate fossil and for commercial collecting of any paleontological resources. *36 C.F.R. § 261*.

## 3.8 MISCELLANEOUS STATUTES

**by E. P. Newman**

Mine operators have been forced to become increasingly familiar with the growing array of environmental laws impacting the air, water, and land. If these statutes are not enough to baffle and confuse, there are also a variety of lesser known acts that may equally frustrate the unsuspecting miner. These acts have not received the degree of national attention afforded the others addressed in this chapter, but they nonetheless may be equally troublesome if not addressed in the initial stages of mine planning and during operation. As discussed below, these acts involve underground storage tanks (USTs), toxic chemicals, oil spills, and cultural and wildlife resources.

### 3.8.1 UNDERGROUND STORAGE TANK REGULATION

In the past, mine operators stored liquid materials, such as fuels, in aboveground tanks. Because of safety concerns, primarily fires and explosions, the trend over the last 20 to 30 years has been to store those materials in underground storage tanks. That move, however, has raised new concerns. It is now known that steel tanks corrode in the ground and that loose pipe connections all lead to leaks of materials into the environment.

EPA has extensively studied underground storage tanks and their related hazards. It is believed that over 2 million underground storage tank systems exist nationwide. Of these, EPA projects that from 1400 to 4200 sites per state are leaking. In response, Congress directed EPA to develop a comprehensive regulatory program for underground storage tanks. Pursuant to subchapter IX of RCRA, EPA promulgated rules in 1988 regulating the design, construction, and operation of underground storage tank systems (*40 C.F.R. Part 280*).

EPA also promulgated regulations establishing procedures for States to obtain EPA approval to administer and enforce a state program in lieu of the federal program. Most states have chosen to conduct their own programs. As a result, there are a myriad of programs to contend with, but most are fashioned somewhat after the federal program. Mine operators must contact the state environmental agency to learn more about the specifics of the individual state program affecting its operation. This section describes the general federal program.

A threshold determination a mine operator must make is whether there are any regulated underground storage tanks at the site. An "underground storage tank" is defined as a tank, including underground connecting piping, that contains a regulated substance and is ten percent or more beneath the surface of the ground. This definition is extremely broad and may include tanks not commonly thought of as underground storage tanks. There are several exceptions to the definition, including tanks of less than 1100 gallons, underground storage tanks used for storing heating oil for consumptive use on the premises where stored, and underground storage tanks located below ground where the tank is above the surface of the floor in that area.

A second key jurisdictional requirement is the characterization of the material contained within the underground storage tank. As mentioned above, to fall within the program the underground storage tank must contain a "regulated substance." Regulated substances include petroleum and petroleum-based substances such as motor fuels, oils and lubricants, and hazardous substances identified under CERCLA that are not hazardous wastes under RCRA. (USTs containing hazardous wastes are regulated under subtitle C of RCRA.)

Tanks covered by the program are subject to registration and reporting requirements, performance standards, and financial responsibility requirements. The regulations require registration of all underground storage tanks in use or in the ground on the effective date of the regulations. Underground storage tank owners and operators must identify the location, size, construction, and nature of contents in the registration form. Most state programs require annual registration fees.

When a release from an underground storage tank is detected, the owner or operator must follow the investigatory and cleanup steps described in the program. For example, after the confirmation of a release, the owner/operator must notify the proper regulatory authority, usually within 24 hours, and take immediate actions to prevent further releases and mitigate dangers of fires and explosions. The owner/operator is then placed on a schedule for investigating, characterizing, and remediating the release.

The regulations establish specific performance standards for new underground storage tank systems as well as phased-in requirements for upgrading existing systems. Performance standards typically require corrosion protection, spill and overflow protection, and leak detection equipment or procedures. By 1998, all existing tanks must either meet the performance standards for new tanks, upgrade requirements, or closure requirements.

Either the owner or operator of an underground storage

tank must show financial responsibility under the federal program to cover corrective action and compensating third-parties for bodily injury and property damage caused by releases from underground storage tanks containing petroleum. A variety of mechanisms are allowed to show financial responsibility, including a financial test of self-insurance, surety bonds, and letters of credit. Many states have established trust funds - financed in part by annual fees - that an owner or operator may rely on to supplement the financial assurance requirements.

Under the federal program, owners and operators (non-petroleum marketers) must have evidence of financial responsibility for corrective action and third-party liability of $500,000 per occurrence and an annual aggregate amount of $1 or $2 million, depending on the number of tanks owned or operated. State trust funds are commonly structured to cover large portions of the liability. For example, in Colorado, the owner or operator must cover the first $10,000 for corrective action and $25,000 for third-party liability with the state picking up the remainder to $1 million. The owner or operator is then responsible for the remaining costs, if any.

### 3.8.2 TOXIC SUBSTANCES CONTROL ACT

The majority of the environmental programs discussed thus far in this chapter deal with limitations on chemical emissions and the effects of chemicals once they have been released into the environment. These acts typically do not regulate chemicals during manufacturing, distribution, and use. Congress recognized that chemical pollution can result from actions other than accidental releases and disposal - such as manufacturing and use - and passed the Toxic Substances Control Act (TSCA) in 1976 (*15 U.S.C. § 2601*). A wide variety of chemicals are used in the various phases of mining and milling operations. Consequently, these operations are potentially subject to the programs established under TSCA.

The primary purpose of TSCA is to protect health and the environment from unreasonable risk of injury caused by chemicals. Programs established under TSCA are principally designed to regulate the introduction of new chemical substances and mixtures into the stream of commerce. TSCA can be viewed as containing three major parts. First, Section 4 to the Act empowers EPA to require chemical manufacturers and processors to test certain chemicals to evaluate the unreasonable risks posed by the chemicals if allowed to enter the environment. Second, Section 5 of the Act requires manufacturers to give notice to EPA before new chemicals are manufactured or old chemicals are given new uses. EPA then has the opportunity to evaluate whether the new chemical poses unreasonable risk to health or the environment. Third, Section 6 of the Act allows EPA to control or prohibit the manufacture and use of a chemical that poses an unreasonable risk to health or the environment.

Most of the TSCA regulatory programs have had little affect on mining operations because the Act addresses activities more intimately associated with industries producing chemical substances and mixtures. Although it is possible that mining as an industry may fall within the scope of TSCA, the programs by and large do not appear to regulate mining activities. For example, Section 8(c) requires manufacturers, processors, and distributors of chemicals and mixtures to keep records of significant adverse reactions to health or the environment. Regulations implementing the requirement expressly exempts mining or other solely extractive functions (*40 C.F.R. Part 717*).

TSCA requires EPA to compile and keep a list of each chemical substance that is manufactured or processed in the United States — the Chemical Substance Inventory. The primary purpose of the inventory is to define new chemical substances for purposes of pre-manufacture notification under Section 5 of the act. If a substance is not on the list, the manufacturer must submit a notification to EPA before manufacturing the substance. This program is expected to have little impact on the mining industry because almost all ores and mill concentrates are listed or inventoried as "naturally occurring substances" (*40 C.F.R. Part 710*).

One TSCA program that has impacted the mining industry is the polychlorinated biphenyl (PCB) regulation (*40 C.F.R. Part 761*). This program is discussed below.

### 3.8.3 PCB REGULATION
**by C. Secrest**

Polychlorinated Biphenyls, or PCBs, are a family of 209 chemicals with two linked phenyl rings and varying degrees of chlorination (Erickson, M. 1986). Some 1.25 billion pounds were manufactured in the United States, primarily for use as a dielectric fluid in electrical transformers, voltage regulators, and capacitors. For many years, PCB dielectric fluid was superior to other liquids because of its low flammability. It also gave electrical equipment a longer service life than other fluids available at the time (EPA, 1976). PCB found a niche in underground mines, particularly in coal, because of its resistance to fire. PCB was the only recommended dielectric fluid for liquid-filled transformers, particularly during the strongest period of growth in the use of electrical equipment underground (Bureau of Mines, 1955). PCBs were also used as a coolant in the electric motors of continuous miners and loaders manufactured by Joy from 1961 to 1973; some 652 of the units were still in service in 1973, requiring some 23,000 kilograms of PCBs per year for "topping off" (EPA, 1976 and 1978). There is also evidence that PCB hydraulic fluid was used in mining equipment, although the amount and specific applications are not well documented (EPA, 1976).

Some coal mines began phasing out liquid-filled transformers underground by the early 1960s. By 1981 the U.S. Bureau of Mines obtained information suggesting that most coal mines had replaced the transformers with more mobile and rugged dry-type transformer units generally known as "mobile power centers." These power centers are

rectangular steel enclosures measuring approximately 22 ft long, 6 ft wide, and 3 ft tall. They are mounted on skids and contain a dry-type transformer. About 10% of the units contain capacitors; units that were manufactured up until the late 1970s may contain PCB Capacitors.

The PCB Transformer phaseout in some underground coal mines was not duplicated in metal/nonmetal mines, or surface mines, where PCBs may remain in use. Surface mines use PCB Transformers and PCB Capacitors at substations, distribution transformers, and mills. PCB Transformers are also found in draglines, shovels, and blasthole drills.

Electromagnets can also contain PCBs, used in place of mineral oil at the request of the buyer. Normally, there is no information on the equipment nameplate concerning the existence of PCBs.

### 3.8.3.1 Health Effects of PCBs

PCBs were not generally recognized as toxic until 1968, with the widespread poisoning in Japan caused by an accidental leak of PCBs into cooking oil. The resulting acute symptoms, which became known as "Yusho" disease, affected 1,291 people (EPA, 1979). The major symptoms included various physical complaints, low birth weights, and skin rash (Erickson, M. 1986). Other early indicators included an incident in 1970, where PCBs were found to be responsible for infertility in mink that was fed PCB-contaminated salmon (EPA, 1979).

Present-day studies have not alleviated the earlier concerns, particularly for children whose mothers eat contaminated fish during pregnancy. Symptoms include lower birth weight, smaller head circumference, deficiency in weight gain, weaker reflexes, and reduced performance in memory tests (Johnson, B. 1992). Disorders of the central nervous system are also believed to be a symptom of PCB exposure (Rogan, W. 1992). Recent studies also suggest a strong link between PCBs and cancers of the liver and skin (Rao and Banerji, 1988; Sinks et al, 1992). Blood levels of PCB remain elevated in environmentally exposed human populations, even though it is no longer manufactured and the substance has been strictly regulated for over 15 years (Hovinga, M., Sowers, M, and Humphrey, H., 1992). PCB is perhaps the most persistent and environmentally widespread contaminant of the industrial era.

### 3.8.3.2 Regulatory Background

By 1975 there was substantial evidence of PCB contamination in industrial effluents, fish, and elsewhere in the environment. Reports of PCB contamination were regularly featured in the popular media. Largely due the this mounting evidence and the public outcry over widespread contamination, Congress singled out PCB for special regulation under the Toxic Substances Control Act of 1976 (TSCA). Section 6(e) of TSCA banned the further manufacture of PCBs, but allowed existing uses to continue in "a totally enclosed manner." Under the Act, the U.S. Environmental Protection Agency was directed to pass regulations concerning the continued use, marking, distribution in commerce, and disposal of totally enclosed PCBs. Between 1978 and 1991, EPA promulgated ten major rules governing a wide variety of PCB issues. Another major rule pertaining to PCB disposal is currently in the making. EPA banned many uses of PCBs. However, PCB Transformers, voltage regulators, and other high-voltage electrical equipment was allowed to remain in use, with certain regulatory conditions.

The regulations that apply to the mining industry include the mandatory phase-out of PCBs in electric motors, and the requirements for use, storage, record keeping, and disposal of PCBs and PCB electrical equipment. The requirements are intended to prevent the risk of further environmental release of PCBs presently in use, and to ensure proper disposal of PCBs that are taken out of service. In short, these rules, hereafter referred to as the PCB Rule (*40 C.F.R. Part 761*), require mine owners and operators to:

- Phase out the use of PCBs in electric motors by 1982.
- Register PCB transformers with the primary fire response personnel for the mine.
- Store no combustible materials within 5 meters of a PCB Transformer.
- Inspect transformers quarterly and keep records of inspection.
- Clean all PCB leaks and spills in accordance with specified spill cleanup procedures (*40 C.F.R. § 761 Subpart G* - PCB Spill Cleanup Policy).
- Mark PCB equipment and transformer access routes with the specified PCB mark.
- Maintain annual documents identifying the type and amount of PCBs at the mine.
- When the equipment is taken out of service for disposal, prepare manifests for shipment of PCBs for proper disposal in a TSCA chemical waste landfill, TSCA incinerator, or an EPA-approved alternative method of disposal. Under no circumstances may PCBs or PCB electrical equipment be abandoned in a mine, or disposed of in any manner other than as specified in the PCB Rule. Other regulatory conditions may apply, depending on the mine's circumstances (e.g., PCB-contaminated waste oil, *40 C.F.R. § 761.20*; PCB storage, *40 C.F.R. § 761.65*).

Under Section 11 of TSCA, EPA inspectors are authorized to inspect any facility to determine its compliance with the PCB Rule. Section 16 provides that any person who violates TSCA or the PCB Rule can be liable for a civil penalty of up to $25,000 per day of violation.

### 3.8.3.3 Identifying PCB Transformers and Capacitors

PCB Transformers were manufactured in the U.S. from 1932 to 1978. They contain PCBs in an oil which is generally called "askarel liquid," however many of the manufacturers identified the PCB askarel liquid by a trade name. There are also mineral oil transformers that have been contaminated with PCB through past servicing procedures. These transformers do not contain askarel but are presumed by EPA to be PCB-contaminated unless tests prove otherwise.

The transformer nameplate, located in a prominent position on the exterior surface, identifies if the transformer is liquid-filled or dry. It usually identifies the type of liquid. Terms such as "Non Flammable Liquid Filled Transformer" or "Inerteen" identify that the transformer is of the PCB askarel type. It is important to note whether or not the transformer is liquid-filled, and if so, to identify the name of the liquid printed on the nameplate. If there is no nameplate, a liquid-filled transformer can be identified by the presence of liquid cooling fins on the outside of the transformer. Transformers without nameplates may contain PCBs. The following are common transformer and PCB fluid names.

| PCB Transformer Manufacturers | PCB Fluid Names |
|---|---|
| Allis-Chalmers | Chlorextol |
| American Corporation | Abestol |
| Esco Manufacturing Co | Askarel |
| Ferranti-Packard Ltd | |
| Hevi-Duty Electric | |
| Research-Cottrell | |
| General Electric | Pyranol |
| ITE Circuit Breaker Co. | Non Flamaable Liquid |
| Kulman Electric | Saf-T-Kul |
| Monsanto (fluid only) | Aroclor |
| Niagara Transformer Corp. | Askarel, EEC-18 |
| Power Zone Transformer | EEC-18 |
| Wagner Electric | No-Flamol |
| Westinghouse | Inerteen, Nepolin, Dykanol |
| Electro-Engineering Works | Various fluid names |
| Envirotech Buell | |
| H.K. Porter | |
| Helena Corp. | |
| Maloney Electric | |
| Standard Transformer Corp. | |
| Uptegraff Manufacturing Co. | |
| Van Tran Electric | |

PCB Capacitors were manufactured in the United States from 1930 to 1978. They range in size from the small capacitors found in fluorescent light ballasts, to the large electric substation capacitors containing 3 lb or more of PCB fluid. In mines, the larger capacitors may be found in the mine's electric power substation, mobile power centers, and control boxes of large electric motors. Many, but not all, capacitor manufacturers identified the PCB fluid on the nameplate, using a PCB fluid trade name. Some common manufacturers and trade names are as follows.

| PCB Capacitor Manufacturers | PCB Fluid Names |
|---|---|
| Aerovox | Hyvol |
| Cornell Dubilier | Dykanol |
| Electrical Utilities Corp. | Eucarel |
| General Electric | Pyranol |
| Jard Corporation | Clorphen |
| McGraw Edison | Elemex |
| Monsanto (fluid only) | Aroclor |
| | Capacitor 21 |
| | MCS 1489 |
| P.R. Mallory & Co. | Diaclor |
| Sangamo Electric Co. | Clorinol |
| Universal Manufacturing | Askarel |
| Westinghouse | Inerteen |
| Axel Electronics | Various |
| Capacitor Specialists | fluid names |
| Electromagnetic Filter | |
| R.F. Interonics | |
| Tobe Deutschmann | |
| York Electronics | |

### 3.8.3.4 The PCB Mark

PCB Transformers and large high-voltage capacitors *must be marked by the owner* with either a yellow or white label ranging in size from 2 inches on each side to 6 inches on each side, depending on the size of the equipment. The mark identifies that the equipment contains PCBs and requires special handling and disposal in accordance with EPA regulations. It also identifies the National Response Center toll-free number (800-424-8802) which must be called in the event of an accident or spill. The marking format is identified in *40 C.F.R. § 761.45, Marking Formats*. Note that the absence of a mark does not mean there are no PCBs. It means that the owner may have failed to attach the mark as required by the PCB Rule.

### 3.8.3.5 PCBs Underground: A Special Regulatory Concern

The U.S. EPA has two major concerns regarding PCBs in underground mines. The first, which applies not only to mines but to all users of PCBs, is compliance with the regulations that reduce the risk of release of PCBs and environmental and human exposure. Transformer maintenance and inspections, fire response registrations,

and other risk-reduction requirements are specified in detail in the PCB Rule and are strictly enforced.

The second, a problem unique to underground mines, is the potential for abandonment of PCB electrical equipment underground.

A NIOSH survey of underground mines in the mid-1980s indicates that, of the 1,800 mines in operation (this figure varied daily), some 900 mines were still using PCBs. While this figure can only be considered an estimate, it indicates there could still be a significant number of mines with PCBs today.

PCB electrical equipment requires regular maintenance to prevent (or repair) leaks. EPA assumes that once electrical equipment is abandoned underground, the PCBs will be released into the ground water. Even where the equipment is not submerged, an abandoned transformer will leak, adding to the atmospheric levels of PCBs if the mine is naturally ventilated.

### 3.8.3.6 MSHA, EPA, and Underground Mines

The Mine Safety and Health Administration (MSHA) inspects every underground mine four times each year. At any one time there are about 1,800 underground mines in operation, some of which are believed to use PCBs. At the time of this writing, MSHA inspectors are filling out PCB checklists for each underground mine and sending them to the appropriate EPA Regional office for follow-up inspections by EPA. Also, MSHA inspectors will distribute handouts describing the PCB Rule, and who to contact in EPA for specific compliance information. By 1994, EPA will know which mines have PCBs, how much is underground, whether there were any apparent violations, and whether the mine is likely to close soon.

### 3.8.3.7 Enforcement and the PCB Penalty Policy

Throughout the 1980s and early 1990s, EPA inspected a number of mines and discovered a variety of TSCA PCB violations. Some examples:

1982 EPA learned that a coal mine illegally abandoned PCB Transformers in a sealed section of the mine. Removal was deemed impossible due to hazardous conditions.

1983 A 500 gallon PCB Transformer ruptured and the entire contents were spilled. EPA denied the company's petition to allow the PCBs to remain underground, citing concerns about ground water contamination.

1984 EPA Superfund removed three PCB Transformers and 21 PCB Large Capacitors from an abandoned metal mine. Also removed were 200 gallons of various petroleum products.

1985 EPA inspected a metal mine and cited use, record keeping, and disposal violations at 10 underground substations. A civil complaint was issued for $45,000.

1986 EPA inspected a metal mine and issued a civil complaint in the amount of $66,000 for use, marking, storage, record keeping, and disposal violations.

1987 EPA inspected a metal mine and issued a civil complaint for $4,500 for PCB disposal and use violations.

1991 Three mine companies agreed to remove PCBs to offset penalties for a number of violations.

1991 EPA Superfund removed 300 PCB Transformers and capacitors from a recently abandoned metal mine.

1991 EPA issued a $1.4 million complaint against an open-pit mine for use, record keeping, and disposal violations.

1993 EPA issued a $174,000 complaint against an open-pit mine for use, record keeping, and marking violations.

EPA first determines whether a violation exists by properly inspecting a facility. The inspector's report is then sent to the EPA Regional office, where a determination is made whether any violations discovered by the inspector warrant an enforcement action. EPA has the following enforcement options:

1. Issue a Notice of Noncompliance. This is a formal letter from EPA to the facility identifying the violations that were found by the inspector, and requesting a reply describing the actions that will be taken to correct them.

2. Issue a Civil Administrative Complaint. This is a complaint seeking monetary penalties calculated under the PCB Penalty Policy.

3. Seek injunctive relief through U.S. District Court against any person who manufactures, processes, distributes in commerce, uses, or disposes of an imminently hazardous chemical substance or article containing such substance.

4. Refer the case to the U.S. Department of Justice for criminal prosecution.

Most significant PCB violations are handled by a civil administrative complaint (CAC). When the EPA issues a

CAC against a party for violating TSCA, the Agency sets in motion a procedural process that is tightly controlled under the Administrative Procedure Act. The rules governing the process are known as the Consolidated Rules of Practice Governing the Administrative Assessment of Civil Penalties and the Revocation and Suspension of Permits (*40 C.F.R. Part 22*). In short, the Agency is required to grant the party a hearing on the matter. Such hearings are normally held before an Administrative Law Judge, who by statute is largely independent of EPA's supervision to ensure impartiality in presiding over cases. Most cases do not go to hearing, but are settled between EPA and the respondent. Nation-wide, and for all industries, EPA concludes some 250 PCB cases each year, collecting $5,000,000 in civil penalties (penalty figures can vary considerably year to year).

Penalties assessed under CAC's are calculated using the April 9, 1990 PCB Penalty Policy. The policy has as its foundation the following principles:

1. TSCA is a strict liability statute. There is no requirement that a violation be willful or knowing in order for EPA to proceed with an enforcement sanction.

2. The penalty is based on the amount of PCBs involved, and the circumstances of the violation. For example, minor record keeping violations involving no environmental release of PCBs may involve a one-time penalty of $200. Conversely, unauthorized disposal of PCBs may be subject to a penalty of up to $25,000 per day of violation.

3. Upward or downward adjustments to the base penalty are made in consideration of the violator's culpability, attitude, history of prior violations, ability to continue in business, and other factors as justice may require. The policy grants significant penalty reductions for those who voluntarily disclose and correct their violations.

4. Conditional settlements to reduce the proposed penalties are encouraged. Historically, EPA has reduced penalties where the violator proposed to properly dispose of all PCBs at the facility. Other environmentally beneficial projects have also been approved by EPA.

Under the PCB Penalty Policy, penalties for PCB violations are divided into two main categories; non-disposal violations, and disposal violations. For users of PCB electrical equipment, some common non-disposal violations include (but are not limited to), failure to affix the proper PCB mark on the equipment, failure to mark the access to the equipment (e.g., a transformer vault door or substation gate), failure to inspect transformers quarterly, failure to maintain annual documents listing the PCBs in use and the PCBs that have been removed from service for disposal, and failure to mark PCB equipment with the date it was removed from service for disposal. Other common non-disposal violations include failure to notify the fire department of the existence of PCBs, storage of combustible materials (such as solvent or paper) on or within 5 meters of a transformer or transformer enclosure, and improper storage of PCBs removed from service for disposal. Examples of penalties involving a PCB Transformer of less than 1,200 kilograms would include $1,000 for failing to affix the proper PCB mark, $3,000 for improper storage, and $12,000 for failing to conduct quarterly inspections.

Common disposal violations include leakage of PCBs, spills that occur while moving equipment, and other releases of PCBs such that the chemical is no longer totally enclosed and isolated from the environment. Many respondents have been surprised to learn that EPA assesses penalties for leaks that appear only as stains, or small drips, on or very near transformers and other equipment. Penalties for the smallest disposal violations range from $1,500 to $5,000, depending on whether or not the PCBs left the surface of the equipment. Another relatively common violation is the failure to properly clean a spill in accordance with the PCB Rule. Although TSCA is a strict liability statute and EPA could assess penalties for accidental disposal or spills, EPA published in the PCB Rule the Spill Cleanup Policy, which if followed, creates a presumption against enforcement for the violation. Respondents that fail to comply with the cleanup policy are assessed penalties for improper disposal.

Disposal violations are the most serious and can result in very substantial penalties. It is not uncommon for EPA to assess penalties of $25,000 per day of violation, for as many days as the disposal violation persists. Abandoning PCB electrical equipment in a mine could result in such per-day penalties, depending on the circumstances of the case.

Copies of the PCB Penalty Policy are available by contacting the EPA Toxic Substances Control Act Hotline at (202) 554-1404. The Hotline can also answer regulatory questions and to provide the names of EPA contacts.

### 3.8.4 NOISE POLLUTION

The statutes discussed thus far deal with the contamination of various environmental media by chemical pollutants. However, there are other forms of "pollution" that can be regulated. One such pollutant is noise. Due to the necessity for large machinery at mine and mill sites - such as heavy trucks and loaders, crushers, and other material handling equipment - the miner must be aware of noise abatement requirements on equipment imposed by federal and state law.

The Noise Control Act of 1972 (*42 U.S.C. § 4901*)

was enacted to promote an environment free from noise that poses a risk to human health and welfare. Programs authorized under the Act include noise control research, establishment of federal noise emission standards for products distributed in commerce, and education of the public regarding noise emission and reduction. Programs of primary importance to the mining industry are those promulgating noise emission standards for transportation equipment (*40 C.F.R. Part 205*) and construction equipment (*40 C.F.R. Part 204*). These programs typically require control equipment to reduce noise emissions, labeling, and testing requirements. The principal impact on the mining industry will likely be the prohibition on tampering with or removing noise abatement equipment from machinery used at the mine or mill (*42 U.S.C. § 4909*).

Mine operators should also be aware of state noise abatement statutes regulating noise levels within designated land uses. These statutes are typically intended to address nuisance situations and should have a small impact on remote mine locations. For example, the State of Colorado has established statewide standards for noise level limits for various land-use classifications (*C.R.S. § 25-12-101*). The levels established vary depending on the land use and time of day. If a sound level is exceeded for the time and zone, it is deemed to be a public nuisance.

### 3.8.5 OIL SPILL LEGISLATION

In response to the Exxon Valdez oil tanker disaster in Prince William Sound, Alaska, Congress enacted the Oil Pollution Act of 1990 (OPA) (*33 U.S.C. § 2701*). In the aftermath of that disaster, existing federal laws were inadequate to fully redress injured parties and compensate for lost natural resources. CERCLA could not form the basis for recovery actions because the petroleum is excluded from its reach. As a result, Congress passed legislation for oil spills patterned after the CERCLA liability scheme.

Under the act, the responsible party of a vessel or a facility from which oil is discharged, or threatened to discharge, into or upon the navigable waters or adjoining shorelines, or the exclusive economic zone, is liable for removal costs and damages that result from the incident (*33 U.S.C. § 2702(a)*). "Damages" can include natural resource damages, damage to real or personal property, loss of subsistence use of natural resources, or loss of taxes, royalties, rents or profits. "Navigable water" is a term of art that has been given a broad reading by the government and the courts under the Clean Water Act. Today, the term has little to do with actual navigability and includes most rivers, streams, lakes, ponds, and wetlands. Consequently, the reach of OPA is expected to be greater than just the ocean disasters that brought about the legislation.

The application of OPA to mining companies will likely be minimal. It is possible that fuel spills from a mine operation into "navigable waters" could trigger cleanup liability. However, the larger risk may come from a potential broadening of the liability scheme by courts. For example, it is possible that a leaking underground storage tank might trigger liability. Although subsurface waters are not included within the definition of "navigable waters," if the nexus can be established between the groundwater and surface waters, the Act may potentially trigger cleanup liability for fuel releases from underground storage tanks and subject the mine operator to damage actions under OPA.

OPA also amended section 311(j) of the Clean Water Act regarding oil and hazardous substance liability. The new provisions set out requirements for oil handling facility response plans and periodic inspections of discharge/removal equipment. In general, response plans must: 1) be consistent with the National Contingency Plan (NCP); 2) identify persons with authority to implement removal actions; 3) identify and ensure private personnel and equipment necessary to remove to the maximum extent practicable a worst case discharge and to mitigate or prevent a substantial threat of such a discharge; and 4) describe the training, equipment testing, periodic unannounced drills, and response actions to carry out the plan (*33 U.S.C. § 1321(j)(5)(C)*).

Affected persons include owners and operators of a tank vessel, an offshore facility, and an on shore facility that, because of its location, could reasonably be expected to cause substantial harm to the environment by discharging oil into or on the navigable waters, adjoining shorelines, or the exclusive economic zone. Mining companies may be subject to the response plan requirement if it owns or operates a facility near a navigable water and it meets the as yet undefined petroleum volume threshold for such facilities.

### 3.8.6 ARCHAEOLOGICAL CONTROLS

Congress has passed numerous laws in order to protect artifacts with historic, cultural, and scientific significance on public lands. Because of the threat of destruction from commercial development, the statutes are directed towards preservation and protection of these resources with historic or archaeologic significance. Mining activities can potentially affect cultural resources through physical disturbance or as a consequence of the impacts of increased traffic or pollution. For example, mining activities in historic mining districts may impact old buildings and other structures with historic meaning. Other times, mining activities may occur in areas where centuries old Native American traces may be found and the increased human traffic in these areas may lead to destruction and vandalism. The following sections introduce several of the federal cultural resource acts.

#### 3.8.6.1 Archaeological Resources Protection Act of 1979

The Archaeological Resources Protection Act of 1979 (*16*

*U.S.C. § 470aa*) and its predecessor, the Antiquities Act of 1906 (*16 U.S.C. § 431*), protect archeological resources on public lands and Indian lands. Under the Antiquities Act, the President is authorized to designate national monuments on federal lands in order to protect structures of historic, prehistoric, or scientific interest. Unauthorized appropriation, excavation, injury, or destruction of such objects of antiquity can lead to criminal penalties under the act.

As a result of court challenges to the Antiquities Act, Congress enacted the Archeological Resources Act which further defined the objectives of the Antiquities Act. The Archaeological Resources Protection Act prohibits the excavation, removal, damage, or other acts that may alter or deface archeological resources in the absence of a federal permit authorized by the federal land manager with jurisdiction over the federal land (*18 C.F.R. Part 1312, 32 C.F.R. Part 229, 36 C.F.R. Part 296,* and *43 C.F.R. Part 7*). "Archeological resources" is defined in the Act as any material remains of past human life or activities which are of archeological interest, such as pottery, basketry, bottles, weapons, weapon projectiles, tools, structures, pit houses, rock paintings, rock carvings, graves, and human skeletal materials (*16 U.S.C. § 470bb(1)*).

The primary purpose of the Act is to protect archeological resources from theft and vandalism by requiring a permit for excavation or removal of archaeological resources. However, general earth-moving construction conducted under another federal authorization does not constitute an activity requiring a permit under the Archaeological Resources Preservation Act. Nonetheless, the federal land manager must still comply with other authorities protecting archeological resources prior to permit or lease approval. The Act would, or course, cover any looting of sites uncovered during the course of the earth-moving activity.

### 3.8.6.2 Natural Historic Preservation Act

The Natural Historic Preservation Act of 1966 (*16 U.S.C. § 470*) requires the identification and protection of properties that qualify for listing on the Nation Register of Historic Places. Section 106 of the Act requires a federal agency with jurisdiction over a federally-assisted undertaking or authorized to issue any license to take into account the effect of the undertaking on any district, site, building, structure, or object that is included on or eligible for inclusion in the National Register. Regulations promulgated under the Act are intended to guide federal agency officials, state historic preservation officers and the Advisory Council on Historic Preservation in conducting the Section 106 review (*36 C.F.R. § 800.1*). An adverse effect occurs when the undertaking diminishes the integrity of the property's location, design, setting, materials, workmanship, feeling, or association. Actions must be taken to avoid or reduce the effects on the historic property.

The mine operator contemplating operations in an area with historical significance must keep several points in mind regarding the National Historic Reservation Act. First, the scope of federal actions that could initiate a review will likely be large. Second, it does not matter if the proposed mining activity is on private or public land. Third, the types of properties on the National Register are varied. And fourth, the Act essentially requires a preconstruction review.

### 3.8.6.3 Historic Sites Act

The Historic Sites Act of 1935 (*16 U.S.C. § 461*) and the accompanying National Historical Landmarks Program (*36 C.F.R. § 65.1*) establishes procedures for identifying National Historic Landmarks sites, buildings and objects that commemorate the history and prehistory of the United States. The criteria for designating a site a National Historic Landmark is somewhat more stringent than the criteria for designation under the National Historic Preservation Act. Any undertaking that may affect an identified Landmark will require the responsible federal agency to minimize harm to the maximum extent possible.

### 3.8.6.4 Historical and Archaeological Data Preservation Act

The Historical and Archaeological Preservation Act of 1974 (*16 U.S.C. § 469*) was enacted to preserve historical and archaeological data that could be lost or destroyed as a result of any federal construction project or federally licensed activity or program. Under the act, the Secretary of the Interior is directed to evaluate whether significant data will be irrevocably lost during such a federal action and conduct a survey of the affected area and recover or preserve data in the public interest. The Act may impact mining operations on public land by delaying the issuance of permits pending a review of archaeological data, or possibly forming the basis for a permit denial.

### 3.8.6.5 State Programs

A State may also protect cultural resources within its boundaries. In fact, most states have some form of legislation protecting and preserving historic, archaeologic, and scientific sites. The mine operator must review the laws of the state where the operation will be located in order to determine whether there are additional requirements it must meet before mine development. For example, in Colorado, the State has reserved title to all historical, prehistorical, and archaeological resources on lands owned by the state (C.R.S. § 24-80-401). Permits are required for removal or disturbance of such resources.

## 3.8.7 MIGRATORY BIRD TREATY ACT

The Migratory Bird Treaty Act (*16 U.S.C. § 701*)

implements provisions in various international treaties for protection of migratory birds. Protected species number almost 1000 birds identified in the treaties and include such common birds as ducks and geese (*50 C.F.R. § 10.13* ). Under the act, it is a criminal offense to kill any protected bird. The Act contains misdemeanor and felony provisions. Moreover, courts have held that it is a strict liability offense. Therefore, it does not matter if the deaths were accidental and measures were taken to avert the killings.

Operators of heap leach operations may inadvertently face liability under the act. As part of the metal recovery process, cyanide or other harmful solutions are often held in open ponds near leach piles. Migratory birds in flight are attracted to the ponds that are often the only water-appearing bodies in desert regions. Exposure to toxic water potentially leads to the birds' death, thus exposing the operator to civil and criminal liability regardless of any mitigating measures the operator may have taken.

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# Chapter 4

# ENVIRONMENTAL CONTROL AT THE STATE LEVEL

edited by G. E. Conrad

## 4.1 INTRODUCTION

Environmental control occurs primarily at the state level. Long before the advent of federal programs, most states had adopted laws and regulations aimed at controlling or abating pollution. During, and even after, the "environmental decade" of the 1970s, the states continued to develop their own environmental laws. Sometimes this development was in direct response to new federal programs, which provided for the submission of state "plans" and for federal approval of "state programs." In other cases, state law developed to address particular environmental concerns, or in response to the emergence of a state constituency favoring increased environmental protection.

The fact is, most environmental law in the United States is *state* law. Every state has detailed laws governing air pollution, water pollution, waste disposal, and resource management. These laws affect more people, more decisions, and more interests than the oft-discussed federal laws. In many states, the federal programs are essentially implemented entirely by state law; that is, a facility's specific compliance obligations under the Clean Air Act, the Clean Water Act, and other statutes, are defined by state law, state regulations, and state permits. While many of these state laws track the federal statutes nearly verbatim, others provide for significant variation. Sometimes this variation reflects the preexistence of established state programs. Other times it reflects conscious efforts by state legislators to address environmental problems in a different way.

Perhaps the most important thing to recognize about state environmental law is its independence of federal authority. While many state laws are patterned on the federal laws, and may even operate as federally "authorized" state programs, the basis for state environmental regulation actually lies in the states' police power–the inherent authority of the sovereign to protect the health, safety, and welfare of its citizens – not upon a federal "delegation" of the commerce power. In short, the federal statutory overlay does not "empower" the states to do anything. Rather, it enlists the states to exercise *their* inherent authority to enact laws regulating activities that affect the environment. All of the state laws operate from their own force. Thus, state environmental law is not simply a vestige operating with respect to federal environmental law. Nor does state law operate solely to "fill in the blanks" set out in federal law. Rather, state law ordinarily sets out a full program of regulation that may include not only those elements needed for federal "authorization," but also numerous additional elements (for example, state water pollution laws regulating non-point sources and discharges to groundwater, laws requiring siting approval for solid and hazardous waste disposal facilities, or laws requiring state permits for "interim status" RCRA facilities that require no federal permit). Unless it is affirmatively preempted, state environmental law operates whether or not there is a federal "authorization" of a given state program.[1]

The preponderance of modern environmental law practice then is the practice of state law. Aggregate state budgets for environmental issues far surpass the federal budget commitment, and state and local government employees working on environmental regulatory issues vastly outnumber their federal counterparts. This state-centered focus commenced prior to the "new federalism" of the Reagan Administration, which merely added an ideological commitment to leave implementation to the states. Thus, environmental law, which was enacted first at the state level rather than the federal level, continues to have a strong state focus even after several decades of federal activism and legislation.

The emphasis today on federal environmental law is

1) For a general overview of federal/state relations in the environmental arena, *see generally* McElfish, James M., "State Environmental Law and Programs", *Law of Environmental Protection* (Clark Boardman, 1990); Pederson, *Federal/State Relations in the Clean Air Act, the Clean Water Act, and RCRA: Does the Pattern Make Sense?*, 12 Envtl. L. Rep. (Envtl. L. Inst.) 15069 (1982); Symposium, *The New Federalism in Environmental Law: Taking Stock*, 12 Envtl. L. Rep. (Envtl. L. Inst.) 15065 (1982).

due only in part to the importance of federal law in defining the national environmental agenda and in prescribing the means of implementation. A major reason for the predominately federal focus has been the sheer magnitude and variability of state environmental laws, regulations, procedures, and institutions. State law must be viewed as a major functional program in order to understand the breadth and scope of environmental law. As environmental law reaches maturity, practitioners and scholars alike have recognized that much of the "action" is really occurring at the state level. It is this level of environmental control on which this chapter will concentrate. Given the magnitude of the subject matter, the chapter will provide an overview of state environmental laws as they affect the mining industry.

The chapter begins with a general discussion of the state-federal allocation of responsibilities. It then turns to a general presentation of how state regulatory programs are structured to address environmental control. Several specific state programs are then discussed in detail as examples of how some states have dealt with environmental regulation. Finally, an overview of several multi-state organizations that represent the interests of the states on environmental issues is presented as an example of how states are working together to solve the next decade's environmental concerns.

## 4.2 STATE-FEDERAL ALLOCATION OF RESPONSIBILITIES

Environmental law operates in the United States most frequently as a mixture of federal and state standards, goals, requirements, limitations, and enforcement authorities. This federal-state combination has been described in various ways. The EPA speaks of the state-federal "partnership." Others refer to the same relationship as "cooperative federalism," the "new federalism," or simply "federalism." The federal role is often described as "oversight." The state role, which is to carry on the direct application of the law under most of the federal statutes, is variously described as state "primacy," state "authorization," program "approval," or "delegation."

The use of various terms reflects the organic and changing quality of federal and state responsibilities under the major federal environmental programs. The terms are often used interchangeably, or to describe specific features of the state-federal interface as perceived at a given time. Regardless, it is important to recognize (as noted above) that none of the federal statutes effectively "delegates" any federal power to the states. Rather, the federal government relies on the states' own inherent and constitutional powers to carry out environmental implementation responsibilities, and, upon recognition of a state's programs, refrains from exercising federal powers to their fullest in that state. Likewise, lack of federal "authorization" in a state simply means that the federal government must promulgate and implement a full-blown federal effort in that state in addition to whatever independent efforts the state might make.

Thus, the actual division of responsibilities between the federal government and the states is significant. The ability of the federal government to persuade (or coerce) states to seek and maintain authorization under each program is also important, as this affects allocation of both federal and state resources. Finally, the federal government's oversight and "residual" enforcement activities in approved or authorized states represent a continuing contact between federal and state officials that significantly influences the actions of state officials and hence also the response of the regulated industry.

Today, state environmental statutes, policies, and institutions reflect not only the outlines of the well-known federal programs, but also the states' diverse ecosystems, political history, and economic dependencies. In many substantive areas the states have served as "laboratories" for the development of new and innovative approaches to environmental problems. In some cases, these approaches have led to the subsequent adoption of national laws and policies drawing on the experiences of a few leading states.

## 4.3 STATE ENVIRONMENTAL PROGRAMS[2]

Each state's approach to environmental regulation, particularly with regard to mining, is as diverse as the geographical and climatic differences between the states. In fact these latter differences often account for the variety that it is found among state regulatory programs and justify the need for flexibility in approaching environmental regulation at the state level. Even with the differences among states, several general observations can be made that will assist the practitioner in understanding how to deal with state regulatory authorities.

### 4.3.1 GENERAL OBSERVATIONS

First, there are certain dominant organizational patterns

2) Significant portions of Section 4.3 are taken from "State Regulation of Mining Waste: Current State of the Art" (November 1992), prepared by the Environmental Law Institute (ELI) pursuant to a grant agreement with the U.S. Environmental Protection Agency. This material is used with permission of the author, Mr. James M. McElfish, Jr., Senior Attorney with ELI, to whom the coordinating author for this chapter is deeply grateful. ELI has recently expanded and expounded upon the results of the original EPA study in a book entitled "Hard Rock Mining: State Approaches to Environmental Protection," available from ELI.

that can be identified. These incorporate key regulatory components in a few, basic variations. The most evident organizational variable is the degree of centralization of regulation. In the vast majority of states, there is one central environmental agency, usually with separate divisions for each medium. In a smaller group of states, there are separate environmental agencies. Most of those jurisdictions use a hybrid approach, combining some media in one agency while allocating others to single-medium agencies. In the other states following the separate agencies approach, each of the environmental media – air, water, and land – is regulated by a separate, medium-specific agency.

A second, major component of state organizational patterns is the allocation of authority as between multi-member boards, on the one hand, and individual staff executives on the other. Here there is considerable diversity in the states' approaches. It is very common, however, for rule making authority and administrative adjudicatory powers to be vested in boards or commissions. Agency chiefs – usually known as executive officers, administrators, or department directors – are often more directed to perform implementation and enforcement functions. Almost all states have allocated environmental regulatory powers to some combination of boards and executive officers. In some instances, boards are created which are only advisory in nature, especially for the purpose of developing or commenting upon proposed regulations or other staff programs.

State environmental statutes generally include both standard setting and enforcement provisions. State standard setting has not been entirely overtaken by federal requirements, although flexibility in such standard setting has been somewhat constricted by federal law. In most states, standard setting has been legislatively delegated to the administrative agencies. In some cases, public commissions with memberships representing various governmental, industry and public constituencies are assigned this function. In a number of states, the agencies are given broad authority to promulgate rules in order to protect the environment.

State enforcement responsibilities are generally carried out by administrative agencies, with or without the assistance of the state attorney general. Every state has the ability to issue administrative compliance orders to enforce air pollution standards. Most states also use administrative orders for water and hazardous waste violations. The availability of administratively assessed penalties varies.

In looking at specific state approaches to the environmental regulation of mining, one finds that the art of mining regulation is still evolving in the states. The primary regulatory elements in most cases are fewer than ten years old. Many are even newer – e.g., Nevada's 1989 "zero discharge" program and its 1990 reclamation program; Arizona's 1990 best available demonstrated control technology (BADCT) draft guidance manual; Idaho's 1988 cyanidation regulations; Missouri's 1989 Metallic Minerals Waste Management Act; Montana's 1990 custom milling and reprocessing regulations; and New Mexico's 1993 hard rock mine reclamation act. Legislation and regulations are constantly being updated due to at least three factors: increasing regulatory experience and advancing technology; citizen and legislator concerns within the states; and the states' anticipation of federal action. The state of the art of mining regulation in the states is therefore a moving target. Practitioners should be prepared to familiarize themselves with the details of each state's regulatory program before proceeding with a mining venture. A listing at the end of this chapter provides a contact agency for each state that should be consulted for further information and updates.

Mining is primarily regulated by either a reclamation-based program, or a water pollution-based program. Colorado, Idaho (except for cyanidation facilities), Missouri, Montana, and South Dakota, for instance, rely chiefly on their reclamation programs for most mining regulation. Arizona, California, Florida, Nevada and South Carolina primarily rely on water quality programs.

Coordination among agencies and units with responsibility for mining is disparate. Varying levels of overlap, underlap, coordination and responsibility occur among the agencies with jurisdiction. In most states there is a sharp division of labor, which is primarily based on the organization of state governmental units and on when the programs were enacted or regulations adopted. As an example, the programs are wholly unified in Nevada, which has both reclamation and water quality approaches administered by the same unit within the Division of Environmental Protection. South Carolina, however, has traditionally divided responsibilities between its Land Resources Conservation Commission and its Department of Health and Environmental Control, but at least as to gold mines, coordinates permitting and other activities very closely. Interestingly, South Carolina has recently set upon an initiative to rest all the responsibilities for the regulation of mining operations within a single agency – the Department of Health and Environmental Control.

The terms and conditions under which mining is actually carried out are primarily determined by negotiation between the mine operator and the state, with varying levels of, and opportunities for, input from other state agencies and the public. Thus, for example, South Carolina, which has few design criteria specific to mine waste units, may nevertheless impose permit requirements similar to those of California, which has lengthy, prescriptive standards. In virtually every case, the standards that matter are those set out in the permit, rather than those appearing in the statute or regulations. Nevertheless, the statutory or regulatory standard is quite

important, because it establishes the terms and conditions under which the "negotiation" takes place. For example, in Nevada, the regulations provide the state with discretion to require considerable quantities of information and justifications. In California, the regulations provide the state with a prescriptive standard that in effect becomes the "default standard" if the parties cannot agree on alternative terms and conditions acceptable to the state. In other states, such as Colorado or Montana, the negotiation is chiefly based on representations about how the broad performance standards can be achieved. In Arizona, the BADCT negotiation follows a format of recommended approaches outlined in a draft guidance document.

### 4.3.2 SPECIFIC COMPARISONS

Despite the difficulty of comparing programs that differ from one another so greatly in structure, coverage, history, mining types, geography, and administration, some fairly specific comparisons can be made. It must be kept in mind, however, that because mine regulation is so permit-specific, comparisons of the regulatory provisions or elements may not accurately reflect what is actually being required on the ground under the states' performance standards and other authorities. Thus, there is a need to contact the respective regulatory authority for specific information.

#### 4.3.2.1 Permitting

The states utilize a variety of permit, license and approval systems to regulate mining. Most states have a mining and reclamation permit or a mine waste permit. Most states also use multiple permits for the various media impacted by a mining operation (air, water, soils). Where a comprehensive permit is utilized, it often covers all media by incorporating by reference the specific conditions of other permits.

In many states, programs are divided between two principal departments, often a department of environmental protection and a department of natural resources. In some cases, departments have the responsibility of balancing environmental protection and economic development. It is not unusual for additional state departments or agencies that deal with occupational health and safety, water resources and water rights, local affairs, and others to be involved in the mine permitting process.

States use a variety of methods to communicate and coordinate among the numerous state, local and federal agencies involved in a mine permit review. Many of the processes are informal; others are established by statute, executive order or memoranda of agreement among the involved agencies. Some states use a designated lead agency to coordinate this process, at least among the major permits and agencies involved. Other states use a coordinated review process, but without a designated lead agency. The majority of the states conduct independent, multi-agency reviews of permits with no formal coordination mechanism. However, some states choose to coordinate major projects through the governor's office or use a conflict/coordination group process to resolve inter-agency conflicts.

In order to initiate the regulatory process, a mining company is required to submit plans describing its proposed mining operations to the state. The form and content of such plans vary greatly from state to state. States also take different approaches to the review of these required plans during the permit issuance, modification and renewal processes. Among the types of plans required are the following:

- Mine plan – which defines an operator's proposed course of action and is submitted to the state for approval.
- Closure plan – which describes how the operator will terminate operations and monitor environmental conditions throughout the duration of the period defined by statute or regulation and in a manner consistent with the site's mine plan.
- Post-closure or reclamation plan – which describes how environmental and physical conditions at the site will be monitored and maintained after the closure plan has been completed.
- Baseline monitoring plan – which describes the condition of the site prior to the existence of the operation in order to determine at a future date, the degree to which the operation has had an impact on the site and to provide a basis for closure requirements.
- Operational monitoring plan – which provides for verification of compliance with standards, criteria and permit conditions. It is usually site specific and includes pollutants to be monitored, monitoring frequency, procedures, locations, etc.

Comparison of state programs demonstrates the great variability in the type and amount of information required at the permit stage. For example, permit programs vary significantly as to the background information they require of applicants on their mining histories, or compliance histories with environmental laws. A number of states, however, including Montana, Nevada, and South Dakota, have "permit block" provisions. Most state programs include some waste characterization requirements in permitting, but few specify methods. California has a detailed waste classification scheme and prescribes both the acid-base accounting approach and the toxicity testing method that

must be used. Monitoring requirements vary among the states as well. Some programs expressly require groundwater monitoring around mine waste disposal units (e.g., Missouri, Montana, Nevada, California, Arizona and Idaho). In other states, such monitoring is discretionarily required as a condition of the permits.

#### 4.3.2.2 Standards Setting

Most permit programs rely substantially on performance standards. Most require assurance of the protection of surface and groundwater quality, control of sediment, protection of wildlife and similar requirements. All states have some form of groundwater regulations that apply to mining waste. Beneficial use categories (e.g. a use for specific purposes such as drinking water or agriculture, as defined by statute or regulation) are used in several states. Many states have non-degradation or anti-degradation standards. Other states have water quality standards for specific pollutants – for example, standards for heavy metals such as lead or cadmium – which are included in their regulations.

With regard to surface water quality, all states apply controls to protect this medium such as water-use categories and non-degradation or anti-degradation standards. All of the states have in-stream standards that set allowable limits for specific parameters. Numerous types of discharge controls apply to the environmental control of mining at the state level in the form of point source effluent limits for mining (usually associated with the Clean Water Act NPDES program) and non-point source controls such as sediment controls, run-off quality limitations and upstream diversion of water to prevent contact with mine waste.

Air quality is an important consideration in mining activities that produce fugitive dust or in cases where the air pollutants may contain hazardous materials such as metals or fibrous materials. Several states have specific regulations pertaining to the same criteria pollutants from mining operations as indicated in the Clean Air Act. Visibility protection and Prevention of Significant Deterioration (PSD) evaluations as well as environmental concerns near Class I areas are normal parts of permit reviews in states that have approved State Implementation Plans (SIPS) under the Clean Air Act. All of the states apply specific controls to fugitive dust from mining and mine waste.

#### 4.3.2.3 Closure and Reclamation Controls

Most of the states currently require mine waste closure to be conducted by the owner/operator under the conditions of one or more permits and approvals. Several states require physical stabilization for structural integrity. Other requirements vary among the states and include specific final landforms (e.g. shape, cover and contours), waste neutralization or fixation, stabilization of final drainage systems (e.g. permanent drainage/flood controls, diversions, etc.), revegetation, and restoration of wildlife habitat. Some states have long-term monitoring requirements to demonstrate compliance with closure requirements and to detect environmental problems. States often have maximum allowable time limits in which to achieve closure. Some states allow for a stand-by status which provides for temporary deferral of final closure with reasonable cause. This is usually provided to deal with the cyclical nature of the mineral business, thereby avoiding premature site closures but at the same time ensuring that a site cannot remain in stand-by status indefinitely. Conditions may accompany these extensions for completing closure including continuation of monitoring and demonstration of compliance with environmental standards and permit conditions, maintaining complete financial assurance instruments, and continued or periodic economic justification for deferred closure.

Not all states distinguish between closure and post-closure. Several states do require site access controls (e.g. fencing, posted signs, security measures) for post-closure. Some of the states have defined allowable final land uses and some have requirements or limitations on ownership/liability transfer. A specific post-closure care period is designated by a few states, but in some of these states the time period can be adjusted on a case-by-case basis. A final state inspection is required in most states before the operator may be released from financial responsibility. Some states require the operator to certify that closure has been completed. In a few states a deed/abstract affidavit indicating that the site contains mine waste materials is required prior to final site release by the state.

#### 4.3.2.4 Financial Assurances

Financial assurance requirements differ significantly from state to state. Some states require financial assurance for the costs of reclamation, while others require financial assurance for discharge contingencies and for closure of waste management units. Several states require both or accept a combined assurance.

The basis of financial assurance coverage varies and some states make distinctions in coverage requirements based upon the magnitude or type of operation. Some states have a specified maximum bond requirement for mines having limited impacts, e.g. disturbances less than ten acres. States project closure costs based on the owner, the state or a third party taking responsibility for executing closure. Financial assurance amounts range from actual reclamation costs in Colorado and Nevada to actual reclamation, contingency, and closure costs in California, to specified per/acre maximum amounts in other states. States allow varying forms of surety, trust

# CALIFORNIA

## MINING WASTE REGULATION

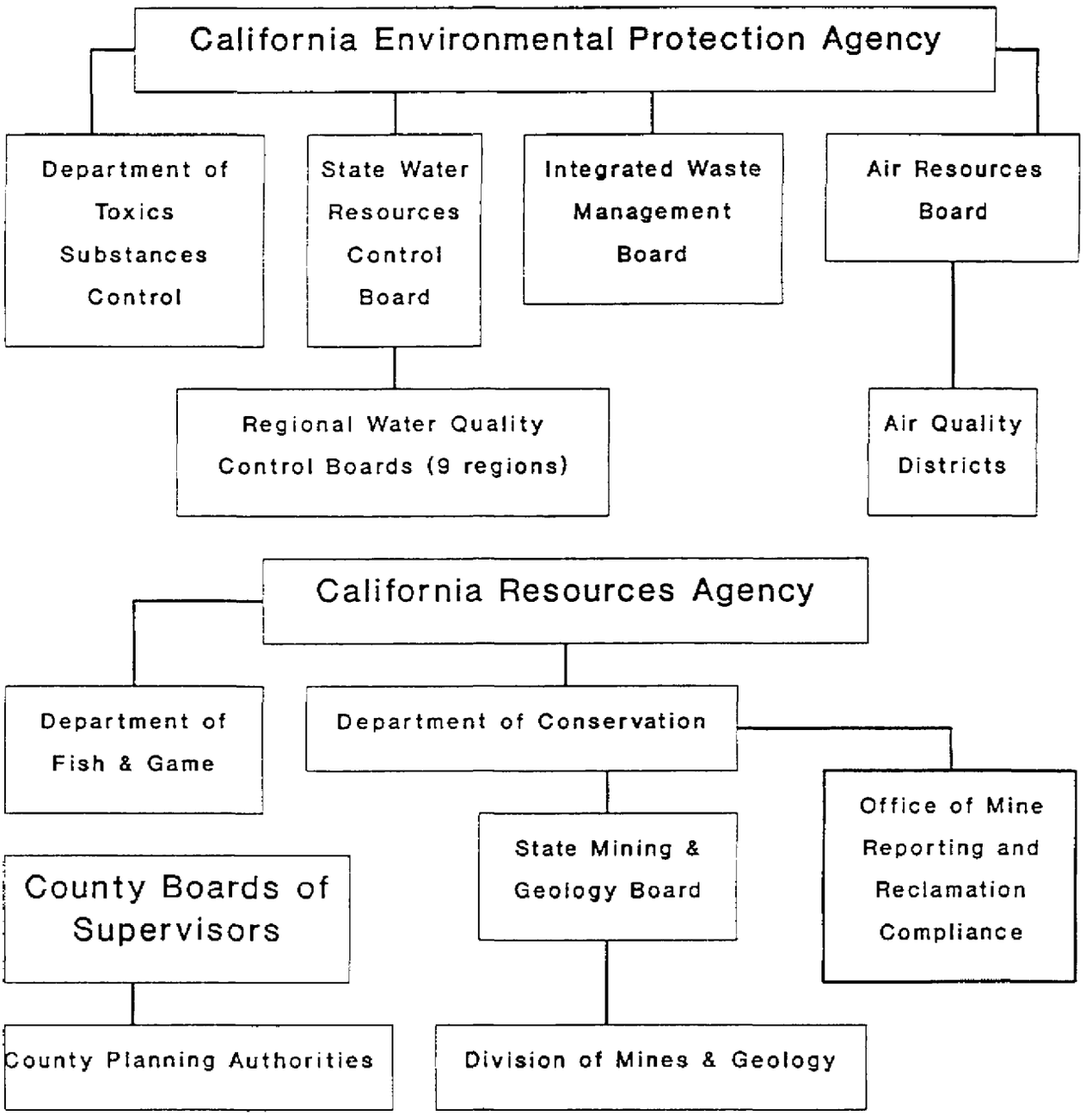



**Figure 1** California Mine Waste Regulation.

agreements, guarantees, or financial tests.

#### 4.3.2.5 Enforcement

Regulatory approaches to enforcement also vary among state programs. Some water pollution control based programs, e.g. Arizona and California, provide for the issuance of administrative compliance orders and the assessment of administrative civil penalties. Other programs expressly provide for a staged response – except in emergency situations – requiring notice to the violator and an opportunity to correct the violation before compliance orders may be issued. Penalty amounts vary, as well. Most of the water pollution control based programs authorize substantial civil penalties. Reclamation law-based systems tend to authorize lower maximum penalty amounts. Most programs provide for treating some violations as criminal violations--usually as misdemeanors. A key difference in state enforcement ability lies in the states' ability to take administrative action without bringing a legal action in the courts. All of the states have authority to seek damages for harm to the environment.

### 4.3.3 PROGRESSION OF EVENTS

The art of environmental regulation of mining is still developing. Programs that were seen as innovative or comprehensive only a few years ago are now joined or surpassed by more complex programs. States with previously minimal regulation of mining (such as Arizona and New Mexico) have moved toward more significant forms of regulation. Financial assurance, design specifications, monitoring requirements, and other program elements have all increased in sophistication in a relatively short time. Programs and program elements have moved at different rates and at different times in the states. Some states are moving toward their own new forms of regulation. This is as it should be given the model of federalism that underlies the Nation's constitutional form of government. The states are laboratories of government invention where innovative approaches for environmental protection and other key societal issues are formulated.

The regulatory, financial, enforcement and technical aspects of state programs operate in combination to achieve environmental results. Viewing the components of a state program in combination provides a measure of the apparent capacity of the program to address units, operations, and environmental resources of concern. A sampling of representative state programs follows that demonstrates those capacities. The effectiveness of those programs can best be measured by the level of on-the-ground compliance and results achieved thereunder. The latter analysis must be undertaken within each state at a particular point in time.

## 4.4 STATE PROGRAM OVERVIEWS

### 4.4.1 CALIFORNIA

**NOTE:** This report is taken from a larger study and report by the Environmental Law Institute entitled "State Regulation of Mining Waste: Current State of the Art" (November 1992). It is used with permission. The report focuses primarily on the regulation of mining wastes but provides a helpful overview of the environmental regulation of mining in California in general.

#### 4.4.1.1 California's Mining Industry

California is the nation's second leading state for the production of non fuel minerals, after Arizona. Among other commodities, it produces precious metals, non-precious metals, asbestos, rare earths, industrial minerals, gemstones, salts, and construction aggregate. California is the leading U.S. producer of asbestos, boron minerals, construction sand and gravels, portland cement, rare earths, and tungsten. California is the second leading producer of gold, after Nevada. The value of non fuel minerals commodities produced annually in California has been estimated by the U.S. Bureau of Mines at approximately $2.7 billion.[3]

The mining industry is diverse and widespread throughout the state. In 1988-89, the state identified 1012 active mining operations. Of these, 668 were construction aggregate mines, 263 were industrial mineral mines, and 81 were metallic mineral mines.[4] In 1991, the state estimated that is had approximately 1200 active operations.

The California mining industry employs a substantial number of people and is important to regional economies within the state. However, it constitutes a relatively small portion of the state's total economic activity, even as a fraction of all extractive/industrial activities. In 1990, the California non fuel mining industry directly employed 9000 workers, 2000 in metal mining.[5]

#### 4.4.1.2 Agencies, Laws and Regulations

Mining in California is regulated by a multiplicity of agencies, boards, and governmental levels. The

3) U.S. Bureau of Mines, State Mineral Summaries, 1991.

4) Cal. Dept. of Conservation, Mines and Mineral Producers Active in California (1988-1989), Special Publication 103.

5) U.S. Bureau of Mines, State Mineral Summaries, 1991.

complexity of the state's regulatory scheme may be unsurpassed among the states. Figure 1 shows the primary agencies and governmental entities with jurisdiction relevant to mining waste.

Mining waste in California is primarily regulated under the state's water pollution control program. The State Water Resources Control Board has adopted detailed regulations controlling the discharge of mining wastes to land. These "Subchapter 15 regulations," issued pursuant to the Porter-Cologne Water Quality Act,[6] create a three-tiered mine waste classification scheme with design standards, monitoring, and other requirements for mine waste piles, surface impoundments, and tailings ponds.[7] Other waste disposal units that may pose a threat to water quality are regulated under broader general authority under the Porter-Cologne Water Quality Act. The Subchapter 15 regulations are directly administered by the nine Regional Water Quality Control boards. The Regional Boards operate independently of the State Board, although they implement the regulations issued by the State Board and their decisions may be reviewed by the State Board on appeal.

The Toxic Pits Cleanup Act of 1984 (TPCA) is also administered by the Regional Water Quality Boards. It prohibits discharges of "hazardous" mining waste to surface impoundments that are within 1/2 mile upgradient from sources of drinking water, and regulates other such discharges.[8] TPCA contains an exemption procedure for mines in existence prior to January 1, 1984, provided the mine applied for the exemption before January 1, 1986. The procedure requires submission of hydrogeological information to show that the impoundment did not pollute or threaten to pollute the waters of the state. A separate exemption applies to impoundments constructed at the direction of the state or the Regional Board to abate pollution from mining waste discharges to surface waters from a mine that ceased operations prior to January 1, 1988. TPCA plays virtually no role in the regulation of mining waste disposal at active operations, although it may serve as an additional enforcement tool if an active operation were abandoned without proper closure.

Prior to 1990, the California Department of Health Services (DOHS) had jurisdiction to classify mining wastes as hazardous or nonhazardous based on submissions by the operator prior to mining. If the DOHS determined mining waste to be hazardous, the waste was potentially subject to the full range of waste handling and disposal requirements of the California Hazardous Waste Control Law.[9] However, most mining waste in California was either classified as nonhazardous or was regulated solely by the Regional Water Quality Control Boards as "special waste" or under a variance from hazardous waste regulation granted by DOHS. In 1989, the legislature enacted Assembly Bill 1413, incorporating the Bevill exemption from the federal RCRA statute in state law and effectively removing most mining waste from DOHS jurisdiction.

Local governments have the lead regulatory authority for siting mining activities and for reclamation. Local governments regulate mining activities through the administration of their comprehensive land use plans and issuance of use permits. They conduct the formal environmental impact review process required under the California Environmental Quality Act (CEQA),[10] and apply their own mining and reclamation ordinances enacted pursuant to the state's Surface Mining and Reclamation Act of 1975 (SMARA).[11]

The State Geologist oversees the Division of Mines and Geology within the Department of Conservation in the State Resource Agency. The State Mining and Geology Board sets the statewide policy for SMARA implementation, and it reviews and approves local and county mining ordinances for consistency with SMARA. The Division is responsible for overseeing implementation of SMARA. Where there is no local program, or where such program is deficient, the Board, Department, and State Geologist are directly responsible for implementation.

Several other state agencies have partial or potential jurisdiction over mining activities, and hence indirectly over mining waste decisions. The California Coastal Commission requires permits for mining activities and other activities in the coastal zone. The State Air Resources Board administers California's state implementation plan through county and regional Air Quality Districts; most mining operations require construction and operating permits because of potential air quality impacts. The Integrated Waste Management Board technically has authority to regulate mining waste as a solid waste; it issues the regulations under which counties and localities control and dispense permits for solid waste disposal. However, this Board has not issued regulations for mining waste, and the regulations specifically authorize counties to exempt solid waste facilities for the disposal of mine tailings from permit requirements.

The Department of Water Resources' Dam Safety Division requires permits for certain dams and reservoirs,

6) Cal. Water Code Sections 13000 et seq.

7) Cal. Code of Regulations Title 23, Ch. 3, Subchapter 15, Article 7.

8) Cal. Health & Safety Code Section 25208 et seq.

9) Cal. Health & Safety Code Section 25100 et seq.

10) Cal. Pub. Res. Code Section 2100 et seq.

11) Cal. Pub. Res. Code, Division 2, Chapter 9 (as amended).

including tailings impoundments above a certain size and capacity.

The Department of Fish and Game is responsible for the protection of fish and wildlife at mining sites. It does no permitting of mining operations, however, except for permitting of stream alterations and diversions. Fish and Game may participate in the CEQA environmental review of mine operating plans by county and local lead agencies, and may also conduct enforcement where wildlife are injured or destroyed by mining waste handling practices.

### 4.4.1.3 Operations Generating Mining Waste

#### *4.4.1.3.1 State Permits Required*

Several required permits have some bearing on the handling of mining waste. Typically, the mine first obtains a local or county use permit incorporating SMARA reclamation requirements, following the completion of environmental impact review under CEQA. The operator must separately apply to the Regional Water Quality Control Board for "waste discharge requirements" governing the discharge of mining waste to land. Other permits may be required.

##### *4.4.1.3.1.1 Porter-Cologne Water Quality Act*

The Porter-Cologne Water Quality Act provides the basis for most regulation of mining waste. It requires a prospective discharger of waste that could affect the quality of the waters of the state to file a Report of Waste Discharge with the Regional Water Quality Control Board. The Board will specify the discharge limits and other requirements.

*Units and Activities Covered.* There are essentially two programs under Porter-Cologne relevant to mining waste. One is the federally approved NPDES program, which concerns point source discharges into the surface waters of the state.[12] The other is the Subchapter 15 program concerning waste discharges to land which may affect the waters of the state.

The Subchapter 15 program is the cornerstone of mining waste regulation in California. It specifically covers waste piles, surface impoundments, and tailings ponds. Although Subchapter 15 is predicated upon discharges of "waste" to land, the Regional Boards take the position that it gives them authority to regulate "process" ponds and other units that may pose a threat to water quality.

*Application Information.* An operator must submit a report of waste discharge to the Regional Water Quality Control Board prior to engaging in any discharge of mining waste to the land. The report filed by the operator must contain information on "waste characteristics, geologic and climatologic characteristics of the unit and the surrounding region, installed features, operation plans for waste containment, precipitation and drainage controls, and closure and post-closure maintenance plans." The operator must also submit a report on the characteristics of the waste that could affect its potential to cause pollution; this latter report must include test results to assess hazard and toxicity, information concerning acid-generating potential and persistence of toxics after disposal; and the potential for long term acid mine drainage, discharge or leaching of heavy metals, or the release of other hazardous substances.

*Procedures.* The statute provides that the Report of Waste Discharge must be submitted at least 120 days prior to any contemplated discharge. However, in practice, a report may be submitted and approved in a shorter time period. After reviewing the report and requesting additional information or testing, the Regional Water Quality Control Board issues draft "waste discharge requirements." These prescribe the design, construction, and operation of the waste units; the monitoring program; financial assurance; closure and post closure. The Board must provide public notice and an opportunity for public hearing before issuing the final waste discharge requirements. The Board votes on issuance at its regularly scheduled public meeting.

*Standards for Issuance or Denial.* Before issuing final waste discharge requirements for mining waste, the Regional Board must determine that the proposed discharge is "consistent with a waste management strategy that prevents the pollution or contamination of the waters of the state, particularly after closure of any waste management unit for mining waste."

##### *4.4.1.3.1.2 Surface Mining and Reclamation Act (SMARA)*

SMARA permitting serves as the basis for approving the mine itself. The local authority with jurisdiction over the mining operation, typically the county planning board, serves as the "lead agency" under SMARA. The lead agency administers its own land use plan, laws, and regulations. These must be consistent with SMARA and the state mineral policy adopted by the State Mining and Geology Board.

*Units and Activities Covered.* "Surface mining

12) Also of prospective applicability is the non point source program under the federal Water Quality Act of 1987. Most mines will be required to apply for permits for storm water runoff, either under the state's general industrial storm water permit implementing the federal program and adopted in November 1991, or under an individual NPDES permit.

operations" regulated by SMARA include the "activities" associated with mining--including removing overburden, open pit mining, auger mining, dredging, quarrying, surface work incident to an underground mine, in situ processes, "the production and disposal of mining waste," and exploration and prospecting activities.

The SMARA permit requirements did not apply to mining operations that had "vested rights" prior to January 1, 1976. However, even these vested rights operations were required to file reclamation plans by March 31, 1988, if they did not already have reclamation plans approved under prior authority. However, SMARA's reclamation requirements apply only to lands disturbed after January 1, 1976.

SMARA does not apply to prospecting or mining if the disturbed area is one acre or less and the amount of overburden is less than 1,000 cubic yards. Nor does it apply to excavations or grading for farming, on site construction, or restoration of flooded land. SMARA does not apply to activities (i.e. "assessment work") conducted solely in order to maintain a mining claim on federal lands. Nor does it apply to certain other infrequent mining operations causing only minor surface disturbances as may be determined by the State Mining and Geology Board.

*Application Information.* The application information is specified in the local ordinances subject to the general requirements of SMARA. The operator must submit an application for permit, a reclamation plan, and financial assurances for review by the lead agency. The permit applies to the entire operation.

The application must include a reclamation plan that provides the name and address of the operator, the anticipated quantity and type of minerals to be extracted, the proposed dates of initiation and termination of the operations, the proposed maximum depth of the operation, the size and legal description of the area to be affected, the general and specific geology of the area, the location of all streams, roads, railroads, and utility facilities within or adjacent to the lands, the location of proposed access roads, and the names and addresses of all surface and mineral owners. The plan must describe the mining method and mining schedule (which schedule must provide for the earliest possible initiation of reclamation of disturbed lands on which activities have been completed). The plan must identify the post mining land use and provide evidence that all landowners have been notified of the proposed use. Finally, the plan must describe how reclamation will be accomplished, including "a description of the manner in which contaminants will be controlled, and mining waste will be disposed," a description of the rehabilitation of stream bed channels and banks, an assessment of the effect of the plan on future mining in the area, a statement of responsibility for completing the reclamation specified in the plan, and such other information as may be required by local ordinance.

The plan must be based on the characteristics of the property and surrounding area, including overburden type, soil stability, topography, geology, climate, streams, and mineral commodities, and must establish site-specific criteria for evaluating compliance.

*Procedures.* Procedures for review of mining permit applications are specified by local ordinance. Under SMARA, permit procedures require at least one public hearing. They are also subject to California Environmental Quality Act (CEQA) procedures as discussed below. Under SMARA, lead agencies must notify the State Geologist of the filing of an application for a permit within 30 days of its receipt. Before approving a reclamation plan and financial assurance, the lead agency must submit them to the State Geologist for review with a certification that they meet the legal requirements. The State Geologist has 45 days to prepare written comments, if any, and send them to the lead agency. The lead agency must consider any comments and prepare a written response concerning why the comments were accepted or rejected. The operator receives copies of the comments and responses. The lead agency issues the permit.

An applicant whose permit application involves an area designated by the State Mining and Geology Board as having statewide or regional significance for mining may appeal a final decision of the lead agency denying the permit to the State Mining and Geology Board within 15 days. Similarly any person aggrieved by the grant of such a permit may appeal. Appeals that are not dismissed for lack of substantial issue must be reviewed by the Board at a hearing held within the area under the jurisdiction of the lead agency within 30 days after the filing of the appeal unless a longer period is agreed to. The Board must limit its inquiry to whether the lead agency's decision is supported by substantial evidence in the record. If the decision is not, the Board must remand the appeal and the lead agency must schedule a hearing to reconsider its decision. The State Board does not have the authority to issue a permit.

Similar review procedures apply for applications in general, and to "unwarranted" failures of a lead agency to make a decision or take action within a reasonable period of time. The Board must hear these appeals within 45 days after filing, unless a longer period is agreed to. If the Board finds that the reclamation plan or financial assurances are deficient, the applicant shall be granted an additional 30 days to correct the deficiencies and resubmit (one time only) to the lead agency for reconsideration.

Under the California Environmental Quality Act (CEQA), any project that a state or local agency proposes to carry out or approve "which may have a significant effect on the environment" must be preceded

by an environmental impact report (EIR). The EIR must identify alternatives to the proposed action, information on environmental impacts, and feasible mitigation measures. The EIR process applies to mining operations. Detailed information provided by the applicant and available to the lead agency must be considered in preparing an initial study to determine whether an EIR is warranted. A lead agency may determine not to prepare an EIR if it adopts a negative declaration, a so-called "neg dec." A negative declaration must be based on a determination either that there is not substantial evidence that the project may have a significant effect on the environment, or that all potentially significant effects identified by the initial study have been avoided or mitigated by revisions to the project plans. Mitigated negative declarations are often used for noncontroversial mining or exploration operations.

There is a public review process for both negative declarations and EIRs. The public is guaranteed no less than 21 days for review and comment upon a negative declaration, and no less than 30 days upon a draft EIR. The EIR process requires consultation with affected agencies, and express findings with respect to issues such as endangered species, archaeological resources, and other specific matters within the purview of such agencies. Where a completed EIR identifies one or more significant effects on the environment, an agency may not approve the project unless changes have been made that mitigate these effects, or unless specific economic, social, or other considerations make infeasible the mitigation measures or project alternatives identified in the EIR. Whenever a lead agency determines to approve a project subject to CEQA, it must give public notice of its decision. Decisions are subject to judicial review for failure to comply with CEQA.

#### *4.4.1.3.2 Design Standards and Performance Standards*

This section of the overview deals with standards applicable to the design, construction, and operation of mine waste facilities during their active life.

##### *4.4.1.3.2.1 Porter-Cologne Water Quality Act*

Subchapter 15 of the State Water Resources Control Board's regulations specifies the exclusive standards for mining waste units. The Regional Boards may, however, impose "more stringent requirements to accommodate regional and site-specific conditions." They may also grant exemptions and variances. Virtually all mining waste units in California are constructed as engineered alternatives to the design standards specified in Subchapter 15.

*Siting and Location.* The regulations specify some siting standards for new waste units. Existing units that received mining waste after the effective date of the regulations must also comply with siting requirements to the extent required by the Regional Water Quality Control Boards. New units may not be sited on Holocene faults or in areas of rapid geologic change. A Regional Board may, however, allow construction in areas of rapid geologic change if containment structures are designed accordingly. New units handling hazardous (Group A) mining wastes must be located outside the 100-year floodplain. Existing waste units of all types, and new waste units handling less hazardous (Group B) or nonhazardous (Group C) wastes may simply be engineered to withstand such an event.

*Waste Characterization and Classification.* Mining waste is classified by the Regional Water Quality Control Boards, upon submission of a Report of Waste Discharge by an applicant, into one of three groups for purposes of applying the design and performance standards. A 1989 amendment specified the technical information that applicants must submit to the Regional Water Quality Control Boards for its waste classification – specifically, technical information on the acid-generating potential of each waste, and toxicity information.

Group A wastes are those that were required to be managed as hazardous wastes under the state Hazardous Waste Control Law, "provided that the Regional Water Quality Control Board finds they pose a significant threat to water quality." These wastes are subject to the most stringent requirements.

Group B wastes are of several types. They include wastes that consist of or contain hazardous wastes which qualified for a variance from hazardous waste regulation from the former Department of Health Services, based on their being insignificant as a hazard or adequately managed under the regulations of another agency (e.g. the Regional Water Quality Control Boards). Group B wastes also include nonhazardous soluble pollutants that exceed water quality objectives or could cause degradation of the waters of the state, including acid-producing and other wastes.

Group C wastes are those from which expected discharges would not adversely affect water quality except for turbidity (e.g. waste rock with no particular leaching characteristics). Operators are permitted to treat wastes in order to render them classifiable as Group C rather than B. In deciding whether to classify a mining waste as Group B or C, a Regional Board is authorized to consider the concentrations of hazardous constituents, the waste's acid-generating potential, and whether a waste is readily containable by less stringent measures.

*Design and Performance Standards*[13]. The regulations list

13) In March 1992, the State Water Resources Control Board

prescriptive design standards for each type of waste management unit. However, most mining operations in California seek and obtain approval for engineered alternatives to the prescriptive standards.

For all three waste classifications other general requirements apply. The materials used must be selected to ensure that structures do not fail because of pressure gradients, physical contact with the waste or leachate, chemical reactions, climatic conditions, or the stress of installation or daily operations. Permeability test methods are described. All containment structures must be designed by a California registered civil engineer, and construction must be supervised and certified by a California registered civil engineer or a California certified engineering geologist.

*Variances.* Regional Boards may approve alternatives to the construction standards or prescriptive standards of the regulations. Virtually all mine waste units in California are operated with such approvals.

First, the Regional Boards may approve an "engineered alternative" to the regulatory standard if the discharger demonstrates (1) that the standard is unreasonably burdensome and substantially more costly than alternatives, or is impractical and will not promote attainment of performance standards; *and* (2) there is an engineered alternative consistent with the performance goal addressed by the construction or prescriptive standard that affords "equivalent" protection against water quality impairment.

Alternatively, regulations provide that a Regional Board may exempt a mining waste pile from the liners and leachate collection requirements if the discharger can clearly demonstrate that leachate will not form in or escape from the waste management unit. If the exemption is granted, the Board may require extensive monitoring in lieu of containment. Contingency plans may also be required, if monitoring shows that the procedures have not succeeded.

#### *4.4.1.3.2.2 SMARA*

*Siting.* Siting of mining operations and waste units is subject to local control by county or local ordinance. No state SMARA standards expressly apply to the siting of such units. However, SMARA requires evaluation by the state Office of Planning and Research, at least every ten years, of areas of the state that are experiencing or will experience urbanization or other irreversible land uses which would preclude mineral extraction. This information is then compared with an evaluation by the State Geologist of the mineral potential of such lands. The lead agencies must take this information into account in preparing and modifying their mineral resource management policies and their general land use plans, to foster the development of identified mineral deposits. If the lead agency plans to authorize a land use that would "threaten the potential to extract minerals in that area" it must prepare a statement of reasons for the State Geologist and the State Mining and Geology Board to review, in addition to any required environmental impact reports with associated public review. Similar requirements apply to areas designated by the Board as having regional or statewide significance.

*Waste Characterization Requirements.* SMARA does not specify waste characterization. This is handled under the Subchapter 15 program.

*Minimum Design and Performance Standards.* Pursuant to an amendment to SMARA enacted in 1990, the State Mining and Geology Board was required to adopt regulations by January 1, 1992 specifying "minimum, verifiable statewide reclamation standards." These standards must include: wildlife habitat, backfilling, regrading, slope stability, recontouring, revegetation, drainage, diversion structures, waterways, erosion control, prime and other agricultural land, removal of structures and equipment, stream protection, topsoil handling, and tailing and mine waste management. While the Board has adopted such standards, as of fall 1992, they had not yet been issued and were not yet effective, pending review by the state's office of administrative law. The newly proposed standards are general and defer most waste issues to Subchapter 15. The Board previously adopted "minimum acceptable practices," which remain in effect as the regulatory standard.[14]

#### ***4.4.1.3.3 Monitoring Requirements***

Most monitoring is conducted under the Subchapter 15 mine waste program. Neither SMARA nor its regulations specify monitoring requirements, although county and local ordinances and the reclamation plans may include some monitoring. Subchapter 15 requires monitoring of surface and groundwater and of waste characteristics. The Subchapter 15 monitoring regulations were substantially revised in 1991. In addition, in 1989, the legislature required the State Water Resources Control Board to adopt policies, standards, and regulations for mining waste, including 1) a statewide

proposed revisions to the regulations. Proposed revisions include requiring double liners for all Group A and B waste units where surface water or groundwater is present. Some of the focus of the revision effort is on the prevention and control of acid mine drainage, increasingly recognized as the major source of water pollution impacts from mining in the state.

14) 14 Cal. Admin. Code Section 3503.

policy for monitoring water that may be affected by such waste, 2) regulations requiring mine Waste Discharge Requirements issued by the Regional Boards to include monitoring consistent with the statewide policy, and 3) standards for reporting monitoring on the Regional Board level.[15]

Group A and B waste management units are expressly subject to groundwater monitoring requirements. The regulations provide that the Regional Board must establish a water quality protection standard for the point of compliance. The allowable concentration limit must be set at "background" unless it is being established for a corrective action program. The water quality protection standard applies during the active life of the unit through the post-closure period.

The pre-1991 regulations defined the point of compliance as located hydraulically down gradient of each waste management unit or cluster of units, in both the saturated and unsaturated zones. The 1991 revised regulations redefine the point as a "vertical surface located at the hydraulically down gradient limit of the waste management unit that extends through the uppermost aquifer underlying the unit."

The prior regulations provided that the Regional Board must require a monitoring network that is designed to detect leakage of fluids, including leachate, "at the earliest possible opportunity." The 1991 regulations specifically require the operator to monitor the uppermost aquifer, and to conduct other monitoring to provide the "best assurance of the earliest possible detection of a release." If waste constituents are detected at compliance points, the discharger must institute an evaluation monitoring program. If a discharge is verified, corrective action is required.

The groundwater monitoring requirements are the same as those specified for California's RCRA Subtitle C-type program, including detection monitoring, evaluation ("assessment") monitoring, and corrective action. The program includes sampling and analysis plans, determinations of statistically significant increases in indicator parameters, reporting, and other measures. The pre-1991 regulations required monitoring of the unsaturated zone "whenever feasible," and specified that water quality standards must be established by the Regional Boards for the unsaturated zone. The 1991 regulations require monitoring of the unsaturated zone unless the discharger demonstrates that there is no device or method that can monitor the unsaturated zone under the existent subsurface conditions.

Waste characterization may be required by the Regional Board throughout the active life of the unit. Permits for metal mines frequently require such characterization semi-annually.

15) Cal. Water Code Section 13172.

#### *4.4.1.3.4 Corrective Actions*

Releases of waste subject to Subchapter 15 onto the land or into the groundwater require corrective action. Units handling Group A or B waste are expressly subject to corrective action. Under the pre-1991 regulations, the discharger was required to notify the Regional Board within 7 days, note what standards were being exceeded, and develop a corrective action program as an amendment to the report of waste discharge within 180 days. Under the 1991 regulations, the discharger must notify the Regional Board within 7 days, submit an amended program for evaluation monitoring within 90 days, conduct evaluation monitoring, and submit and carry out a corrective action program. The Regional Board may approve a cleanup standard of greater than background only if the Board finds it technologically or economically infeasible to reach background, and the constituent will not pose a substantial present or potential hazard to health or the environment so long as the standard is observed.

#### *4.4.1.3.5 Closure and Reclamation*

##### *4.4.1.3.5.1 Porter-Cologne Water Quality Act*

Both new and existing mining waste management units must undergo closure "so that they no longer pose a threat to water quality." Closure requirements are prescribed in the operation's closure and post closure plan, which must be approved by the Regional Board. This plan must "incorporate" the SMARA reclamation plan. Closure of mining waste units must be supervised by a California registered civil engineer or a California certified engineering geologist. New and existing Group A and B waste piles must be covered with at least two feet of foundation material and not less than one foot of clean soil above the foundation to serve as a low permeability layer. This layer must be compacted to a permeability of $1 \times 10^{-6}$ cm/sec. or less (or equal to the permeability of any bottom liner system or underlying geologic materials), and covered with not less than one additional foot of clean soil to serve as a rooting layer for revegetation.

Closed waste piles must be graded to prevent ponding and to provide slopes of at least 3%. Throughout the post closure period, the operator must maintain the containment structures, operate the leachate collection and removal system so long as leachate is present, and conduct monitoring. New and existing Group A and B surface impoundments must be closed by removing all free liquid, and removing all residual wastes and placing them in an approved unit. A surface impoundment may be closed in place if dewatered and covered, and if the liner (or outer liner, if double lined) is clay. New and existing Group A and B tailings ponds must be closed by

removing all free liquid, and by then capping them in the manner prescribed for Group A and B waste piles. New and existing Group C waste units must be closed "in a manner that will minimize erosion and the threat of water quality degradation from sedimentation." Closed units must be provided with at least two permanent monuments installed by a state licensed land surveyor or registered civil engineer.

The post closure maintenance period ends only when the Regional Board determines that water quality aspects of reclamation are complete and waste no longer poses a threat to water quality. No specific time period is identified in the law or regulations. No post-mining land uses are permitted that might impair the integrity of containment structures. Revegetation may not impair the integrity of containment structures, nor may the irrigation of vegetation cause or increase the production of leachate.

*4.4.1.3.5.2 SMARA*

An operator must have an approved reclamation plan as part of its use permit. If an operation becomes "idle," the operator must within 90 days submit to the lead agency for review and approval an interim management plan. The review of this plan is not subject to CEQA requirements, but is considered an amendment to the reclamation plan. It must specify how the site will be maintained during the period of idleness. The plan may remain in effect for not more than five years, at which time the lead agency may either grant a five-year renewal or require the commencement of reclamation. The lead agency must review and approve the plan within 60 days (or longer if so agreed by the operator); or it must notify the operator of any deficiencies and allow the operator 30 days (or longer if agreed by the agency) to correct any deficiencies, and approve or deny the revised plan within 60 days after receipt. A denial of approval may be appealed to the lead agency's governing body, which must schedule a hearing within 45 days. Unless review of an interim management plan is pending, a surface mining operation idle for over one year is considered abandoned and the operator must complete reclamation in accordance with the approved reclamation plan.

***4.4.1.3.6 Financial Assurances***

*4.4.1.3.6.1 Porter-Cologne Water Quality Act*

Subchapter 15 requires a discharger to post financial assurance to guarantee the costs of closure and post closure maintenance for waste management units. The statute and regulations do not, however, specify the form of financial assurance that may be posted; acceptability of any particular form is within the discretion of the Regional Water Quality Control Board. If a local lead agency has required financial assurance under SMARA (required of all operations since January 1992, and true of many operations prior to that date), such assurance may be used to satisfy the Subchapter 15 requirement if the Regional Board approves and is an alternate payee.

The amount of financial assurance is not determined according to a formula or handbook. Rather, the applicant must submit a justification (usually a risk assessment) for its proposed assurance amount. The assessment ordinarily addresses the amount of funds necessary to support operations (including closure and post closure) in the event of a default, to cover cleanup contingencies and repairs in the event of a release, and (if the assurance is combined with that under SMARA) the reclamation costs. The regulations do not specify whether the financial assurance amount has to be sufficient to satisfy both the reclamation obligation and the closure and post closure obligation simultaneously. Financial assurances must be "periodically" reviewed and modified by the Regional Board to reflect the current status of the operation and changes in costs. Changes in the assurance instrument or amount are not subject to public review, and may be handled by the staff of the Regional Board without formal Board action. There are no specific public processes associated with release of the assurance upon completion of the post-closure period.

Forfeiture procedures are not spelled out in the regulations. However, in general, the assurance must be made payable to the Board upon findings by the Board that 1) the discharger has failed to comply with its waste discharge requirements, after ten days' notice and opportunity for hearing, and 2) identification by the Board of expenses that are necessary in order to comply.

*4.4.1.3.6.2 SMARA*

Financial assurance was discretionary with lead agencies until a 1990 amendment to SMARA made it mandatory for new operations permitted on or after January 1, 1992, and for all existing operations by January 1, 1992. Now, the lead agency must require an operator to post financial assurance to assure that reclamation is performed in accordance with the approved reclamation plan. Financial assurance may take the form of surety bonds, irrevocable letters of credit, trust funds, or other forms authorized by regulation, but not financial tests.

Financial assurances must remain in effect for the duration of the surface mining operation and any additional period until reclamation is completed. Financial assurances must be adjusted annually to reflect newly disturbed areas, areas reclaimed, and the effect of inflation on reclamation costs. The operator remains liable for any reclamation costs in excess of the financial assurance amount. Financial assurances may be released by the lead agency upon written determination by the lead agency that reclamation has been completed. There

are no public review processes for this determination.

#### *4.4.1.3.7 Inspection*

The Subchapter 15 waste discharge regulations do not specify any inspection frequency for the Regional Water Quality Control Boards. Inspections are carried out by the regular staff of the Regional Boards.

SMARA requires the lead agency to conduct an annual inspection to verify compliance with the approved reclamation plan. Inspections must be conducted within six months after a mining operation files the annual notice giving its operating status as required by law. The inspection need not be made by a state employee, but may be made by a state-registered geologist, civil engineer, landscape architect, or forester, who is experienced in land reclamation and who has not been employed by the particular operation being inspected during the preceding 12 months. The operator must pay for the inspection. Within 30 days after completion of the inspection, the lead agency must notify the State Geologist, provide the State Geologist and the operator with a copy of the inspection form, and identify any violations.

In order to assure that agencies are apprised of the ongoing condition of mining operations, since 1990 SMARA has required every mining operation "of whatever kind or character" to file an annual report that gives its status, total acres disturbed and reclaimed the previous year, proof that it has been inspected, copies of its approved reclamation plan, and other information.

#### *4.4.1.3.8 Enforcement*

##### *4.4.1.3.8.1 Porter-Cologne Water Quality Act*

Failure to furnish a discharge report or pay fees is a misdemeanor civilly punishable by a Regional Board by administrative civil penalty of up to $1,000 per day of violation, and in court for up to $5,000 per day of violation. If the violation involves hazardous waste and a knowing failure to provide information or to file, the amounts are $5,000 per day and $25,000 per day respectively. The Attorney General, at the request of the Regional Board, may seek injunctive relief.

In general, Regional Boards may issue cease and desist orders requiring compliance, assess administrative civil penalties, seek injunctive relief, or take direct remedial action and recover the costs thereof. Negligent or intentional failure to comply with waste discharge requirements or an order of the Regional Board concerning a discharge of waste may result in penalties of up to $5,000 per day administratively and up to $15,000 per day judicially. Where the waste cannot be recovered and cleaned up, administrative charges of up to $10 per gallon or civil charges of up to $20 per gallon may be imposed. Where the violation is of an order of the Regional Board, but there is no discharge, the administrative penalty is limited to a maximum of $1,000 (but not less than $100 for each day of violation); the civil judicial penalty is up to $10,000 per day.

For violations of NPDES permits, or releases into the surface waters of the state, the primary tool used is administrative civil penalties. Liability is strict. The law provides that the Regional Board may assess up to $10,000 per day of violation, plus up to $10 per gallon for each gallon of unrecovered discharge over 1,000 gallons. Civil judicial liability is up to $25,000 per day, plus up to $25 per unrecovered gallon of discharge over 1,000 gallons. Payment goes to the state water pollution cleanup and abatement fund. Violations in connection with failures to report spills and releases, and failures to respond also carry substantial civil penalties.

##### *4.4.1.3.8.2 SMARA*

If a lead agency or the State Geologist determines that a mining operation is not in compliance, based on an inspection, it "may" notify the operator by personal service or certified mail. If the violation continues for more than 30 days after service of the notice, the lead agency or the State Geologist may issue an order requiring compliance (or, if the operator lacks an approved reclamation plan, requiring cessation of mining activities). The order must specify a reasonable time to come into compliance, taking into account the seriousness of the violation and any good-faith attempts to comply. An order does not take effect, however, until after the operator has been provided an opportunity for hearing, and the hearing may not be scheduled sooner than 30 days after the date of the order.

Any operator who fails to comply with an order after its effective date is subject to a further order imposing an administrative penalty of up to $5,000 per day assessed from the original date of noncompliance. In determining the amount of the penalty, the lead agency (or the State Geologist) shall take into consideration the nature and extent and gravity of the violation, the operator's history, the degree of culpability, economic savings realized because of the violation, and other factors. Orders setting penalties are effective upon issuance, and payment must be made within 30 days unless the operator petitions the legislative body of the lead agency (or the Board, for orders issued by the State Geologist) for review. Review is on the existing record supplemented by other relevant evidence. Any final order by the reviewing body is effective upon issuance, unless the operator petitions the superior court for review within 30 days of the order of the reviewing body. In order to petition, the operator must deposit the amount of the penalty with the lead agency (or State Geologist) where it will be held in an

interest-bearing escrow account. Review is on the record, but the court shall exercise its independent judgment of the evidence.

If the lead agency or the State Geologist determines that an operation is in violation and is causing an imminent and substantial endangerment to the public health or the environment, the lead agency (or the Attorney General, on behalf of the State Geologist) may seek a court order enjoining the operation. The Attorney General may bring an action to recover administrative penalties and to compel compliance upon request by the Board, the State Geologist, the Department of Conservation, or on his or her own initiative.

#### 4.4.1.4 Local and County Requirements

Local and county regulation of mining waste occurs primarily through the CEQA environmental impact review and SMARA reclamation requirements. SMARA operates as a decentralized regulatory program delegated from the state to the county and local planning boards, which are responsible for its direct administration. County and local agencies must adopt ordinances to establish programs for review and approval of reclamation plans, the issuance of permits, and review of financial assurances. The State Mining and Geology Board must review local agency ordinances to certify that they are in accordance with or more stringent than the requirements of SMARA and state policy. In areas without a certified ordinance, no person may operate a surface mining operation unless it has submitted a reclamation plan to, and had such plan approved by, the state Board.

If a lead agency adopts an ordinance that the State Mining and Geology Board finds is not in accordance with state policy under SMARA, the Board must notify the agency and give it 90 days to submit a revised ordinance for certification. The Board must review the revised ordinance within 60 days of its receipt. If the lead agency's revised ordinance still fails to satisfy SMARA, the Board allows it a second 90 day period for revision. If the lead agency does not submit a revised ordinance, or fails to meet the requirements upon its second try, the Board assumes full authority for review and approval of all reclamation plans until such time as the lead agency conforms its ordinances to SMARA.

If the Board finds that a lead agency has approved reclamation plans inconsistent with SMARA, failed to inspect or require inspections, failed to forfeit (collect) financial assurances, failed to take appropriate enforcement action, intentionally misrepresented the results of inspections, or failed to submit information to the Department of Conservation, the Board must take over the powers of the lead agency (except for permitting authority). In order to make such a finding and take such action, the Board must notify the lead agency of its deficiencies and allow it 45 days to correct the deficiencies. If the deficiencies are not corrected, the Board must hold a public hearing in the area concerned upon 45-day written notice to the lead agency, the operators, and the public. Oral and written evidence is received, subject to reasonable limits on oral testimony. If, after hearing, the Board decides to act, it must make written findings in support of the action, addressing the significant issues raised at the hearing. The transcript, written testimony, and exhibits constitute the exclusive record for decision. Judicial review of the Board's action may be obtained by the lead agency or any interested person filing a petition for writ of mandate in the superior court within 30 days. The court must rely on the record, but may allow other relevant evidence necessary to effectuate the purposes of SMARA. The court must exercise its independent judgment of the evidence. The same procedural requirements apply to the restoration of authority by the Board to a lead agency. The law provides that such a restoration may occur *no sooner* than three years after a takeover. Any reclamation plan approved by a lead agency that did not conform to the state policy when approved is subject to amendment by the Board. Any reclamation plan approved by the Board when it has jurisdiction is not subject to subsequent amendment by the lead agency, but may be modified by the Board.

A 1990 amendment to SMARA requires the Department of Conservation to retain a consultant to evaluate the "effectiveness" of lead agencies, the board, and the department in implementing the law, and to file a report with the legislature on or before March 1, 1994. The report must evaluate compliance by operators, agencies, and others, the adequacy of implementation resources, the adequacy of available information, and recommended changes to legislation or regulations.

#### 4.4.1.5 Interface Over Federally Owned Lands

Subchapter 15 waste discharge requirements apply, and are enforced by the Regional Water Quality Control Boards even on federal lands (other than Indian lands). Thus, although 36 CFR Part 228 and 43 CFR Part 3809 apply, the substantive regulation of waste management units is primarily state determined. Site reclamation is coordinated with federal authorities. In 1979, the California Resources Agency entered into a Memorandum of Understanding (MOU) with the U.S. Forest Service (USFS)and the Bureau of Land Management (BLM). The MOU provided that "lead agencies" (normally county agencies) would work cooperatively with federal agencies to ensure that federal conditions to minimize adverse environmental impacts would conform to all state, local, and federal laws and regulations. It further provided that lead agencies may

accept federal operating plans, studies, and reclamation plans as functional equivalents of SMARA documents provided that they meet or exceed the minimum statewide standards set under SMARA; and that BLM and USFS would accept SMARA documents as functional equivalents when they meet or exceed federal regulations.

In 1990, the Department of Conservation and the State Mining and Geology Board, within the Resources Agency, entered into a new MOU with the BLM superseding the 1989 agreement as to BLM. The new MOU provides much greater specificity than the prior agreement. Its first two substantive paragraphs repeat the cooperation and functional equivalence provisions of the 1989 document. In addition, the new MOU explicitly provides that NEPA documents and CEQA documents may be treated a functional equivalents. Local lead agencies are encouraged to enter into "specific area agreements" with BLM, including processes for reviewing reclamation plans, carrying out public inspections and enforcement, and bonding provisions. The MOU provides that BLM *may*, by written agreement, delegate authority to a lead agency to be "solely" responsible for permitting and approving mining operations on BLM land, subject only to an opportunity for BLM to comment. The MOU provides that for BLM "notice" operations (5 acres or less), the BLM shall forward such notices within 5 days to the local lead agency, which may impose its own requirements upon the operator directly. For mines requiring a Plan of Operations, BLM will notify the lead agency and provide it with an opportunity to comment, consult, and assist in the development of any environmental assessments and the reclamation plan. For these operations, the lead agency must submit its comments to BLM within 30 days. After BLM's review procedures are complete, the documentation is then forwarded to the lead agency for review and permitting, including any public hearings where required. The lead agency then issues or denies the permit. Where the lead agency adopts conditions different from those of BLM, it must notify BLM.

Measures to mitigate off-site impacts of federal land mining operations on non-federal lands remain under the control of the lead agency or other responsible state agency. Lead agencies and BLM must coordinate their procedures where mixed federal and private lands are involved. To the extent practicable, enforcement is to be cooperative. Finally, BLM is responsible for determining whether a reclamation bond is needed on federal lands and the amount of such bond, including any adjustments and bond releases. BLM's determination is to be made in consultation with the lead agencies. Any federally-required bond or financial assurance may be used to satisfy the state bonding requirements. For reclamation purposes, BLM remains solely responsible for operations not subject to SMARA, such as those disturbing less than 1000 cubic yards of material in an area of one acre or less, or operations simply performing assessment work in order to maintain a valid mining claim.

## 4.4.2. MINNESOTA'S MINING REGULATIONS
**by W. J. Lynott**

### 4.4.2.1 Introduction

The environmental regulation of mining at the state level in Minnesota is a shared responsibility between the Department of Natural Resources (DNR) and the Pollution Control Agency (MPCA), each of which has a distinct set of laws and rules to administer. However, because of the way in which mining and its regulation have evolved over the years, a considerable amount of coordination has developed between the two agencies in order to minimize regulatory overlap and maximize environmental protection while not unduly hindering the industry.

Although considerable exploration has taken place in Minnesota for base and precious metals, particularly since 1966, the only metal mining of any consequence that has ever occurred in the state is iron ore mining. At present (1992) there are seven active operations producing, in the aggregate, 42 million tons of taconite pellets per year. Oxide minerals dominate the lithology of these facilities, and, consequently, Minnesota is to a large extent not faced with the challenges from acid mine drainage and heavy metal contamination that exist in other regions of the country. The one exception involves one taconite mine which has sulfidic minerals in a portion of its waste rock.

The DNR and its mineral regulatory function have existed in one form or another since the early 1920s; by contrast, MPCA's regulatory career began in 1967. The rise of environmental awareness in the late 1960s-early 1970s considerably influenced both agencies, and much of the legislation governing mining regulation dates from that time.

Minnesota mines peat for the horticultural market. Although exploration for uranium and petroleum have taken place in Minnesota, and test burns of peat have been conducted from time to time by several utilities and peat-to-gas feasibility studies have been done, no significant energy extraction activities have ever occurred.

### 4.4.2.2 Environmental Regulation of Mining

The state administers statutes that directly affect the regulation of mining, as follows:

- Minnesota Statutes sec. 93.44-51, the Mineland Reclamation Act, administered by DNR; provides

authority to regulate mine planning, mine waste disposal, reclamation of mined land, permitting, financial assurance, and enforcement.

- Minnesota Statutes ch. 105, the Water Resources Conservation Law, administered by DNR; provides authority to regulate the construction and operation of water control structures, including dams, as well as water appropriations.
- Minnesota Statutes ch. 115, the Water Pollution Control Law, administered by MPCA; provides broad-ranging authority to control the discharge of pollutants to ground and surface water, requires permits for discharges, and requires compliance with water quality standards.
- Minnesota Statutes ch. 116, the Pollution Control Agency Law, administered by MPCA; creates the agency and defines its powers and responsibilities.

The state also administers the following rules that apply to the mining industry:

- Minn. Rules ch. 6130, the Mineland Reclamation Rules, administered by DNR.
- Minn. Rules ch. 6115, the Public Water Resources Rules, administered by DNR.
- Minn. Rules ch. 6131, the Peat Rules, administered by DNR.
- Minn. Rules ch. 7001, the MPCA Permitting Rules.
- Minn. Rules ch. 7005, the MPCA Air Quality Rules.
- Minn. Rules ch. 7050, the MPCA Water Quality Rules.
- Minn. Rules ch. 7060, the Ground Water Protection Rules, administered by MPCA, presently undergoing extensive revision.

MPCA also administers the State Superfund Law (Minn. Stat. ch. 115B), the Petroleum Tank Release Compensation Law (Minn. Stat. ch. 115C), the Solid Waste Rules (Minn. Rules ch. 7035), and the Hazardous Waste Rules (Minn. Rules ch. 7045). These generally have less relevance to mining than the above, although they may apply to mining operations under certain circumstances.

In addition, the Minnesota Department of Health administers the State Explorers and Exploratory Boring Rule (Minn. Rules ch. 4727), which sets standards for closure of exploratory boreholes. MDH also administers the State Well Code (Minn. Rules ch. 4725), which regulates the construction, operation and closure of water wells, including dewatering wells. Both of these rules are based on Minn. Stat. 103I, the Wells, Borings, and Underground Uses Law.

Finally, the Environmental Quality Board administers the State Environmental Review Program (Minn. Stat. ch. 116D, Minn. Rules pts. 4410.0200-4410.7800). This program assigns the responsibility for environmental review of mining projects to the DNR.

In recognition of the recent increased level of nonferrous metallic mineral exploration in Minnesota, DNR has adopted rules to regulate the mining of base and precious metals, codified as Minn. Rules ch. 6132. A recent review of MPCA regulatory programs as they relate to nonferrous mining indicates that this industry will fit well into existing MPCA environmental control programs, and few changes are likely to be necessary.

As alluded to above, DNR and MPCA coordinate their regulatory activities in order to minimize conflicting and duplicative requirements. This relationship has been formalized in a Memorandum of Agreement which specifies those regulatory areas in which each agency has the lead responsibility.

#### 4.4.2.3 Scope of Regulatory Coverage

The regulation of mining in Minnesota is simplified somewhat by the facts that iron ore is the only metal mined, and that acid mine drainage is a relatively localized problem associated with sulfide mineralized stockpiles at one mine. The division of labor which has evolved between MPCA and DNR assures that water and air quality, hazardous and nonhazardous waste disposal, and spill cleanup (MPCA), and facility siting, design and operation, erosion control, site demolition and cleanup, revegetation, dam safety, and public waters protection (DNR), will all be addressed from mine opening through closure/post closure in the course of the permitting and enforcement activities of the two agencies.

There are no exclusions from environmental requirements for mining operations which were active after August 1, 1980, except that small natural iron ore mining operations which rework previously disturbed mining areas, known as "scram" operations, may in some cases be exempt from environmental review. However, all operations require permits, as follows:

- Mineland Reclamation Permit, the "Permit to Mine," required of any project that extracts minerals from the earth, and that regulates the facility from initial operation through closure (DNR).
- Dam Safety Permit, required in most situations where water (or tailings) will be impounded (DNR).
- Protected Waters Permit, required for work that alters the course, current or cross section of public waters, including dams that may be too small to qualify for a Dam Safety Permit (DNR).
- Appropriations Permit, required of any operation that takes water for any purpose, including mine dewatering, above certain trigger levels (DNR).
- National Pollutant Discharge Elimination System Permit (NPDES), required (pursuant to the Federal

Clean Water Act) for any facility that discharges waste water (including, among others, process waters, sewage, mine pit dewatering, and storm water) to surface waters, and sets limits on pollutant levels (MPCA).

- State Disposal System (SDS) Permit, required of any facility that operates a disposal system, typically issued together with the NPDES permit in cases where the discharge is to surface water, and additionally covers systems that do not discharge and also those which discharge only to ground water (MPCA).
- Air Emission Permit, required for any facility (such as a pellet plant) that would emit more than 25 tons per year of any criteria pollutant or that is subject to a New Source Performance Standard under the Federal Clean Air Act (40 CFR 60) (MPCA).
- Hazardous Waste Facility Permit, required of facilities that generate, store, or treat hazardous wastes (all generators must also disclose certain information about their wastes, whether or not a permit is required) (MPCA).
- Solid Waste Management Facility Permit, required for facilities that dispose of solid waste or demolition debris on site (MPCA).
- Tanks Permit, required for certain categories of tanks (MPCA); (for all tanks, whether required to be permitted or not, MPCA imposes registration, installation and monitoring requirements).

The parameters of most concern from a water pollution control standpoint have been total suspended solids, asbestos, biochemical oxygen demand (BOD), chlorine and coliforms (asbestos is a concern only at certain taconite mines). Mining companies are required to perform a one-time broad spectrum scan for metals and many nonmetal parameters before the issuance of permits. From an air quality standpoint, sulfur dioxide and particulates have been of primary concern. With the rise of flotation techniques in the taconite industry, and their importance in the nonferrous milling industry, control of flotation chemicals and their by-products in air emissions and waste water is expected to become more important.

MPCA must approve all plans and specifications for pollution control facilities before construction can begin. Emphasis is placed on the proper design, operation and maintenance of pollution control and waste management systems to prevent pollution before it becomes a problem.

DNR must approve the mining plan, and all other aspects of the mining and reclamation operation before it can proceed. Of particular concern is the siting, design and operation of mining facilities to ensure the encouragement of staged or progressive reclamation as opposed to delaying reclamation until the end of operations.

All MPCA permits are public-noticed for 30 days to allow the public to review and comment on the permit. Anyone may, upon a showing of a substantive issue, request a public hearing on any MPCA permit.

The DNR Mineland Reclamation Permit is public-noticed for four successive weeks for public review and comment at the time of application for the permit. The DNR Protected Waters Permit and Appropriations Permits are not public-noticed, but are submitted to the local unit of government with jurisdiction for local review. Public hearings on these permits may be requested as well.

#### 4.4.2.4 Emergency Response

Major spills and other contamination events at mining sites have been rare in Minnesota. These are emergency situations and cleanups are handled through the MPCA Tanks and Spills Program, a section of the Hazardous Waste Division. On the other hand, cleanup of areas of chronic contamination (as distinguished from acute situations such as spills) such as rail yards, vehicle maintenance facilities, and workshops are dealt with as part of the closure operation. The state is evolving toward requirements for better housekeeping at such facilities to minimize problems of this nature. Other emergencies such as dam failure and subsidence have similarly been rare. They are dealt with by DNR on a site-specific basis, with the emphasis on prevention by good facility design and maintenance, and annual inspections.

#### 4.4.2.5 Closure and Post Closure Care

There has been only one taconite mining facility closure since the state's mining regulatory program was adopted, although numerous scram mining operations have opened and closed in that time. The state is presently working with another mining company to develop a closure plan for one of its mining areas. The process as it has evolved to date involves the preparation by the company of one closure plan document which addresses the regulatory requirements for closure of both agencies. Joint meetings are held to discuss these closure requirements and seek resolutions.

The DNR's Mineland Reclamation Rules are quite explicit as to requirements for closure. All facilities are to be constructed in such a way as to leave them stable, free from hazards, and erosion-free after closure of the mine. Requirements for revegetation, demolition and removal of buildings, railroads, and other appurtenances are provided. Release from the permit and any financial assurance can be sought when these activities and any necessary post closure maintenance have been

satisfactorily completed. MPCA, on the other hand, has no specific requirements in law for closure of mining facilities, since its rules and programs apply uniformly to industries statewide. The agency's approach has been to require a closure plan, and to require continuing compliance with air and water quality standards after closure by requiring that all permits remain in force through the post closure period. Release from the permits and any financial assurance can be sought after a suitable post closure care period which demonstrates that compliance with all water and air quality standards is assured in the long term.

#### 4.4.2.6 Environmental Review

As noted above, DNR has the responsibility for environmental review of mining operations. All new metallic mining operations require an environmental impact statement, as do evaluations of radioactive mineral deposits, new tailings basins, and new mineral processing facilities. A shorter form of environmental review, called an Environmental Assessment Worksheet, is required for nonferrous mineral deposit evaluations, waste disposal area expansions, and expansions of mineral processing plants. EAWs can lead to EISs if significant unresolved issues remain when the EAW process is completed. EISs and EAWs are reviewed by government agencies and the public. Public meetings are required in connection with EISs, and, while not required for EAWs, are often held if significant public controversy surrounds a project. Permits cannot be granted until environmental review has been completed, and no project can be started until permits are in hand.

The state emphasizes cooperation and communication in its dealings with the regulated community. Permittees/operators are encouraged to communicate with the regulatory agencies early in their project planning in order to properly factor in the regulatory component. Regulatory difficulties with the state can often by traced to "last minute" requests for permits, and incomplete data submittals for additional information. The state's position is that planning to minimize environmental impacts is an integral part of project development. Early and continuing communication and responsiveness will aid considerably in keeping projects on schedule.

#### 4.4.2.7 Enforcement

Both agencies have the authority to issue, issue with modifications, or deny permits. Both agencies can levy fines and suspend or revoke permits for violations. MPCA uses Notices of Violation, Stipulation Agreements, Consent Orders, and Administrative Penalty Orders in its enforcement activities. Litigation is used when necessary.

#### 4.4.2.8 Agency Permitting and Enforcement Decisions

As mentioned above, the public can request a public hearing on a permit upon the showing of a substantive issue over which the agency has jurisdiction. Companies who are denied permits to mine, appropriate water, or work in the beds of public waters by DNR can also request public hearings. Under Minnesota law, such hearings take place before a hearing examiner who, after hearing the evidence, prepares a report to the commissioner of the agency. The commissioner must then consider the examiner's finding in making the final decision.

The MPCA is headed by a citizens board, which exercises the policymaking function in that agency. For MPCA permits, the hearing process works the same way, except that the examiner reports to the board. Minnesota law (Minn. Stat. 166D subd. 9) provides that the Environmental Quality Board may reverse or modify agency decisions on any action which would significantly affect the environment if it finds the action to be inconsistent with state environmental policy. Agency decisions on projects may also be appealed to the district court.

#### 4.4.2.9 Compliance Verification

MPCA requires extensive monitoring of ground and surface waters in the vicinity of waste disposal areas to serve as an early warning of contamination problems. The NPDES/SDS permit contains the specific requirements for location of wells and stations, timing of sampling, and analysis methods. Hazardous and Solid Waste permits would, if issued, address monitoring as well. Minn. Rules chs. 7050 and 7060 both address monitoring.

Ambient monitoring is not routinely required for air quality purposes, unless contaminants of special concern are expected. Air quality monitoring is sometimes done for compliance purposes at a specific site, but is more often aimed at determining whether an area is attaining the ambient standards prescribed by the Environmental Protection Agency. If nonattainment is found, the source of the problem is identified through modeling or other means, and corrective measures implemented.

DNR routinely inspects each mining operation at least once each year for the purpose of advising the industry on the resolution of reclamation problems and correcting violations.

#### 4.4.2.10 Environmental Standards and Criteria

MPCA's air quality standards track with the Federal Clean Air Act requirements, and are found in Minn.

Rules ch. 7005. They are mostly technology based.

The MPCA surface water quality standards are found in Minn. Rule ch. 7050. Ground water is classified in Minn. Rule ch. 7060 according to its highest use, which is potable water supply, and managed accordingly. An exception occurs when ground water connects with a surface water, in which case the more stringent aquatic life standards may apply. Contamination above the applicable limits requires cleanup according the requirements in Minn. Rule ch. 7060.

Standards for stockpile siting, construction and design, erosion control, revegetation, landform stability, and site demolition and debris cleanup at closure are found in Minn. Rule ch. 6130, administered by DNR.

As mentioned above, the agencies must approve plans and specifications for the operation before construction can proceed.

#### 4.4.2.11 Closure and Post Closure

The presently existing taconite mining operations have submitted deactivation plans to DNR. These will be updated at closure and implemented. MPCA has not routinely required closure plans in the past. Instead, the agency has made it a condition of the permit that a company inform MPCA two years prior to closure that it intends to close down. MPCA can then require preparation of a closure plan. This policy caused difficulties in the case of the one closure that has occurred in Minnesota, in that the closure was caused by bankruptcy. This in turn resulted in an immediate shutdown, essentially without any advance closure planning or notice to the agencies.

Accordingly, new metal mining operations in Minnesota, whether ferrous or non ferrous, will be required to submit a draft closure plan to both agencies with the application for permits (this is already required by DNR). Since this point is quite early in the mine development time frame, it is expected that this plan will be somewhat speculative and rudimentary. However, the intent is to avoid the type of emergency situation alluded to above, and to introduce planning for closure at an early stage so that subsequent mine operations can be planned with the aim of making closure as efficient as possible.

MPCA permits are issued for 5-year periods, and must be reapplied for as each one expires. Closure plan updating will be a component of the reissuance process. The DNR permits are issued for the life of the project.

As noted above, the operator will be expected to implement the closure requirements given in the Mineland Reclamation Rule in order to be in compliance with DNR closure requirements. MPCA will require that all permits remain in force through the post closure period, in order to assure continuing compliance with environmental standards while closure and post closure activities are ongoing. The activities required by the approved closure plan will be aimed at achieving long-term compliance with standards. At the completion of the post closure period, if it can be demonstrated that the closure techniques used will assure long-term compliance, the operator will be released from the permits. The operator does, however, retain liability for environmental violations after release from MPCA permits.

#### 4.4.2.12 Financial Assurances

The state does not routinely require financial assurance of the iron mining industry in Minnesota, but this may change in the event of the adoption of a federal program which requires it. Minnesota does intend, however, to require financial assurance of any new nonferrous operations which come to Minnesota.

The amount of financial assurance will be based on estimates of the costs which would be incurred by the state or other third party in performing the closure itself. The aim of financial assurance is to assure that sufficient funding to perform this work will be available when needed regardless of circumstances.

The Mineland Reclamation Law contains authority to require financial assurance when the DNR Commissioner deems it necessary. Considerable latitude to determine the amount and type of financial assurance is a feature of this law. It is possible that one financial assurance instrument which satisfies the needs of both agencies will characterize the state's approach. This should minimize the potential for duplicative requirements.

### 4.4.3 NORTH CAROLINA'S MINING REGULATIONS
**by C. H. Gardner and T. E. Davis**

The North Carolina Mining Act of 1971 (Act), North Carolina General Statute 74, Article 7, is the statutory authority that regulates mining activities conducted in North Carolina. The Act was drafted with the assistance of the Interstate Mining Compact Commission. This law was enacted on June 11, 1971, and states that "no mining shall be carried out in the State unless plans for such mining include reasonable provisions for protection of the surrounding environment and for reclamation of the area of land affected by mining." The administrative rules governing mining activities are found in Title 15A NCAC 5A.0100 - 5F.0012.

The Mining Act provides for the issuance of mining permits and for site specific operating and reclamation conditions in each permit. It outlines permit application and renewal procedures, provides for public hearings and appeals, establishes criteria for permit denial, and provides for permit modification, suspension or revocation. It also requires a performance bond or other

security to assure reclamation. The Act requires that each operator submit an annual reclamation report and provides for permit and bond release on completion of reclamation. Enforcement provisions include civil and criminal penalties and injunctive relief. The Act specifies that none of its provisions shall supersede any zoning regulations or ordinances adopted by local governments, so long as they do not conflict with the Mining Act. A 1990 amendment provides for mining permit fees to improve the permitting and enforcement program. The Mining Act requires that air, water, and groundwater laws be met, as a condition of mining permits, and provides for permit coordination among permitting agencies.

Parallel legislation, NCGS 143B-290, created the North Carolina Mining Commission, a 9-member "citizens" board appointed by the Governor. The Commission has authority to establish Administrative Rules (regulations) and to hear appeals. The Mining Act specifies that the Secretary of the Department of Environment, Health, and Natural Resources (DEHNR) carry out the permitting, inspection, and enforcement requirements of the Act. The Secretary has delegated this authority to the Director, Division of Land Resources.

### 4.4.3.1 Scope of Regulatory Coverage

The Act covers all persons or firms involved in a land disturbing activity that affects one (1) or more acres of land and involves any activity or process that:

- Results in the breaking of the surface soil in order to remove minerals or other solid matter; or,
- Is all or part of a process for the removal of minerals, soils and other solid matter from its original location; or,
- Involves preparation, washing, cleaning or other treatment of minerals or other solid matter to make them suitable for commercial, industrial or construction use.

Such operations can range from large stone quarries to soil borrow pits. Exemptions from the Act include those mining operations affecting less than one acre. In calculating the affected acreage, the pit area(s) as well as any disturbed areas associated with the excavation, such as haul roads, stockpiles and waste piles, are taken into consideration. Other exemptions are on-site excavating or grading when conducted solely to aid farming or construction on the same tract. Borrow pits used solely for Department of Transportation projects are also exempt from the mining permit requirements but they are required to meet the Act's minimum standards and are overseen and enforced by the Department of Transportation. The Act exempts mining on federal lands under a valid permit from the U.S. Forest Service or the U.S. Bureau of Land Management.

### 4.4.3.2 Program Implementation and Enforcement

The staff of the Land Quality Section, Division of Land Resources, is required by law to make routine inspections of all permitted mines within the State. The staff is responsible for determining if an operator is in compliance with the provisions of the mining permit. The staff also assures that those persons or firms operating without a permit comply with the Act. To determine how to comply with the Act and to properly obtain a valid mining permit, the interested party should:

- Contact the North Carolina Department of Environment, Health, and Natural Resources, Division of Land Resources, Land Quality Section at P. O. Box 27687, Raleigh, North Carolina 27611, (919)733-4574 or the regional office that covers the area in question before beginning any land-disturbing activity or to confirm that a mining permit is needed.
- Obtain a mining permit application form and a copy of the Act and corresponding Regulations which are available at each office or, upon request, will be mailed to the appropriate person or firm.
- Submit in duplicate, with the appropriate mining permit processing fee, the completed application form and corresponding mine maps, design calculations, etc. to the Land Quality Section Central Office in Raleigh.
- Be notified of the application's approval or denial or need for supplemental information *within 60 days* of receipt of a complete application and following a review by the appropriate agencies. When a proposed operation will involve crushing, waste water processing, air emissions, disturbance of wetlands, possible disturbance of archaeological remains, or other issues that may require special conditions in the mining permit or additional permits, the Land Quality Section Central Office will route a copy of the relevant application materials to the appropriate agencies. These may include one or more of the following:

A. Division of Environmental Management, DEHNR
   (i) Air Quality Section
   (ii) Water Quality Section
   (iii) Groundwater Section
   (iv) Water Quality Planning, 401 Water Quality Certification Section

B. Division of Coastal Management, DEHNR
C. North Carolina Wildlife Resources Commission, DEHNR
D. Division of Parks and Recreation, DEHNR
E. Division of Solid Waste Management, DEHNR

F. Division of Archives and History, Department of Cultural Resources
G. Department of Transportation
H. U. S. Army Corps of Engineers
I. Others as deemed necessary

In 1993, the Act was amended to require that all requests for a public hearing be made within 30 days of receipt of the notice of application. Such a public hearing may be held at the discretion of the Director, Division of Land Resources, DEHNR, if significant public interest exists. If held, it must be within 60 days following the 30-day period for hearing requests.

- If approved, the applicant must post a suitable reclamation bond on a form provided by the Department. Bond amounts range from $500 to $5,000 per disturbed acre.
- When an acceptable bond is posted, the applicant will be issued a mining permit for a term not to exceed 10 years.

If a person or firm violates the Act, he may be subject to the following enforcement action:

- If he is found to be mining without a permit, such violation is punishable under the authority of General Statute 74-64 by the assessment of civil penalties of up to $5,000 for each day the violation continues.
- If he is found to be violating any part of his mining permit, such violation may result in the assessment of civil penalties of up to $500 per day for each day the violation continues. Also, the permit may be suspended or revoked.

#### 4.4.3.3 Compliance Verification (Monitoring)

An on site inspection is conducted of the site prior to issuance of the mining permit, and inspections during the operation are conducted at least on a yearly basis as required by G.S. 74-51 and G.S. 74-56. Mining reclamation reports must be filed by February 1 of each year the mine site is in operation and within 30 days of completion or termination of mining in any area under permit as required by G.S. 74-55.

#### 4.4.3.4 Environmental Standards and Criteria

The Mining Act of 1971, North Carolina Administrative Rules, Application for a North Carolina Mining Permit, and Guidelines on Reclamation Bonds outline the general standards and requirements for applying for and obtaining a mining permit. The mining permit contains specific operating and reclamation conditions, which may differ depending upon the type, location and size of the mining operation, that address any relevant requirements and design criteria noted during the multi-agency review of the mining permit application. These conditions may include, but are not limited to: compliance with water and air quality permits and wetland permits, minimum buffer zone requirements, detailed erosion and sedimentation control plans, minimum slope angles, substantial highwall barricades, specific blasting practices and procedures, detailed groundwater monitoring programs, appropriate visual screening practices, protection of archaeological resources, and detailed reclamation and revegetation plans.

#### 4.4.3.5 Closure and Post Closure Requirements

As reclamation means the reasonable rehabilitation of the affected land for useful purposes and the protection of the natural resources of the surrounding area, the basic objective of the Act is to require the establishment, on a continuing basis, of vegetative cover, soil stability, water conditions and safety conditions appropriate to the area. The operator is required to submit a reclamation plan with the application which outlines the method to be used in restoring the land to a condition suitable for its intended future use. The operator has the right to select the use for which the land is to be reclaimed. Common examples are forestry, agriculture, wildlife conservation, recreational or water-storage lakes, residential developments and industrial uses. Whatever the choice, reclamation must be completed no later than two years after the completion or termination of mining on any segment of the permit area.

The reclamation bond is held by the State until successful reclamation has been completed. At that time the bond is returned to the operator. In the event the operator fails to complete reclamation, a court order may be issued requiring the operator to reclaim the land in question and the bond can be seized and used by the State to complete the reclamation.

#### 4.4.3.6 Financial Responsibility and Liability

As mentioned above, the operator is fully responsible for the cost of complete restoration and reclamation of the land disturbed by the mining operation. Schedules outlining the mining permit processing fees and the required bond amounts are located in the Administrative Rules.

#### 4.4.3.7 Corrective Action Programs

As mentioned above, civil penalty assessments may be levied against the violator by the Department to gain compliance with the Act. Additional enforcement tools

such as injunctive relief, suspension or revocation of the mining permit and bond forfeiture may be used by the Department.

## 4.4.4 ENVIRONMENTAL REGULATION IN SOUTH DAKOTA
**by S. M. Pirner**

### 4.4.4.1 Mining in South Dakota

The Black Hills of South Dakota have hosted gold mining for more than a century. Much of the history of the area has been created by the continuous quest for and extraction of gold from the hills. Over 40 million ounces of gold have been produced since 1876. During much of that time period, it was common and accepted practice to dispose of mine wastes, such as tailings, directly into the nearest stream. It was not until the late 1960s and early 1970s that the adverse environmental consequences of discharging tailings to streams in the Black Hills were identified. From that point in time, it took until 1977 to plan, design, and construct facilities necessary for the impoundment of tailings so that this practice could be halted entirely. In the early 1980s, surface mining with heap leach processing came to the Black Hills. This expansion of gold mining brought growing public concern over the environmental impacts from mining. Consequently, gold mining has received a great deal of public and political attention over the last ten years.

The policies of the state with regard to mining are stated in the South Dakota Mined Land Reclamation Law which is found in South Dakota Codified Law 45-6B (SDCL 45-6B-2). The legislative findings state in part: "Every effort should be used to promote and encourage the development of mining as an industry, but to prevent the waste and spoilage of the land and the improper disposal of tailings which would deny its future use and productivity. Proper safeguards must be provided by the state to ensure that the health and safety of the people are not endangered and that upon depletion of the mineral resources and after disposal of tailings the affected land is usable and productive to the extent possible for agricultural or recreational pursuits or future resource development; that water and other natural resources are not endangered; and that aesthetics and a tax base are maintained, all for the health, safety and general welfare of the people of the state."

### 4.4.4.2 Scope of Regulatory Coverage

With all of the attention to gold mining, a very comprehensive regulatory program has evolved over the years. South Dakota uses a multi-permit approach to regulate mineral development. There are a total of 15 state permits, notices, or certificates that could be applicable to any one mining operation, as listed in table 1. However, the first five permits listed are the primary ones.

The most important concept of the overall regulatory scheme is that the permits, as a whole, provide for multi-media regulatory coverage such that all critical pollutant pathways are being controlled and monitored. This includes emissions to the air, to surface water, to soils, and to ground waters. Through this comprehensive approach of preventing or controlling pollutant discharges to the environment, the Department can insure that mining occurs in such a manner so as to be protective of public health and the environment.

Many states utilize variations of the permits listed in Table 1. However, South Dakota is somewhat unique in its regulatory approach in three areas. The first is the Ground Water Discharge Permit, which establishes limits on degradation of the state's ground water. Figure 2 illustrates the key components of a ground water discharge permit for an off-load heap leach facility. In an off-load facility, ore is loaded, leached, and detoxified to acceptable criteria on the leach pad. Then the treated spent ore is off-loaded to a depository that is typically unlined. Stringent monitoring requirements specified in the ground water discharge permit assure that the beneficial uses of ground water outside of the perimeter of operational protection (POP zone) are not impacted.

The second unique area of South Dakota's regulatory approach is the Special, Exceptional, Critical or Unique Determination. This finding must be made by the South Dakota Board of Minerals and Environment before the mine permit is issued in order to provide for either special mitigation or restrictions that are necessary to protect these lands.

Finally, it should be noted that a solid waste permit is not used to regulate mine wastes in South Dakota. The reason for this exclusion is that extensive requirements are contained in the mine permit which include both closure and post closure provisions. Thus, mine waste has been excluded from the state definition of solid waste.

### 4.4.4.3 Program Implementation and Enforcement

In the absence of a federal program for regulating mining, the state has been able to develop an approach to regulate mineral development activities that is uniquely tailored to mining conditions in South Dakota. One of the distinguishing features is that all environmental permits, including mine permits, are issued by the South Dakota Department of Environment and Natural Resources (DENR) and its Boards. The organizational structure is shown in Figure 3. Thus, identifying the institutional participants in the environmental regulation of mining at the state level is relatively simple.

By state law, the Department is required to consult

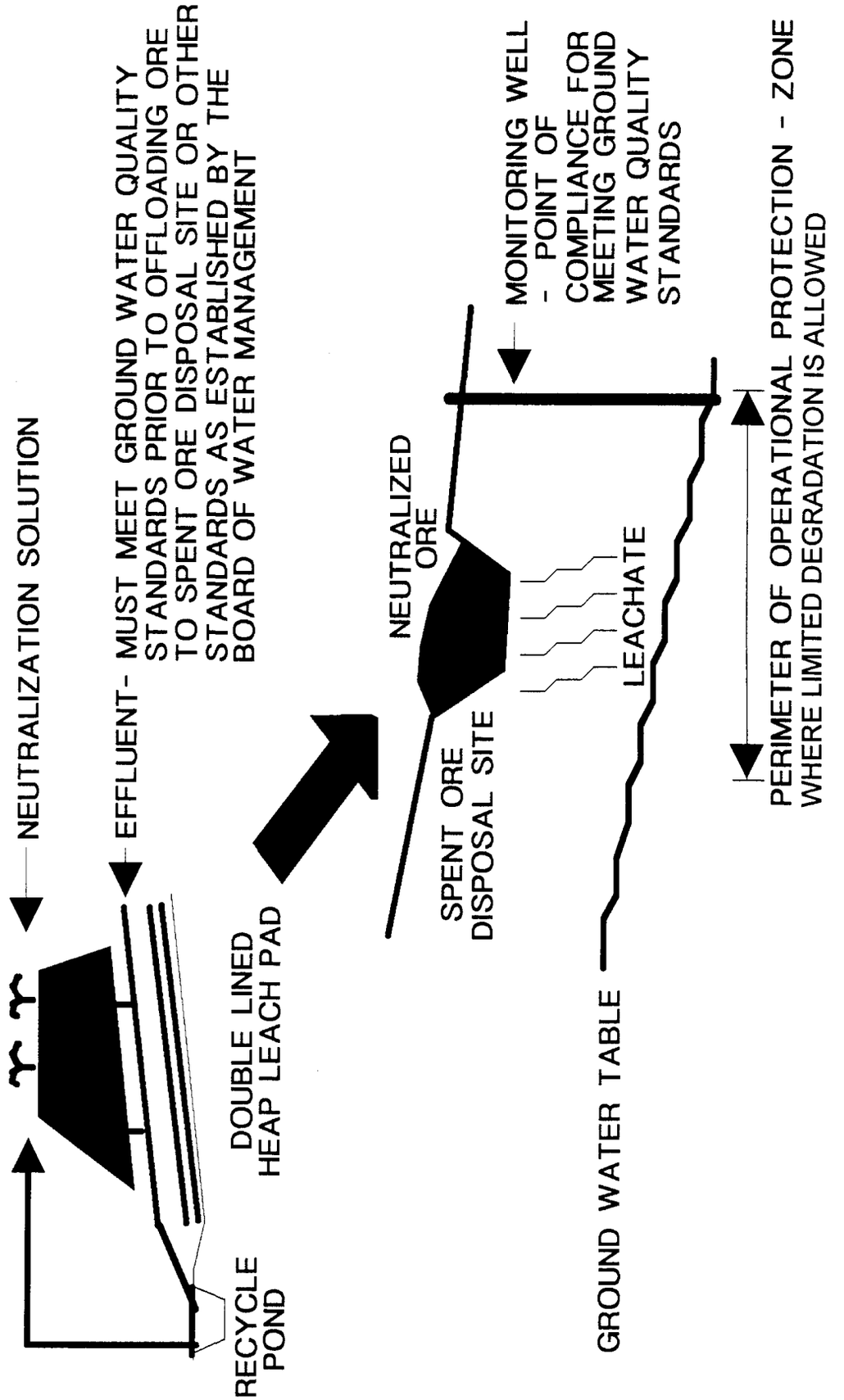



**Figure 2** South Dakota Ground Water Discharge Permit Components.

**Table 1** Environmental Control Mechanisms Used in South Dakota

| State Permits (as per SDCL) | Purpose | Issued By * |
|---|---|---|
| Mining (Lead Permit) | Establish Operating Criteria, Best Management Practices, and Reclamation Standards | DENR/BME |
| Water Right | Allocate Water for Use | DENR/BWM |
| Air Quality | Establish Pollutant Limits for Air Emissions from Point Sources | DENR/BME |
| Surface Water Discharge | Establish Pollutant Limits for Discharges to Surface Waters | DENR/EPA |
| Ground Water Discharge | Establish Pollutant Limits for Discharges to Ground Waters | DENR/BWM |
| Special, Exceptional, Critical or Unique Land Determination | Determination if Lands to be Mined Require Special Protection or Reclamation | DENR/BME |
| Notice of Intent to Explore | Establish Operating and Reclamation Requirements | DENR |
| Sand, Gravel, and Rock to be Crushed and Used in Construction Mining License | Establish Operating Criteria, Best Management Practices, and Reclamation Standards for These Types of Mines | DENR/BME |
| School & Public Lands Lease | Allows Mineral Exploration and Development on State Lands | School & Public Lands |
| Flood Control Permit | Establish Criteria for Changing the Stage of Surface Water | DENR/BWM |
| Hazardous Waste Treatment, Storage, or Disposal Permit | Establish Criteria for the Handling, Storage, and Treatment of Hazardous Wastes | DENR/BME |
| Uranium Exploration Permit | Establish Operating and Reclamation Requirements | DENR/BME |
| Underground Injection Permit | Establish Criteria for Injecting Wastes into Ground Waters | DENR/BWM |
| Notification and Regulation of Underground Storage Tanks | Establishes Tank Construction Standards and Spill Response Requirements | DENR/BWM |
| Notification and Regulation of Aboveground Storage Tanks | Establishes Tank Construction Standards and Spill Response Requirements | DENR/BWM |

* **Legend:** DENR — South Dakota Department of Environment & Natural Resources
BWM — South Dakota Board of Water Management
BME — South Dakota Board of Minerals & Environment

with several other state and local agencies prior to making any final recommendations on a mine permit application. These consultations must include the South Dakota Departments of Education and Cultural Affairs; Game, Fish, and Parks; Agriculture; and Health. At the local level, the Department must consult with the local conservation districts and the county commissioners.

In addition to consulting with state and local agencies, the Department also consults and coordinates its permitting activities with the United States Forest Service when lands under its jurisdiction are impacted. The state has signed a formal Memorandum of Understanding which lays out the procedural arrangements for this coordination, and has also developed with the U.S. Forest Service a "Best Minerals Management Practices" manual which both agencies use as a guide in the review of mine applications and reclamation plans. Finally, the Department actively participates on inter-disciplinary review teams when a federal Environmental Impact Statement is required by the Forest Service.

#### 4.4.4.4 Compliance Verification (Monitoring)

Compliance verification through ambient monitoring networks for nearly all environmental media including

**Figure 3** South Dakota Department of Environment and Natural Resources Organization Chart.

surface water, ground water, and air, is performed by the mine operator as required by various permit conditions. In addition, a number of the operational systems used in the mining and processing of the ores require compliance verification. Examples of these operational systems include leak detection systems between liner systems which have action leakage rates described in the mine permit conditions and heap neutralization systems prior to off-loading. Heap neutralization is monitored very carefully to insure that the leached and neutralized ore meets stringent off-load criteria for various metals, pH, and weak-acid disassociable cyanide prior to being moved from the pad to the spent ore dumps. Verification of compliance monitoring by Department personnel is a continuous activity and consists of collecting both independent compliance samples and split samples.

#### 4.4.4.5 Environmental Standards and Criteria

South Dakota uses both performance standards and design and operational criteria in regulating mining activities. Many of the performance standards are based on or related to the state environmental standards. The environmental standards consist of both numeric and narrative criteria which have been determined to be necessary to protect the beneficial uses established for a given media. A listing of these South Dakota standards is provided in Table 2. Most of these environmental standards have been promulgated using the state rule-making procedures and are in the form of Administrative Rules of South Dakota (ARSD).

On the other hand, most of the design and operational criteria have not been promulgated into rules. The reason for this is that design and operational standards are generally applied in a site specific manner and therefore require a greater degree of flexibility than can be specified in a rule. Most of the design issues are handled through the review and approval process for plans and specifications, while most operational standards are set as conditions in the various permits that are applicable to an operation. Examples of design criteria would include double liner requirements for heap leach facilities, storage capacity of process and storm water ponds, and land application systems for process solutions. Operational standards might include maximum water levels allowed in process ponds, tons per year to be mined, and off-load criteria either in terms of heap effluent water quality or solid sample analysis that has to be met prior to spent ore disposal.

#### 4.4.4.6 Closure and Post Closure Requirements

In South Dakota, the long term consequences of improper mining, mine waste disposal, and reclamation have been recognized and the state has both closure and post closure requirements. In order to properly close a mine area, it is essential that both the mine operator and the Department understand that proper management of the ores and wastes must begin with the initial exploration activities, be incorporated into the project feasibility studies and design stages, and continue through and even after the close of the operation. Figure 4 depicts the process used in South Dakota and emphasizes the constant interaction that is critical to cooperatively identify potential problems, alternatives, and solutions that will protect the operator, the public, and the environment.

This attention to closure requirements is necessary because of the volume of mine wastes, the unique geochemical properties of any specific mine waste, and many other factors that are variable not only between different operations but even within different areas of the same operation. Therefore, mine operations and waste management practices must be constantly evaluated, and adjustments made when warranted. Complying with closure and post closure requirements are not activities

**Table 2** Environmental Standards Established in South Dakota

| Standards | Goals of Standards |
|---|---|
| Air Quality Standards | Protect Public Health<br>Protect Property<br>Protect Livestock and Wildlife<br>Protect Vegetation<br>Protect Visibility |
| Surface Water Quality Standards | Protect Designated Beneficial Uses of:<br>Domestic Water Supplies<br>Cold Water Fisheries<br>Warm Water Fisheries<br>Recreation<br>Livestock and Wildlife<br>Irrigation<br>Commerce and Industry |
| Ground Water Quality Standards | Protect Designated Beneficial Uses of:<br>Drinking Water<br>Other |
| Soil Application Guidelines * | Protect Public Health<br>Protect Vegetation<br>Protect Ground Waters<br>Protect Surface Waters |
| Reclamation Standards | Stabilize Affected Land<br>Restore Land to a Beneficial Use<br>Provide Visually and Functionally Compatible Contours |

* Have not been promulgated as rules

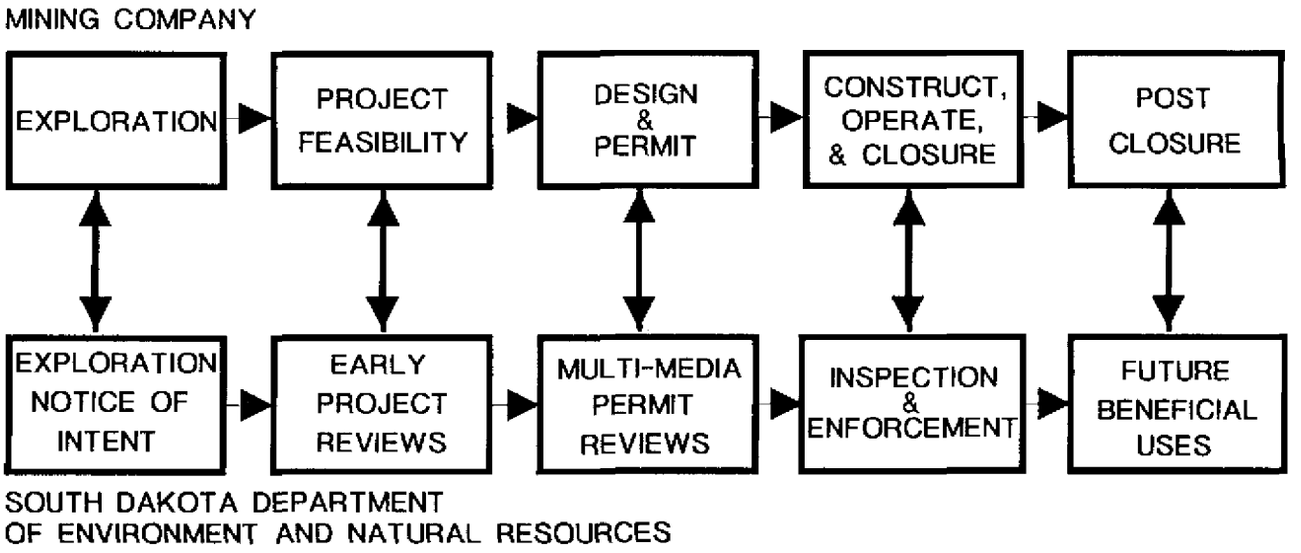



**Figure 4** Mine Waste Management Process in South Dakota: Concept to Closure.

that can be handled during the last year of the mine life, but must be designed and managed throughout the entire life of the mine.

#### 4.4.4.7 Financial Responsibility and Liability

South Dakota Codified Law provides for four different types of financial assurances to be provided for those mines that must receive a mining permit, and are listed in Table 3 below.

**Table 3** Financial Assurance Requirements That May Apply to Mines in South Dakota

| Purpose | Type | Limits |
|---|---|---|
| Reclamation Bond | To Neutralize any Ores being Processed, and to Reclaim Affected Lands as per the Approved Reclamation Plan | None |
| Leaching Bond | To Remediate Accidental Releases of Leaching Agents | $25,000 to $500,000 |
| Environmental Assurance Bond | To Remediate any Pollution, Contamination, or Degradation of the Environment | None |
| Postclosure Financial Assurance | To Guarantee the Costs of Postclosure Care and Maintenance over the Postclosure Care Period | None |

#### 4.4.4.8 Corrective Action Programs

Corrective action programs for mine activities in the state have focused on the near-term type of incidents, such as leaks and spills of process solution, and long-term reclamation activities focusing on acid mine drainage mitigation. However, the Department plans to consider additional requirements for long-term closure and post-closure plans together with corrective action plans for responding to future contamination problems.

## 4.5 OVERVIEW OF WESTERN STATE REGULATORY PROGRAMS

In 1990, the Western Governors' Association (WGA) undertook a survey of states to determine the nature and extent of non-coal mine environmental regulatory programs with special emphasis on the regulation of mining wastes. The results of the survey can be found in two documents available from WGA– "Tabulated Responses to a Survey of State Non-Coal Mine Waste Regulatory Programs" dated August, 1990 and "Results of a Multi-State Survey" dated September 30, 1990. They are helpful in providing an overview of the extent of mining activity occurring in the states, the types of mining activities that the surveyed states currently regulate under existing statutory and regulatory authorities and the extent of regulatory coverage by program element.[16]

[16] A similar effort was undertaken by Public Resource Associates (PRA) of Reno, Nevada and is included in a report entitled "Review of Hardrock Mine Reclamation Practices in Western States." PRA compared western states' reclamation legislation, regulations, guidelines for exploration and development, and bonding practices. This information was gathered through telephone interviews with state reclamation personnel and research conducted on each state's

The WGA survey, as well as other recent surveys of state environmental regulatory programs, have highlighted the fact that state regulation of mining is an evolving and dynamic process. As this chapter is written, major organizational changes and related procedural adjustments are being undertaken in Florida, South Carolina, New Mexico and Colorado. With each year come additional revisions and enhancements to existing state regulatory programs as a result of changing technology, emphasis on new environmental issues, and legislative initiatives. It is important to note that even without the direction or stimulus of federally mandated programs, states are taking steps to respond to the specific needs of the environment and protection of human health.

In reviewing any overview of state environmental regulation, it becomes dramatically evident that although there are many similarities among the broad regulatory program elements, the specifics of each state's approach varies significantly. As noted above, this is consistent with the federalist scheme of government whereby the states are vested with primary governmental authority to regulate matters within their borders. This allows the states the flexibility to experiment with different formulas for effective regulation that are consistent with federal standards set forth in national legislation that establish generic goals and objectives to be implemented by the states.

Given the wide variety of regulatory approaches to environmental control at the state level and the dynamic nature thereof, it becomes incumbent upon the practitioner to familiarize himself or herself with the specific state regulatory program that will impact future mining operations. Therefore, a listing of contact agencies in each state is included at the end of this chapter where the potential mining operator should begin his or her investigation of permitting and regulatory requirements for the state of interest. Each state generally provides a copy of its applicable laws, regulations, guidelines and permit applications to interested parties upon request. Permit applicants will also find state regulators eager to assist with any questions or problems encountered by the applicant.

## 4.6 INTERSTATE COOPERATION AND ENVIRONMENTAL PROTECTION

State governments are faced with significant responsibilities and challenges in their roles as primary regulatory authorities in the areas of mineral development and associated environmental protection. It takes considerable effort to properly focus the issues surrounding development of our nation's abundant mineral wealth so as to assure production in an environmentally sound manner. State governments are pressed from all sides to perform their regulatory or research roles regarding mineral production in such a way that they satisfy environmental, multiple-use, socioeconomic, and industrial concerns. The charge from the citizenry of the respective states, as contained in duly enacted laws, is essentially to establish and maintain programs of land and other resource development, restoration, and regulation that assures adequate supplies of needed materials and yet copes with the impacts of their production.

One of the mechanisms that governments have of accomplishing these objectives, especially in an area such as mineral development, is through coalitions – local, regional, and national. One of the practical reasons for the use of coalitions is that, many times, mineral development and some of its environmental impacts do not respect state or other artificial boundaries. Minerals must be mined where we find them, and the environmental consequences of mineral development may spread beyond even the best designed and projected permit area. When one adds to this the economic impacts that may arise from interstate competition, the need for interstate cooperation becomes obvious. In fact, such concerns have led to federal preemption on several occasions as evidenced by the Clean Water Act, the Clean Air Act, the Surface Mining Control and Reclamation Act, and recent efforts to revise the 1872 Mining Law.

The value of coalitions is that they provide an avenue for cooperation among states, between governments (be they state, local, or federal), and even among several affected parties such as government, industry, and conservationists. Perhaps the most formal type of coalition of states that exists today is the interstate compact. A compact is both a statute and a contract. It is almost always a statute in each of the jurisdictions that is party to it. Even in those cases where this may not be strictly true, the instrument has the force of statutory law.

statutes. The report found that between 1989 and 1992 many states enacted legislation which fine-tuned their hardrock mining reclamation regulations. Some altered permitting requirements or redefined small miner exemptions from permits or bonding. In other cases, major changes were made. Oregon, for example, enacted rigorous chemical process mining regulations in response to an increasing number of disseminated gold mining operations locating their cyanide-leaching mines within the state. Nevada experienced a dramatic increase in hardrock mining activity during the 1980s and passed legislation addressing reclamation in 1989. Some states, such as Washington, Wyoming, California and Montana, have adopted state environmental policy or quality acts which enhance their reclamation statutes by requiring a variety of agencies to oversee and coordinate environmental assessment of proposed mining operations. In general, the report found that states appear to be tailoring their reclamation laws to suit the unique industrial, environmental and social circumstances within their borders.

### 4.6.1 THE INTERSTATE MINING COMPACT COMMISSION

The Interstate Mining Compact Commission (IMCC) fits very much into the mold of a traditional compact. It had its beginnings in 1964. In April of that year in Roanoke, Virginia, the Council of State Governments held a conference on surface mining, attended by state and federal legislative and administrative officials, by mining industry representatives, and by conservationists. In the aftermath of this meeting, the Southern Governors' Conference, that fall, called on the Council of State Governments to assist the states in developing one or more compacts to deal with surface mining problems. These initiatives led to the subsequent adoption in many states of strengthened laws and programs for regulating surface mining. To supplement these intrastate activities, the Interstate Mining Compact was drafted and became available for the states' consideration in the legislative sessions of 1966.

The Interstate Mining Compact was thus conceived and Kentucky became its first member, followed by Pennsylvania and North Carolina. With the entry of Oklahoma in 1971, the compact was declared to be in existence and operational. In February 1972, a headquarters office was established in Lexington, Kentucky and an executive director was retained. Since 1972, 13 additional states – West Virginia, South Carolina, Maryland, Tennessee, Indiana, Illinois, Texas, Alabama, Virginia, Ohio, Louisiana, Arkansas, and Missouri – have become members. New York joined the Compact as its first associate member in 1994.

The Mining Compact is designed to be advisory and not regulatory, and its defined purposes are to:

- Advance the protection and restoration of the land, water, and other resources affected by mining.
- Assist in the reduction or elimination or counteracting of pollution or deterioration of land, water, and air attributable to mining.
- Encourage (with due recognition of relevant regional, physical, and other differences) programs in each of the party states that will achieve comparable results in protecting, conserving, and improving the usefulness of natural resources, to the end that the most desirable conduct of mining and related operations may be universally facilitated.
- Assist the party states in their efforts to facilitate the use of land and other resources affected by mining, so that such may be consistent with sound land use, public health, and public safety and to this end study and recommend, wherever desirable, techniques for the improvement, restoration, or protection of such land and other resources.
- Assist in achieving and maintaining an efficient and productive mining industry and increasing economic and other benefits attributable to mining.

Participation in the Compact is gained through the enactment of legislation by the states authorizing their entry into the Compact. The states are represented by their respective governors who serve as commissioners. The Compact also provides for the establishment of a mining advisory body within each state consisting of representatives from conservation interests, the mining industry, and other public and private interests.

Among the Compact's powers are the study of mining operations, processes, and techniques; the study of conservation, adaptation, improvement, and restoration of land and related resources affected by mining; the gathering and dissemination of information; making recommendations; and cooperating with the federal government and any public or private entities having an interest in any subject within the purview of the compact. The Compact acts through several committees that have responsibility for particular subject matter or policy areas including: environmental affairs, abandoned mine lands, resolutions, and finance. The governors are represented on these committees by duly appointed delegates from their respective states.

The IMCC was founded on the premise that the mining industry is one of the most basic and important in the nation. Our manufacturing activities, transportation systems, and the comfort of our homes depend on the products of mining. At the same time, it is essential that an appropriate balance be struck between the need for minerals and the protection of the environment. The IMCC recognizes that individual states have the power to establish and maintain programs of land and other resource development, restoration, and regulation appropriate to cope with the surface effects of mining. The Compact would not shift responsibility for such programs. On the other hand, its 18 member states believe a united position in dealing with the federal government affords them a decided advantage. The Compact feels strongly that the collective voice of many is important in its efforts to retain some semblance of states' rights.

Over the years the IMCC has become an organization of national scope serving as the eyes, ears, and spokesperson for the mining states in Washington, D.C. It strives to effectively represent the interests of the mining states in their dealings with Capitol Hill and the executive agencies in an effort to articulate the concerns and recommendations of the states in their role as primary regulators of mining activities within their borders.

### 4.6.2 THE WESTERN GOVERNORS' ASSOCIATION

Established in 1984 through the merger of two

governors' organizations, the Western Governors' Association (WGA) is an independent nonpartisan organization of governors from 17 western states, two Pacific territories and one commonwealth. The Association was formed to provide strong regional leadership in an era of critical change in the economy and demography of the region. The organization is founded on the understanding that the vital issues and opportunities shaping the future span state lines and are shared by governors throughout the West.

The WGA identifies and addresses key policy and governance issues in natural resources, the environment, human services, economic development, international relations and fiscal management. The issues are selected by the governors based on regional interest and impact. WGA helps the governors develop strategies both for the complex, long-term issues facing the West and for the region's immediate needs. Through WGA the governors develop and advocate policies that reflect regional interests and relationships in debates at the national and state levels.

The WGA has six basic objectives:

1. *Develop Regional Policy.* The WGA enables governors to identify issues of regional concern, to formulate regional policy for those issues, and to take action that promotes western interests.

2. *Serve as a leadership forum.* The WGA provides a forum for governors and other leaders to exchange ideas, positions and experiences.

3. *Build a Regional Capacity.* Through the WGA, governors and their staffs exchange information and ideas about problem solving for a wide range of practical management concerns. The exchange helps governors manage their resources more efficiently and builds rapport among governors, cabinet officers and gubernatorial staffs in the region.

4. *Conduct Research.* The WGA is staffed by experts in western issues and maintains up-to-date information on a wide range of subjects important to western policy makers, business leaders and educators. The WGA produces white papers and other analyses used in the development of policy on matters important to the West.

5. *Form Coalitions and Partnerships.* Through the WGA, western governors form coalitions to collectively express their positions on matters of shared interest and together advocate a western agenda before Congress and the executive branch of the federal government.

6. *Build Public Understanding.* Through its annual convention, meetings, media briefings, background papers, and the *Western Governors' Report*, WGA provides timely information for media and the public.

WGA members include the governors of Alaska, American Samoa, Arizona, California, Colorado, Guam, Hawaii, Idaho, Kansas, Minnesota, Montana, Nebraska, Nevada, New Mexico, North Dakota, Commonwealth of the Northern Mariana Islands, Oregon, South Dakota, Utah, Washington, and Wyoming. WGA plans, manages and reports on its activities in four program areas: Environmental Management; Lands and Waters; Regional Development; and the Washington, DC, Monitoring.

In the area of mine waste, WGA formed a Mine Waste Task Force (MWTF) in April of 1988 under the leadership of Utah Governor Norman Bangerter. Participating states include Alaska, Washington, Oregon, California, Arizona, New Mexico, Utah, Colorado, Nevada, Wyoming, Idaho, Montana, South Dakota and Minnesota (all WGA member states) as well as Texas, Missouri, Wisconsin, Michigan, North Carolina, South Carolina and Florida (all non-WGA member states having significant interests in the mine waste issue). The MWTF coordinates the views of the member states on a variety of mine waste issues and works with EPA, the mining industry, the environmental community and the public in the development of a workable mine waste management program. Pursuant to a cooperative agreement with EPA and through a joint working relationship with IMCC, WGA's MWTF has prepared three significant reports on mine waste regulatory activity at the state level: *Results of a Multi-State Survey on State Non-Coal Mine Waste Regulatory Programs* (August and September 1990); *Projected Regulatory, Programmatic and Fiscal Impacts of EPA's Strawman II on State Mine Waste Management Programs* (December 1991) (Three volumes); and *Inactive and Abandoned Noncoal Mines: A Scoping Study* (August 1991 and July 1992) (Four Volumes). Copies of these documents are available from WGA.

### 4.6.3 CONCLUSION

The real value of multistate organizations like the IMCC and WGA is their ability to coordinate action and to speak as one voice on issues of importance to the states. Without opportunities such as these, the states are left to fend for themselves or, worse yet, are criticized as being unable to effectively handle issues or resolve problems that are uniquely within the province of the states. This then serves as a justification for federal preemption, and the states find their authority being superseded by national legislation.

Environmental protection and resource management

call for a stabilizing federal presence, but the federal government must guard against fostering well-intentioned programs that produce costly activity without progress. Problems are inevitable with federal legislation that paints the entire nation with the same broad stroke. Americans live in a land of diverse environmental conditions and problems. Federal regulation of our environment must reflect the diversity of this country's many regions. Efforts to achieve and sustain a cleaner world require a balanced partnership between states and the federal government, an arrangement that recognizes and builds upon the relative strengths of the partners.

For their part, the states shoulder the primary responsibility for planning, designing, implementing, and enforcing programs to achieve federal and state goals and standards. This involves exercising discretion in the design and operation of environmental programs as long as program goals are achieved. It also involves the right to establish standards more stringent than federal minimums, in accordance with the states' fundamental obligation to protect their citizens' health and welfare. Flexibility is also one of the best incentives the federal government can offer for innovative and speedy environmental protection. For their part, the states are committed to meeting the challenge of protecting the environment while assuring the responsible development of our Nation's abundant mineral resources.

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# Chapter 5
# ENVIRONMENTAL EFFECTS OF MINING

edited by F. K. Allgaier

## 5.1 PREFACE

This chapter provides an overview of the effects that mining operations can have on the environment. The chapter is divided into sections based on the category of effects. These categories are land surface effects, hydrologic effects, biologic effects, air quality effects, societal effects, and blasting and subsidence effects. Chapter 6 is then similarily organized to provide a cross reference from the description of the effects in this chapter to the technologies for remediating the effects, contained in Chapter 6.

The chapter presents a broad-based coverage of the types of environmental effects that various types of mining activities can produce. The approach in assemblying the information for this chapter has been to attempt to cover the most often encountered effects from the most common types of mining operations. Not every specific problem or situation can be covered, nor can the individual effects be explained in comprehensive detail. The intent is to provide a starting point by way of a general description, with reference material added to further guide the reader. This chapter attempts to help answer the following questions. What environmental resources are affected by mining? What are the effects? What causes the effects?

## 5.2 LAND SURFACE EFFECTS

**by T. Brown**

### 5.2.1 INTRODUCTION

Mining is a transitory use of land that requires disruption and/or disturbance to provide man with essential mineral and energy needs. Whether mining is associated with surface or underground operations, the nature of such operations requires the disturbance of our lands either at the surface or to great depths within the earth's crust. During the "early" years of mining prior to the issuance of environmental laws and regulations, those involved with the operations usually did not worry about land reclamation or the quality of surface and ground waters as a result of mining. Not until significant amounts of land were disturbed and important water resources were significantly impacted did people begin to worry about such environmental influences. Even today when reclamation and remediation efforts are very important considerations of the mining operation, severe impacts occur. However, not all impacts associated with mining are negative. Sometimes efforts expended during reclamation or amelioration of affected sites result in situations that are better or more productive than the initial land use. Today, some of the "hard pan" soils of east Texas are destroyed by mining operations and are replaced with soils made of reduced overburden that the U.S. Soil Conservation Service has designated as prime farmland soils. In this section, the effects of mining on the topography and the soil and overburden will be discussed. The impacts of the various kinds of mining operations on the topographic features of the land will be addressed in the first part of this section and the latter part will provide an overview of the impact of mining on the soils and overburden associated with the affected land.

### 5.2.2 TOPOGRAPHY

The mining methods used to extract various materials from the earth will determine many aspects of the postmining topography. Each mining operation will result in disturbances dependent on the geological structure associated with the commodity mined, on the depth of the deposit from the surface, on the surface character of the topography, and on the mining method used. Most mining methods can be grouped into two general categories that result in surface disturbances and underground influence that may affect surface topography. Methods of mining that can be categorized as surface disturbance include: area or strip mines often used to extract coal, uranium, and metals in the Western United States; quarries or open pit mines often used to remove granite, limestone, and other bedded materials; mountain top removal and contour removal often used to mine coal in steep areas; and placer or dredging

operations that usually pertain to creek beds or abandoned creek beds. Mine shaft and/or drift or adit extraction for coal and other materials and *In situ* solution mining are underground operations that can greatly influence the land surface.

Specific areas associated with the impact of mining on topography include the destruction of geomorphic features, rill erosion and mass wasting, differential settling of fills and regraded mine areas, fills resulting from waste rock and tailings, and subsidence due to underground mining. Many of the surface features in the premining topography cannot be replaced in the postmining condition. Landscape diversity is often lost. Landscape features such as badlands, escarpments, rim rock, and microsites are often destroyed by surface disturbance associated with mining and cannot be reestablished without significant economic hardship to the mining operation. Such landscape features are important both for the aesthetic value and for critical plant and wildlife habitat. The elimination of such features can be a major factor contributing to a decline in wildlife use of an area and may result in the elimination of specific plant species present in the affected area.

The natural land surface is drastically changed by mining activities through the removal and placement of materials and the dumping of waste rock or tailings. Depending on mining conditions and equipment availability, widespread changes in the locations of the materials will occur. For example, an adequate amount of material may not be available to fill the final pit of a surface coal mine or a limestone quarry. As a result, the area will usually be regraded to a topography that includes a lake or basins and depressions with at least a portion of the area having relatively steep slopes. Reclamation of contour mines and sometimes mountain top removal mines often results in some very steep slopes due to the inability to access the site with appropriate equipment for reclamation, and because the economics of moving the large amounts of earth required to establish gradual slopes are often prohibitive. Areas of excess spoil will often be graded as hill or mound areas that may contain relatively steep slopes. Because of the steepness of slopes and the loose, nonhomogeneous nature of the materials present, such areas are usually morphologically unstable and are subject to erosion and mass failure. Even on gently sloping areas, erosion problems often occur due to the loose, unstructured nature of the materials. The final result is the development of anthropogenic or unnatural land forms that are often in states of disequilibrium relative to the natural environment where they are created. Therefore, rill erosion and mass wasting are often found to be major problems associated with mining operations. The primary role of reclamation is to achieve a landscape that approximates premining conditions assumed to be near equilibrium with the local environmental factors.

Waste rock and tailings are products of the mining process that influence the postmining land surface. Usually these waste materials are placed in the postmining topography. In the case of mountain top removal and contour mining methods, waste materials are often used to fill adjacent canyons or hollow areas. When associated with canyon fills, these anthropogenic land forms may be flat or gently sloping on top, but often have steep sideslopes and tend to be very erosive. Also, because of the nature of the material (i.e., unconsolidated, nonhomogenious,) water penetration can cause instability thus enhancing mass wasting and the formation of seeps containing high levels of various elements that could impact downslope sites.

Stream channel distruction due to area surface mining operations and placer mining methods often means the elimination of a somewhat stable landform condition. Usually stable stream channels have developed following hundreds of years of interaction with their environment under natural conditions. Often such streams are stabilized by bedrock or other natural controls. These controls are usually destroyed during the mining process and are replaced with unconsolidated materials that can readily degrade into a severely unstable situation. Development of stable stream channels on reclaimed lands proves to be a costly and challenging undertaking.

Reclamation of mined areas often results in landscapes that meet the premining criteria, that is, good landscape diversity with slopes that will reduce significant erosion and mass wasting. However, differential settling due to changes in material consolidation from one point to another on the landscape often causes severe disruption of the surface topography. The amount of differential settling will be dependent on the equipment used during the reclamation process. For example, dragline/dozer reclamation would be expected to show significantly more differential settling than would be found at a site reclaimed using scrapers, which would tend to compact the materials during grading operations.

### 5.2.3 SUBSIDENCE

Subsidence can have a major effect on the topography of the land surface. In this context, subsidence is associated with underground mining and sometimes with *in situ* solution mining operations. Following the removal of the commodity of interest, the roof materials may cave, causing collapse of the overlying rock strata resulting in subsidence of the surface. The degree of collapse of the overlying rock strata can vary from practically no collapse with no resulting surface impacts to total collapse with more pronounced changes at the surface. The amount of subsidence that occurs is usually related to the amount of material excavated or otherwise removed, the thickness and strength of roof material, the

nature of the overburden material, and the overall depth of mining. Subsidence features can be small, localized events or the lowering of larger areas, shallow depressions or deep pits, gradually sloping troughs or steep offsets, cracks or fissures, or combinations of the above.

Over bedded deposits that are longwall mined, or mined with other full-extraction techniques, such as coal or trona, the subsidence is often a shallow trough. In very flat terrain, this trough may be quite visible and may cause local changes in drainage and possibly ponded water in areas with shallow ground water or large amounts of precipitation. In hilly areas or areas of steep terrain, a shallow subsidence trough may be visibly undetectable and cause little or no surface impacts or drainage problems. In the United States, subsidence from active coal mining results in the largest effect to the land surface in terms of area undermined, although the effects are often relatively small in terms of overall topographic relief. Other impacts of subsidence such as damage to surface structures and changes to surface and subsurface hydrologic resources are generally of more importance than the impacts on topography or surface features.

Subsidence from shallow abandoned coal mines often results in abrupt, but localized changes in topography that reflect the collapse of individual rooms or voids that collapse over time. This type of subsidence can be an isolated, single collapse or can involve a larger area with many individual subsidence pits. The latter represents a significant and noticeable change in the local topography.

Subsidence from hard rock or *in situ* mining can produce either a shallow, gradually sloping subsidence depression or a deep, steep-sided subsidence feature depending on the nature of the mining method, amount of material extracted from the mine, overburden material, and depth of mining.

Each mining situation and geologic setting will determine a unique subsidence scenario with a particular impact on the land surface. Each case must be analyzed with respect to these unique, site-specific parameters. Generalized case histories and prediction methods are available to estimate or precalculate the impact on the surface, but field measurements are almost always required to definitively characterize the surface impacts of subsidence.

### 5.2.4 SOILS

Soil can be defined as a natural body consisting of layers or horizons of mineral and/or organic constituents of variable thicknesses, which differ from the parent material in their morphological, physical, chemical, and mineralogical properties and their biological characteristics. Soils in their natural state are developed over long periods of time due to the influences of pedogenic processes such as parent material, climatic conditions, biota, topography, and time. The chemistry and biology associated with a specific soil will reflect the pedogenic processes relative to the specific site under which the soil was developed. Pedogenesis results in the development of soil structure that has a prominant role in the formation of the pore size distribution, which is the distribution of the micropores and macropores relative to each other in the soil profile. The pore size distribution influences the availability of water and nutrients for plant uptake as it has a direct impact on the water- holding capacity and mobility of solutions in the soil.

In the past, reclamation was not considered to be an important component of the mining operation and the soil resource was often treated as part of the overburden material. As a result, soils were completely lost during mining due to mixing with spoil or other materials or to improper handling and storage. Once it became apparent that mined and/or disturbed lands must be reclaimed, the topsoil resource became vitally important to aid in the reclamation process. Most mining operations now are required by State and Federal regulations to remove the soil materials from a site prior to disturbance and to replace the soil at the surface after the site is regraded or no further disturbance is planned. Sites that have prime farmland soils usually have the A and B horizons of the soil profile removed separately and stockpiled for reclamation purposes. In areas where very little soil is present on a site prior to mining, the A, B, and C horizons are usually removed as a mixture to provide as much suitable plant growth material as possible for reclamation. However, topsoil removal and replacement does not necessarily mean that equivalent growth potential will exist in the postmining and premining systems.

Disturbance of the soil profile during a mining operation usually has a significant effect on the soils resource from a physical, chemical, and biological perspective. As a result, the disturbance can cause significant impacts to plant growth. However, the degree of impact is site specific and in some cases the distruction of the soil profile does not cause stress to the vegetation re-established on the site.

As noted previously in this discussion, soils present in the premining condition were formed over a long period of time. The structure and pore size distribution characteristics are developed during pedogenesis. The network of macropores and micropores that are present in the soil allow the movement of gases and solutions in the soil system. The ability of the soil to accomodate the exchanges of gases and solutions with the root systems of plants is important to the vegetative productivity of the site. Once the soil is disturbed, these characteristics are eliminated, and the soil system is much different than it was prior to mining. The continuation of large and small soil pores throughout the soil profile is disrupted,

and the consolidated nature of some portions of the soil profile is destroyed. Without the inherent soil structure, water-holding capacities may be much different, and the movement of solutions and gases through the soil material may change. However, re-establishment of the soil structure will occur over a period of time depending on the characteristics of the soil materials and the climatic conditions existing at the various site locations. At locations in the Northern Great Plains, after the development of some structure in replaced silt loam, prime farmland soil re-establishment is apparent in about 6 to 10 years. However, the development of structure to predisturbance conditions may take tens or hundreds of years. The influence of the distruction of soil structure on the productivity of vegetation has not been adequately quantified at this time. However, notable declines in vegetative productivity apparent at some sites undoubtedly are related to the depletion of soil structure.

Topsoil can also be impacted if stockpiled for long periods of time. Studies have shown that this practice has a negative effect on the microbial populations present. Materials stockpiled for long periods of time may contain a limited amount of viable microbial populations important for elemental transformations that occur in a healthy soil environment. The importance of this influence on the reclamation success of a site may not be significant; since the stockpiled materials are replaced on a reclaimed site, the microbial populations seem to reestablish in a relatively short period of time.

A major environmental effect of mining on plant productivity of topsoil is associated with the replacement of the topsoil material following regrading of the backfill. Often topsoil replacement is done using scrapers and other equipment that can cause compaction. The problem often occurs at the regraded overburden/soil interface and can exist in the soil materials at the interfaces between lifts. Compaction has a major impact on root penetration and water availability for plant use. Water movement characteristics are often modified. The reduction of water movement into the soil often causes increased runoff and erosion and decreased water-holding capacity, which results in site instability and draught conditions for the vegetation. Techniques can be implemented to alleviate compaction problems during reclamation activities.

Mining of sites that have an extremely limited soil resource such as might exist in a rugged rock-type environment, may result in a complete loss of the soil resource. Methods of soil removal at these sites are very limited and expensive. As a result, the reclaimed site would be clottered with rock and boulders with very limited revegetation possibilities.

Mining can also have positive influences on the soil resources. Soil resources associated with many mine sites have limited productivity due to textural problems or due to the presence of clay and/or iron hardpans. The removal of these soil materials and their replacement with good quality spoil can result in increased productivity. In fact, several soils developed from reduced overburden have resulted in the formation of prime farmland soils where acid, hardpan soils existed prior to mining.

### 5.2.5 OVERBURDEN

Disturbance of the overburden due to surface mining causes significant changes in the physical and chemical nature of the system. The consolidated nature of the bedrock materials is destroyed during the mining process resulting in a significantly different system. Precipitation and surface runoff from adjacent sites can easily infiltrate through the surface and percolate into the system. At sites where the disturbed or unconsolidated overburden is in contact with an aquifer, percolated water will contribute as recharge. Where the unconsolidated materials are surrounded by consolidated unpermeable materials, a new aquifer can be established that resembles a bathtub. Under certain conditions, the postmining system can provide a beneficial contribution to aquifer recharge. However, circumstances often lead to the formation of waters that contain high levels of elements, and in the cases where pyritic materials are present, acid waters are formed and often discharged into the adjacent aquifers and/or to the surface at some point in the landscape.

The chemistry of the overburden materials often changes from the premining condition to the postmining condition. Such changes are due to the influence of water on the now available soluble salts and to the changing redox conditions resulting from the influx of oxygen into the system that was previously oxygen depleted. The disruption of the consolidated overburden and the increase in water penetration into the reclaimed areas often results in high concentrations of salts and/or elements into the existing or reestablished ground water aquifer system. Such conditions have a major impact on the mineralogy of the system as the dissolution and formation of minerals and amorphous materials of various solubilities are rapidly occurring.

The presence of soluble salts such as sodium in regraded overburden can cause saline and sodic conditions in topsoils if conditions allow the upward migration of these salts. Also, the oxidation processes result in significant changes in chemistry. When sulfides such as pyrite are present, acid is produced, and the solubility of elements tends to increase. Acid mine drainage typically has pHs below 2.3, acidities near 5000 mg/L, and anionic concentrations (mostly sulfate) exceeding 10,000 mg/L (Caruccio et al., 1981). Iron disulfides in the form of pyrite and marcasite are the predominate contributors to the production of acid mine drainage. The following reactions occur during the oxidation of the disulfides as described by Stumm and Morgan (1970):

$$FeS_2(s) + 7/2\ O_2 + H_2O \Leftrightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (5.2.5.1)$$

$$Fe^{2+} + 1/4\ O_2 + H^+ \Leftrightarrow Fe^{3+} + 1/2\ H_2O \quad (5.2.5.2)$$

$$Fe^{3+} + 3H_2O \Leftrightarrow Fe(OH)_3(s) + 3H^+ \quad (5.2.5.3)$$

$$FeS_2(s) + 14Fe^{3+} + 8H_2O \Leftrightarrow 15Fe^{2+} + 2SO_4^{2-} + 16^+ \quad (5.2.5.4)$$

This reaction proceeds quite slowly. In fact, Stumm and Morgan (1970) observed half-times for $Fe^{2+}$ oxidation on the order of 1,000 days. Once the $Fe^{3+}$ is formed, it combines with $H_2O$ to form insoluble $Fe(OH)_3$ as shown in equation (5.2.5.3). As the $Fe^{3+}$ concentrations increase with increased acidity, the $Fe^{3+}$ becomes important as an oxidizing agent. Several research efforts have shown that pyrite is rapidly oxidized by $Fe^{3+}$ in the absence of oxygen and at low pHs (Garrels and Thompson, 1960; Smith et al., 1968). This reaction is shown above as (5.2.5.4). These researchers also found that the presence of $O_2$ did not influence the kinetics of the reaction. Since pyrite can reduce $Fe^{3+}$ to $Fe^{2+}$ faster than $Fe^{2+}$ can be regenerated into $Fe^{3+}$ by $O_2$, the pyrite will reduce all the $Fe^{3+}$ and then the reaction will stop. Thus the $Fe^{2+}$ to $Fe^{3+}$ oxidation is considered to be the rate-limiting step in the production of acid. A major catalyst of this reaction is the bacteria *Thiobacillus ferrooxidans*, which is known to increase the $Fe^{2+}$ oxidation rate by six orders of magnitude (Singer and Stumm, 1970; Nordstrom, 1976). This reaction makes $Fe^{3+}$ readily available for pyrite oxidation.

## 5.2.6 EROSION
**by B. W. Hassinger**

Erosion is defined as the general process or the group of processes whereby the materials of the earth's crust are loosened, dissolved, or worn away, and simultaneously moved from one place to another (Anon., 1980a). As mining is the process of extracting mineral deposits from the earth, the mining process, by its very nature, results in disturbed areas of the earth's surface. These disturbed areas include exposed, loosened, and weakened soil and bedrock, mine waste rock, and process wastes/tailings. Uncontrolled runoff, lack of vegetation, steep slopes, and mining and construction practices can result in the movement and deposition of these materials, changing the topography of the source areas and the areas where the materials are deposited.

### 5.2.6.1 Media Affected by Erosion

In the mining sequence, vegetation is removed from soil, bedrock is exposed, and mine and process wastes are deposited. These are the media most likely subjected to the erosion process.

#### *5.2.6.1.1 Soil*

Erosion of soil as a result of mining is generally due to the destruction of soil conditions and surface topographies that existed before mining commenced. As most minable mineral commodities occur in bedrock formations, the exposure of soil in mining operations is generally limited to the soil overburden thickness around the perimeter of open-pit operations, above the rock face of drift mine entries, and the surface exposure/disturbance of soil around an underground operation. Soil removed as overburden and deposited nearby is discussed below as mine waste.

The potential productivity of soil for plant growth is generally reduced after mining activities have disturbed the soil. In addition to the removal of organic topsoils, soils disturbed by mining activities many times become chemically active and toxic. The rate of soil erosion is influenced by the vegetative cover, runoff characteristics, and slope of the land. Some soils erode more readily than others, however, even when the above conditions are the same. The factors that influence erosion by water are the same factors that affect the infiltration rate of soil, such as permeability and porosity, and factors that affect the dispersion, splashing, abrasion, and transporting forces of runoff (Walters et al., 1986). When these physical properties are disturbed or changed, soil erosion is generally accelerated.

#### *5.2.6.1.2 Mine Wastes*

The term "mine wastes" includes overburden soil and rock and rock dumps. These include soils from surface and placer mining operations and excavated and mined rock from surface and underground operations. Their characteristics vary according to geological origin, type of mining or excavation equipment, particle size of the mined material, and moisture content. Mine wastes are sometimes used for backfilling mined areas; however, the bulk of mine wastes are dumped adjacent to the mine. As mine wastes consist of material ranging from soil to rock and minerals, the particle sizes range from clay size to very large rock fragments. The primary sources for these materials are soil and rock overburden from surface mining operations and to a lesser degree, rock removed from shafts, haulageways, and underground working spaces. Mine waste materials placed on the surface are called waste embankments. Waste embankments can be constructed as nonimpounding or impounding embankments. Impounding embankments are more frequently used in conjunction with mine processing wastes or tailings.

#### *5.2.6.1.3 Process*

Process wastes or tailings are the portions of washed or

milled ore deemed too poor to be treated further. The particle sizes for process wastes can range in size from very soluble materials occurring in solution to fairly coarse (gravel size) particles. Process wastes occurring in solution or as a slurry are generally deposited behind tailings embankments (impounding embankments) using overburden material or coarse tailings. Coarse and dry fine wastes are stored separately or together. Process wastes or tailings include materials from hard resistent quartz to mudstone. These materials differ greatly in physical properties and can have very different susceptibility to erosion by water or wind (Coates and Yu, 1977).

#### *5.2.6.1.4 Exposed Bedrock*

Bedrock is exposed in surface mines, highwall access face for drift mines, and sometimes for mine access roads. The exposed bedrock can range from soft mudstones and shales to very competent metamorphic and igneous rocks such as quartzite and granite. The rock terrain and climate probably have the most important influences on the susceptibility of bedrock to erosion.

### 5.2.6.2 Causes of Erosion

The causes of erosion are natural or artificial. In the context of the effects of mining, the focus is on artificial causes, however, the artificial cause can initiate downstream or adjacent natural causes. Anything that weakens or destroys the vegetative cover or oversteepens slopes may accelerate runoff and erosion.

#### *5.2.6.2.1 Uncontrolled Runoff*

Most erosion is caused by uncontrolled runoff. Water that does not enter the ground or evaporate becomes surface runoff. In areas where there is vegetation, there is generally a balance between the loss of soil through erosion and the generation of new soil through the weathering process. In mining areas where the protective shield of vegetation is broken and the slopes are often times steepened, the balance between erosion and soil creation is upset, increasing runoff and erosion.

#### *5.2.6.2.2 Lack of Vegetation*

The role of vegetation is very critical in controlling runoff. Vegetation increases the infiltration rate by promoting a thicker soil cover, better soil texture, and by breaking the impact of raindrops on the ground surface. When raindrops strike unprotected soil, soil fines are thrown into suspension by the impact and then redeposited in an impermeable glaze. This glaze lowers infiltration and increases runoff (Cook, 1979).

#### *5.2.6.2.3 Steep Slopes*

Historically, there has been little thought given to minimizing steep slopes at mining sites. Steep artificial slopes at mines are generally of four types: highwalls, overburden piles or mine waste, process waste or tailings, and impoundments. Many of the slope faces are at or near the angle of repose of the material. Erosion is generally not an important means of material movement at highwalls. As highwalls generally consist of fairly competent bedrock, the most prevalent movement of particles is through rock falls or by mass wasting, discussed later in this section.

Overburden piles are frequently impacted by erosion at mining sites. This material is generally mechanically excavated and occurs in discrete particles that are susceptible to erosional forces. Erosion rates for overburden piles are dependent on the composition of the material, such as the percentage of sand, silt, clay, and rock fragments (Coates and Yu, 1977). Overburden consisting of rock blocks and fragments with little compaction and high porosity will drain quickly and generally remain stable during wet conditions. On the other hand, soils and poorly cemented rock are highly susceptible to erosion.

Process wastes or tailings are wastes from a milling operation. Particle sizes from mineral processing operations can vary from coarse blocks resulting from crushing/grinding operations to fine wastes discharged as a slurry. As with the mine wastes, the coarse material will generally drain and generally be resistent to erosional forces. The fine tailings, especially shales and water-sensitive clays, can be subject to severe erosion on steep slopes. Impoundments are waste piles that store water. The embankments for these impoundments are constructed of tailings, waste rock, natural soils, or a combination of these materials. As impoundments are generally more carefully engineered than other mining waste structures, erosion stabilization is generally a design consideration. Most of the problems relating to embankments are slope failures due to weak foundation materials, placement of the embankment material at too high or steep a slope, high pore water pressure within the embankment, or weak foundation material (Anon., 1977b).

#### *5.2.6.2.4 Mining/Construction Practices*

As previously mentioned, very little thought has been given to slope steepness at mining waste disposal facilities. Steep slopes at mining sites can generally be attributed to lack of planning and engineering relating to material disposal. In steep terrain, overburden has been pushed over the side from bench cuts, fine tailings are

placed in embankments too steep to be mechanically compacted, and many slopes cannot be planted because of the steep slope, or they will not support vegetation because of toxicity. The other major contributors to erosion at mine waste facilities are poor drainage patterns and lack of compaction control (Anon., 1977b). Exploration activities such as road construction, preparation of drill sites, and test pits are also contributors to erosion.

### 5.2.6.3 Topographic Expression of Erosion

In a general sense, if erosion is unhindered, it would level highlands, fill up lowlands, and reduce the Earth to a topographically smooth sphere (Young, 1970). The several types of erosion resulting from uncontrolled runoff are named after their topographical expression. These types of erosion are discussed below along with wind erosion and sediment deposition.

#### *5.2.6.3.1 Sheet Erosion*

All rivulets of water from accumulated rainfall move small grains of soil downslope. The impact of the raindrop actually dislodges small particles, suspends them, and then transports them by the rivulets. The total effect of these small movements is called sheet erosion, which results in the downslope transfer of surface soil without obvious channeling (Howard and Remson, 1978).

#### *5.2.6.3.2 Rill Erosion*

Rill erosion occurs at the same time as sheet erosion; however, the water becomes more concentrated in definitive channels. As rills are easily removed during grading operations, this type of erosion is commonly included with sheet erosion. If rills are allowed to continue to develop, they will form gullies. Once gullies are formed, erosion proceeds very rapidly (Walters et al., 1986).

#### *5.2.6.3.3 Gully Erosion*

Gullies are small valleys that are generally too deep to be removed by normal grading operations. Gullies can develop from several different sources such as low areas or depressions, excessive rill development, differential settlement, slope failures, headward cutting of rills, and piping through the subsurface. When gullies form in low areas where flow can become channeled, they can develop more depth and velocity and more erosive power.

#### *5.2.6.3.4 Deflation*

Deflation, or the sweeping away of loose material by wind, is generally not as extensive a problem at mining sites as is runoff erosion. Most problems relating to wind erosion can be attributed to the disposal of fine process-related materials. At tailings impoundments, where surface materials are loose and dry and the surface is smooth, wind erosion can result in blowouts, similar to the effect of wind action on sand dunes. Also, if overburden soil contains a high percentage of fine soils, wind will winnow out clay and silt-sized particles, leaving larger sized particles behind (Walters et al., 1986). Generally, however, overburden piles are not overly susceptible to wind erosion because of their extensive rock content and their ability to support vegetation.

#### *5.2.6.3.5 Sediment Deposition*

The processes of erosion and the impacts of these processes discussed above relate to the effects of erosion on the surface topography at the mine site. However, just as erosion removes material and changes topography, the deposition of sediment from the erosional process adds material and changes topography near the mine site and in many cases at some distance from the mine. The goal of modern mining practice is to divert as much water as possible from disturbed areas at a mining operation using natural topography and diversion ditches and channels (Anon., 1977b). Designs that provide detention storage to surface runoff or reduce the surface slope will tend to reduce erosion and siltation; however, they also may increase infiltration and recharge. This may have desirable effects; however, if poor quality water is allowed to infiltrate, mine drainage problems may be prolonged. Also, techniques designed to promote surface runoff and reduce infiltration and recharge may increase a sediment problem. Sediment deposition can impact surface water quality, cause flooding in small streams, and shorten the life of small lakes and reservoirs.

## 5.2.7 MASS WASTING

Mass wasting is the lowering or wasting of the land surface by mass movement (Howard and Remson, 1978). Mass movements are defined as movements of material by gravity. Soil and rock material is loosened and transported downslope under the direct application of gravitational body stresses. This includes slow movement such as soil creep and solifluction, and rapid movements such as rockfalls, rockslides, and soil flows (Thornbury, 1962). The nature of the mass movement generally depends on the interaction of the soil and rock particles and the moisture content of the material.

### 5.2.7.1 Media Affected by Mass Wasting

#### *5.2.7.1.1 Soil*

Mass wasting of soil at mining sites is generally

classified as soil creep, slides, and falls. In many cases the movement is a combination of these types of movements. This is particularly true at vertical cuts for surface mine pits, drift mine entries, and haul road cuts, where a substantial thickness of soil or unconsolidated material occurs above bedrock or more consolidated soil. These types of excavations or cuts probably cause most of the mass wasting of naturally occurring material at mining sites. The more common occurrence of mass wasting of soil at mining sites occurs at overburden piles which are discussed below. Generally, the cause of the mass wasting of natural soil is the removal of underlying support by excavation and then overloading due to an increase in moisture content and/or an additional material load (Howard and Remson, 1978).

#### *5.2.7.1.2 Mine and Process Wastes*

The most visible and detrimental type of mass wasting with respect to mine and process wastes at mining sites is slides. Creep is generally not a problem at active sites, as ongoing maintenance can generally correct this type of movement. However, if creep is not corrected at mine and process waste embankments at abandoned mine sites, long-term creep can have an impact on the surrounding area if creep becomes deep-seated and generates massive slides.

Slides at waste embankments are generally referred to as shear failures. A waste embankment will fail in shear if the applied shearing stress on the surface of the embankment exceeds the shear strength of the materials along or below that surface (Anon., 1977b). The frictional and cohesive shear strengths of the materials are the resisting forces (Ziruba and Mencl, 1976). The factors contributing to a loss in frictional and cohesive strength are discussed below.

### 5.2.7.2 Causes of Mass Wasting

Mass wasting occurs when the gravitational force exceeds the frictional and cohesive resisting forces or external support (Howard and Remson, 1978). The principal factors causing mass wasting at mine and process waste piles are as follows:

*Change in material properties* - Weakening of materials by weathering, dissolution, frost action, and seismic events. For example, some minerals swell or become slick when wet.

*Increase in moisture content* - Water adds weight, affects internal pore pressures, and decreases cohesion of clay minerals.

*Overloading* - Caused by increase in moisture content, additional waste/fill loading, and loads due to addition of structures.

*Removal of underlying or lateral support* - Removal of material at the toe of embankments by erosion or excavation, and removal of subsurface support by mining.

*Seismic events* - Ground motion from earthquakes and blasting reduces internal friction of material or dislodges masses of material.

### 5.2.7.3 Topographic Expression of Mass Wasting

Soil and rock falls at mining sites generally occur at highwalls, pit sidewalls, or road cuts. They range from small soil clumps and small rock fragments to large masses of soil and rock that drop from steep or overhanging cut faces. They generally leave vertical faces on the cut face, with debris piles at the foot of the slope.

The surface expression of a slide is generally a planar surface (Howard and Remson, 1978). These planes develop along soil or rock layers (bedding) or fractures where the material slides down a slope. In some cases slides result in curved or scooped-shaped surfaces, where masses of soil or rock slump away from a slope. In unconsolidated materials, slumps may occur as steplike slumps due to the continued undercutting of the base of the slope (Howard and Remson, 1978).

## 5.2.8 FILLS

The mining materials previously discussed (i.e., soil and bedrock overburden, mine waste rock and process wastes) all can be designated fill materials because they are artificially generated deposits that when placed, change the existing topography or grade. Process wastes or tailings and for the most part mine wastes are disposed of as unusable materials, and the fill section or resulting embankment does not have a secondary function. On the other hand, soil and rock overburden frequently are placed to fill depressions, valleys, or low areas to serve as platforms for construction of mine facilities (i.e., processing plant, offices, parking) roads, railroads, and town sites.

### 5.2.8.1 Overburden and Mine Wastes

Generally, the initial stages of surface mine development involve the removal of overburden, which is placed nearby. Underground mines require shafts or access drifts which also generate waste rock. As previously indicated, these materials are initially used to build up level areas near the mine where the mine facilities can be constructed. Additionally, these materials are used to develop townsites, roads, and railroads to service the

mine and the related community. The excess overburden and mine wastes generated during the life of the mines are generally placed in valleys or hollows (valley fills) if available or large surface embankments if the mine is located in a topographically flat area. In the past, in steep areas, overburden was pushed over the side of the hill or dumped down hill. Regulatory changes have eliminated this practice for the most part. Also, the regulatory requirements to backfill benches to the previously existing slope and to backfill pits have eliminated much of the visible overburden piles and embankments.

#### 5.2.8.2 Process Wastes

Process wastes or tailings embankments generally consist of two types; nonimpounding embankments and impounding embankments. The impounding embankments are capable of impounding water (Anon., 1977b).

The nonimpounding embankments include valley fills, sidehill embankments, ridge embankments, and heaps. The impounding embankments include cross-valley embankments, side-hill embankments, diked ponds, and excavated ponds (Anon., 1977b). These structures generally impact the existing topography by raising the general grade of valleys or flat areas, or in the case of diked ponds, creating depressions. The embankments generally have large exposed slopes extending from the previously existing grade to the crest of the embankment, which are subject to erosion and mass wasting as discussed above. The impounding embankments are also subject to failure due to sudden flooding.

## 5.3 BIOLOGIC EFFECTS

### 5.3.1. VEGETATION
**by D. Helm**

Mining effects on vegetation are particularly important because (1) vegetation is visible, (2) it stabilizes soils, and (3) it integrates soil and environmental responses. One of the first conditions people notice after mining is the lack of vegetation. Erosion may follow if natural or planned revegetation does not occur and no engineering techniques are used to stabilize the site. Vegetation not only protects the soil but is also an indicator of soil conditions and provides food and cover for wildlife. Plant species require certain conditions to grow, but these conditions vary according to plant species. If no one attempts to alter the conditions, then certain species might be expected to colonize. Reclamation techniques can alter the habitats so that other plant species may colonize it. The response to disturbances such as mining without amelioration would be similar to that of other natural disturbances.

In this section, we will first define some structural characteristics of vegetation and describe some general effects of mining. In the following two sections, the effects of past and present mining techniques will be addressed. The past mining techniques section will include discussions of effects ranging from the most severe, when nothing was done, to the almost unnoticeable, when the operator implements a well-designed reclamation plan. Effects of altered environmental conditions on vegetation will be described. Case histories of natural revegetation of mined lands will be presented.

#### 5.3.1.1 Structural Characteristics

Six main structural characteristics of vegetation will be discussed: cover, density, productivity, composition, diversity, and plant morphology. Each of these describes a different aspect of vegetation structure and function. Any one or all of these characteristics may change as a result of mining.

*Cover* is the vertical projection of living plant material onto the ground. Sometimes, the meaning of cover is extended to include litter and standing dead plant life. Cover is equivalent to the percentage ground covered by a shadow cast by all plant parts with the sun directly overhead. It is always less than or equal to 100% no matter how many layers of vegetation are present. Cover is related to protection provided by vegetation to the soil against rain drops. If one assumes that roots mirror the aboveground plant parts, then cover is also related to the horizontal extent of the root system. This is related to the "holding" power of roots to stabilize the soil. Cover is one of the most easily measured vegetation parameters and is frequently used as a standard for reclamation bond release.

*Density* is the number of stems per unit area. It is related to crowding and competition or to forestry stocking rates. Natural colonization of sites after mining or other disturbances usually has low densities to start, increases with time to a maximum, then natural thinning results in an ultimate long-term density. This process may take several years or hundreds of years depending on plant species and site conditions. Sites that have too few plants may be an indicator of (1) poor site conditions for those species or (2) insufficient time for the plants to colonize. Stands with high densities initially may become dog-hair stands. Early densities need to be great enough to accommodate mortality but low enough to accommodate plant growth. Natural thinning will adjust the density to a stable value in the long-term. Stem densities are low to start, reach a peak during mid-successional stages (about 25 to 50 years after initial

colonization on floodplains), and decrease as individuals die (100 years). Vegetation changes after mining follow the same pattern, but the time scale may vary depending on site conditions and distance to closest vegetation.

*Productivity* is the change in biomass per unit time, usually measured on an annual basis. For herbaceous species such as grasses, this is usually interpreted as the net new living biomass at the end of the growing season. Insects, as well as small and large mammals, including domestic livestock and wildlife, graze the plants, thus reducing the apparent production as measured by clipping studies. Sometimes available forage, which is living plant material above the lowest level that is safely grazable, is used as a measure of grass production. For woody plants, technically the productivity would be the leaves, new twigs, and cambium inside the older twigs and trunk. A more usual measure of productivity used for trees is the height, dbh (diameter-at-breast-height, about 1.5 m aboveground), or volume at a given age. Productivity is related to plant and ecosystem health. Large plants may produce more per plant, but productivity by smaller plants with more stems in a unit area may produce more per unit area. Large, old plants may be mostly standing biomass and have low productivity, whereas young plants have mostly actively producing tissues.

*Composition* is the relative cover or density of plant species or a list of species. It is related to community appearance. The appearance of the site is different if plants occur in different relative proportions. For instance, if a stand contains mostly one species of tree, such as paper birch, with only a few white spruce trees, the stand has a different appearance than if it were mostly spruce trees with a few birch trees, yet the cover and densities may be the same.

*Diversity* is a measure of the number of species (richness) and the evenness of distribution of cover (or some other measure) of the species in the community (Hurlbert, 1971; Hill, 1973). Stands with completely different species may have the same diversity. Stands with the same species but different relative amounts may have different diversities. Numerous measures of diversity exist. A commercial wheat field with no weeds is a monoculture and would have the lowest diversity, usually a 1, but may vary based on the diversity index used. Communities with large relative representations of many species would have the greatest diversity. A field dominated by one species that also has one individual of 10 or 20 different species probably has a lower diversity (slightly greater than 1) than a field with two or three species approximately equally represented (values near 2 or 3). Diversity starts low during initial colonization, increases over time until a peak is reached, then usually decreases as a stand ages. The timeframe will vary with site conditions.

*Plant morphology* is the structural appearance of a plant and can be indicated by measures such as height, twig or stem diameters, and number of branches or twigs. Colonization by plants on abandoned mined lands with no developed soils or other disturbances on nutrient-poor soils are sometimes stunted. Plants 15 to 20 years old may be <1 m tall and have twisted stems on disturbed sites. Sometimes the leaves may be chlorotic (yellowish) or deformed.

### 5.3.1.2 Effects of Mining on Vegetation

Reclamation is considered a part of mining in most segments of the mining industry today. Reclamation may be as "simple" as stabilizing the site with straightforward contouring or as complex as planning wildlife habitat and edge effect for several different plant and animal species or constructing wetland to control wastes. In the past, however, reclamation efforts were minimal or nonexistent. The effects varied from minor disturbances to erosion of hillsides. This section will examine effects of mining on vegetation from major to minor.

#### *5.3.1.2.1 Erosion*

The most obvious effect of mining is the total removal of vegetation. If no remediation is applied, this could result in major erosion, including erosion of hillsides. This, in turn, would degrade water quality downstream from the mine, both with sediment and any toxic wastes. During and immediately after a mining operation, sites are vulnerable to erosion until vegetation can be established or some artificial stabilization is achieved. Plant establishment may range from nonexistent to slow succession. If native vegetation is nearby or if the plant growth substrate contains buried rhizomes or seeds, then succession proceeds more quickly and the site is stabilized sooner.

Intermediate effects may result when the land is backfilled and some remedial action taken, but no revegetation or other soil stabilization techniques are applied. Some mine operators may be able to replace topsoils, but many have been, are, and will be limited to overburden, mill tailings, other waste products, or soils that are low in nutrients and moisture-holding capacity. Existing plant communities and their associated wildlife values are disrupted or eliminated. Succession, the change in plant and other species over time, may still be slow.

#### *5.3.1.2.2 Toxicities*

Acid mine or rock drainage occurs when bacteria reduce

sulfates so that sulfuric acid results. This may happen around coal mines with high sulfur content or around hard-rock or placer mines with pyrite. Soil pH values may drop to 3 or lower in which no plants or only specially adapted plants can grow. Areas with low-sulfur coal, such as Alaska, generally do not have these challenges.

Other toxicities may result, particularly around heavy metal mines, and may include lead, zinc, iron, copper, and cadmium. Some metals have different mobilities and may be absorbed at different rates by plants and animals, thus leading to different effects. Cadmium has a greater potential for accumulation through lower terrestrial trophic levels than both lead and zinc. The low transfer potential of zinc may be associated with its essential role in biological systems. The high mobility of cadmium may result from its accumulation in soft tissues rather than skeletal components, the latter constituting the principal sites for deposition of lead. Bioaccumulation of lead and cadmium increased significantly, and survival, growth, and development were impaired in one or more invertebrate taxa during chronic (10 to 120 days) exposures to leachates from cover treatments of vegetation and organic mulches on abandoned deposits of lead-mine tailings in southeast Missouri (Besser and Rabeni, 1987). Titlyanova and Mironycheva-Tokareva (1990) also found major effects of mining on fresh-water species.

The concentration of heavy metals can be sufficiently high around abandoned copper and zinc mines to prevent most vascular plants from colonizing the area. Cyanide is also a potential hazard resulting from high- and low-impact disturbances.

#### *5.3.1.2.3 Changes in Communities*

Effects of mining on vegetation vary from minor to major even where sites have been revegetated. If the objective of the reclamation is to reestablish local vegetation, and that vegetation is suitable for reclamation, then the short- and long-term effects of mining may be minimal. If desired plant species are not suitable for initial revegetation seedings because they require shade or some other conditions, then a longer time period may be needed to reduce the impacts of mining. In other cases, totally different vegetation may be the goal.

Some plant species used in revegetation may be chosen for their commercial availability and cost with little regard for adaptability to the site or suitability for postmining land use. Effects on vegetation would be substantial since either a different vegetation type would be replaced or a failure would occur. Many mine operators today, however, are planning their reclamation in more detail so that species are selected for adaptability to the site and suitability for the postmining land use. This may be more cost effective because it requires less maintenance. Sometimes this means selecting species that are the same as that found in surrounding vegetation or the vegetation that existed on the site prior to mining, and an attempt is made to restore the original vegetation. At other times, the desire to achieve better production, a longer grazing season, or increased diversity dictates that other species should be used. Surrounding vegetation may have quantities of grass for grazing but little hiding cover for wildlife. In this case, trees or shrubs may be added to the reclamation plan. In these cases, long-term changes to vegetation composition may occur, but these effects of mining are desired. Also some of the existing vegetation may not be achievable on mined sites immediately because of plant species growth requirements. Hence vegetation on a recently mined site will differ from the native vegetation or the desired postmining vegetation in the short term in spite of the best efforts at reclamation.

Changes in vegetation can be either positive or negative, depending on what values are being used and the goals of the project. Reestablishment of nutrient cycling and other ecosystem functions may be difficult unless topsoil with the appropriate soil and rhizosphere (root-zone) organisms are present. For instance, litter may be very slow to decompose under low nutrient conditions.

Wetlands may be created or destroyed by mining. Many mining operations left open water wetlands in regions of Pennsylvania and the number of water impoundments has decreased after the Surface Mining Control and Reclamation Act (SMCRA) was passed in 1977 (Brooks, 1990). Wetlands can be used to improve wildlife habitat in conjunction with coal mining and to improve drainage from some mines.

### 5.3.1.3 Succession

*Succession* is the change in species composition and function that occurs over time. Soil horizons accumulate organic material, plant species change, microorganisms and animals change, and abiotic factors change. *Primary succession* occurs when these changes start from barren ground with no biological precursors. Natural examples of primary succession include changes on floodplains, recently deglaciated terrain, and deep volcanic deposits. Succession on overburden or tailings from mining mimics primary succession and may have complicating factors such as acid mine drainage or toxicities. Plant growth media may vary drastically compared to native vegetation. Secondary succession occurs when a biological community or remnant was already present. Examples include succession after fire and on "live" topsoils after mining. "Live" topsoils are surface soils above the parent material that could be placed by direct haul-back with little or no stockpiling.

Succession that might occur on mined lands or other drastic disturbances proceeds from early colonizing species, through intermediate stages, to stable, self-reproducing communities. In many environments, nature does not achieve the final stable state after hundreds of years or may never achieve it because disturbances reoccur. The success of different plant species on mined lands depends on their role in succession.

Presence of "safe sites" for seed germination is essential for the first steps in natural colonization. "Safe sites" are sites suitable for seed germination, plant establishment, and ultimately reproduction. Characteristics that affect safe sites include light, moisture, temperature, and protection from wind. Some species may require high light for germination while others germinate and grow better in shade.

### 5.3.1.4 Characterizing Early Successional Species

Different species usually characterize early successional communities compared to mid- to late-successional or stable communities, although overlap may occur in some cases. Early colonizers are usually dispersed by wind or water and sometimes birds, are very prolific, and usually are poor competitors with other plant species. They can grow in direct sunlight on mineral soil and tolerate low nutrient levels. They may be "weedy" species or desirable, long-lived woody species suitable for wildlife habitat. Early successional plant species are believed to be less dependent on mycorrhizae. Mycorrhizae are positive relationships of fungi with plant roots. The fungi help the plant absorb nutrients and moisture from the soil while the plant provides carbon substrates (energy) for the fungi. Mycorrhizae are found on most plant species of the world under field conditions and are essential for normal growth by most species.

Late-successional plant species may need shade, moisture, nutrients, or organic substrate for establishment. Hence some species may not be able to establish initially on mined lands because they require shade or some site characteristic that cannot be readily provided. Sometimes shade can be provided by topographic features, but this is not the complete shade found under a forest canopy.

Early arriving plant species may be suitable for wildlife browse. Hence mining effects could be positive. Open communities may be desired aesthetically for recreational areas. Mature vegetation may be needed by certain forms of wildlife although the productivity of many of these stands may be low. Some native species may be undesirable compared to more desirable nonnative species.

Early colonizers may vary considerably according to geographic region and other site characteristics. "Volunteer" forbs dominated early sites in western Wyoming but were replaced by seeded grasses (Parmenter et al., 1985). Shrub cover was still less than adjacent vegetation after 6 years. Mined areas had different composition than undisturbed areas (Parmenter et al., 1985). In contrast, early primary successional species in Alaska are woody species that may remain in the vegetation until a mature forest develops, even though this forest may change over time. Secondary successional species also include forbs and grasses that help stabilize the site and can outcompete many seeded grasses on some sites. On other sites within Alaska, natural regeneration may not do as well after a site has been seeded.

Environmental conditions as well as plant species change over time. Some environmental changes permit other plant species to colonize while some changes are the direct result of plants colonizing the site. These characteristics include abiotic factors such as sunlight, moisture, temperature, and wind; edaphic factors such as soil texture, nutrients, moisture, and organic matter; biotic factors such as soil organisms, other plants, and herbivores; and landscape factors such as topography, position on slope, and distance to native vegetation that may function as a seed source.

### 5.3.1.5 Abiotic Factors

Proper abiotic factors may be critical to germination and initial establishment of plant species. Some plant species require shade. These are not likely to become established initially on abandoned or reclaimed mined lands. Some species require sunlight, but seedlings cannot establish in the shade. These species might colonize an area but would drop out of the community when the stand matured, and the next generation of that species could not grow and reproduce. Balsam poplar is an example of the latter type of species. It colonizes many abandoned mine lands in Alaska.

Moisture is essential for germination. Some species such as alder that may be very common during secondary succession or in low areas may be lacking from abandoned mined lands because of low moisture. Other species such as poplar or paper birch may be able to establish here. Moisture levels are affected by slope, aspect, substrate particle size, and wind exposure. Plant species may grow on different aspects of slopes because of the moisture. Natural regeneration or artificial seeding may result in one community on a moderate north-facing slope on sandstone materials and another community on a south-facing slope on gravel material.

Similarly, proper temperatures are needed for germination. Cold temperatures may hinder germination, whereas hot temperatures may be fatal to young seedlings. Temperatures fluctuate more rapidly on exposed sites after mining. Mulch may conserve moisture and prevent overheating at temperate latitudes,

but at cooler latitudes it may keep the soils too cold for germination and decomposition.

Wind may blow seeds into an area, or it could keep seeds from being deposited. Rough surfaces such as found in gravelly or cobbly areas, in furrows, or on leeward slopes may increase the deposition of seed and organic debris in the area.

### 5.3.1.6 Landscape Factors

Topography and position on slope are important for moisture and also for seed deposition. Terraces provide breaks in slopes to reduce potential erosion. Troughs of furrows and bases of slopes above terraces have more moisture than flat or convex slopes so that plant survival and diversity may be increased there.

Landscape factors may include distance from existing vegetation. Light-seeded species or those dispersed by animals may colonize at distances from the seed source. More woody stems may colonize where the edge of the adjacent vegetation forms a cove rather than where it forms a point or convex boundary. Varied edges can also provide increased edge effect and hiding cover for wildlife. Hence the very layout of the disturbed site and its relation to surrounding vegetation or seed sources may affect the colonization rates.

Vegetation from abandoned lead-zinc mine sites in eastern Oklahoma structurally and compositionally were similar to vegetation on other disturbed sites (Gibson, 1982). However, it lacked the oak and hickory trees typical of undisturbed communities but which are not dispersed as far as those of the plant species characteristic of disturbed vegetation and whose seeds are dispersed by wind and birds.

### 5.3.1.7 Edaphic Factors

Substrates resulting from mining activities affect vegetative reestablishment. If a site is rocky, much of it may be unsuitable for plant growth. However, rocks may provide microsites which are protected from the wind and have increased moisture where water runs down the rocks. Fine substrate particles usually form better seed beds than coarser materials on placer mine dredgings. Some plant species grow better on sandy or gravelly sites while others are found on siltier sites on river floodplains. Different mining techniques may result in different particle size distributions, resulting in different rates of natural colonization after mining. Nutrients may also be low in the growth medium, whether it is overburden or fresh topsoil. This may affect plant establishment directly, but may also slow decomposition and nutrient cycling. More closed grass communities have been found in areas of finer soil textures where soil nitrogen and moisture are greater compared to that of more open communities in Midwestern States.

### 5.3.1.8 Biotic Factors

#### *5.3.1.8.1 Soil Organisms*

Perhaps some of the most important effects of mining on vegetation are the removal and disruption of the soil macroorganism and microorganism communities (Tate and Klein, 1985). These organisms affect the rate at which the vegetation can become a self-reproducing community. Microorganisms assist with decomposition, nutrient absorption, and nitrogen fixation. Some soil organisms are essential to various levels of decomposition, from the initial shredding of material down to chemical changes. Others, such as mycorrhizal fungi, help plants absorb nutrients from the soil. Some microorganisms, usually bacteria, help transform atmospheric nitrogen to nitrogen usable by plants. Almost all of these organisms are disrupted by the mining process. In the process of repopulating the mined sites, these organisms may change as the plant communities develop.

Microorganisms are important to colonizing plants for nutrient absorption and nitrogen fixation (Harley, 1970). Plants that have a symbiotic relationship with bacteria to fix atmospheric nitrogen may be important to facilitate succession, but they are frequently not the first colonizers on a site. They may require initial levels of nitrogen to start the process. The effect of disturbance to mycorrhizal fungi on the growth of colonizing plants varies with plant species and environmental conditions since some species are more dependent on mycorrhizae than other species. Effects will vary with the extent of disturbance and distance to neighboring vegetation, which would be a source of microorganisms. Salt concentrations in arid areas may affect plant development and mycorrhizal infection. But some mycorrhizal fungi are adapted to saline conditions and may increase the plant's tolerance of salinity (Allen and Cunningham, 1983). Different species of mycorrhizal fungi may be tolerant of or susceptible to heavy metals or salinity .

Belowground plant growth may also be affected by mining activities. Although root biomass may decrease on disturbed sites compared to undisturbed sites, root biomass on fertilized and seeded coal mine spoils was greater on a mined site compared to that on native range in any condition (excellent, good, poor) near Colstrip, Montana (Holechek, 1982). Root biomass on 40-year-old naturally revegetated mine spoil was similar to that of excellent condition native range (Holechek, 1982).

#### *5.3.1.8.2 Plant Species Interactions*

The effects of mining on vegetation will vary substantially based on the climatic regime, mining techniques, and local site characteristics. Plant species interactions may be positive or negative depending upon

local conditions and land-use plans for the site. Desirable species at one site may be undesirable at another site. Grasses may be beneficial for stabilizing the soil and for grazing of elk and domestic livestock. However, herbaceous plants resulting from natural regeneration or from artificial seeding may compete with the desired woody plants where browse is desired for wildlife habitat for deer or moose. Sometimes initial arriving plant species act as nurse plants for later species. One effect of nurse plants is to provide a microenvironment to increase seed deposition and to shelter new seedlings from wind. Nonmycorrhizal plants may produce a physical environment suitable for later arriving plant species or they may compete with later arrivers depending on the species (Allen and Allen, 1988).

#### 5.3.1.9 Case Histories

Coal-mined lands are perhaps the most extensively studied mined lands in the United States, partly because of their extent and partly because of the Federal and State requirements on the mining process, including reclamation. Studies in Canada, especially Alberta, may also be relevant because of the similarities of their sites to the Northern Great Plains and Rocky Mountain Foothills.

Natural revegetation of abandoned coal-mined sites in the Rocky Mountain Foothills of Alberta about 26 years after abandonment was slow and plant cover was <10% (Russell and LaRoi, 1986). Communities on these coarse spoils were dominated by perennial grasses and forbs (Russell and LaRoi, 1986) in contrast to those of Oklahoma where woody plants dominated (Johnson et al., 1982). Seven communities were identified, and these corresponded strongly to soil conditions, especially fines and slope position (Russell and LaRoi, 1986).

Many unreclaimed coal strip mines aged 10 to 70 years were evaluated in Oklahoma for soil and vegetation characteristics (Johnson et al., 1982). Natural recolonization was dominated by small trees, shrubs, and woody vines. Herbaceous cover was sparse, and the ground was covered predominantly by the woody plant leaf litter. These sites had lower densities of trees than upland or floodplain forests, and the trees were much smaller, averaging only 40% of the upland forest and 22% of the floodplain forest. However, diversity was greater in the overstory and understory of the mined sites compared with the native upland forest sites. Grass cover was less where woody cover was greater, probably because of the shade intolerance of most grass species in the area. Bare ground usually occurred where soils were poor. Although structural characteristics of these sites were approaching that of mature upland forest, species composition was very different.

Most oil shale operations are near northwestern Colorado, Utah, and Wyoming. Natural revegetation on 50- to 60-year-old oil shale sites in northwestern Colorado had vegetation which had similar total cover and diversity to undisturbed areas, but the species differed between undisturbed and disturbed sites (Mackey and DePuit, 1985).

Effects of heavy metal mining vary considerably. Nicklasson and Soderberg (1980) reported that levels of heavy metals prevented growth of most vascular plants around abandoned copper and zinc mines. On the other hand, Gibson (1982) found high concentrations of heavy metals on lead-zinc mines in Oklahoma, but potential toxicities were alleviated by high pH and calcium.

Operators of bauxite mines in the southwestern part of Western Australia are trying to return the mined sites to the original native forest habitat by replacing topsoil (Nichols and Michaelson, 1986). Where they used the top 5 cm of topsoil fresh, the understory was the closest to the native vegetation on an unmined forest control compared with using topsoil and overburden mixed fresh or stockpiled (Nichols and Michaelson, 1986). The number of species increased 4 to 7 years after reclamation in some cases, probably from recruitment from the adjacent vegetation. In other cases the number of species decreased, probably from competition.

### 5.3.2 WILDLIFE
**by R. T. Moore**

#### 5.3.2.1 Impact Categories

Mining activities can affect wildlife populations in a wide variety of ways ranging from lethal effects on individual organisms to subtle, but potentially significant, effects on reproductive success of populations. In some instances the activity may negatively affect one species while providing positive benefits for another. To examine the mining activities that affect wildlife and plan appropriate mitigative measures, it is helpful to categorize the impacts by type of impact mechanism involved. The discussion in this section will focus on the following principal categories:

Physical injury/mortality
Habitat loss/fragmentation
Loss of wetlands
Loss of crucial habitat types
Toxicities
Increased human activity
Induced harvest changes
Migration barriers

Each of these categories and the manner in which they affect wildlife populations are discussed in the following text which provides an overview of the impacts to wildlife from mining activities. For more in-depth discussion of these potential impacts the reader is

referred to major articles, reports, and texts addressing this and closely related topics (Down and Stocks, 1977; Moore and Mills, 1977; Samuel et al., 1978; Streeter et al., 1979; Cedar Creek Associates, 1985).

#### *5.3.2.1.1 Physical Injury/Mortality*

Perhaps the best understood and most easily mitigated type of wildlife impact from mining activities is the direct physical injury or mortality of animals. Primary examples include roadkills of big game on access or haul roads, crushing of small burrowing animals or low-mobility creatures in the path of heavy equipment operations, falls of big game animals from highwalls, powerline electrocution of raptors, and direct injury effects of sediment on fish and other aquatic organisms.

- Roadkills of wildlife are most prevalent *In situ*ations involving development of new mining operations, heavy nighttime traffic, and roadways through or adjacent to high-quality wildlife cover or forage habitat.
- Mortality to small mammals and other forms of wildlife in the path of heavy equipment operations tends to be localized and of minor impact to most affected populations. Small wildlife species tend to have high natural reproductive and mortality rates, and localized losses are typically offset within a single reproductive cycle. On the other hand, in the case of threatened or endangered species populations with low reproductive potential (e.g., desert tortoise or black-footed ferret), such mortalities, even though limited in number, can be of major legal and biological significance.
- Injuries of wildlife associated with falls at active or inactive highwall sites are rare under normal circumstances, but can occur when groups of animals are frightened (e.g., by human activities or predators) or forced to the precipice by extreme weather conditions (e.g., blizzards).
- Electrocution of raptors is infrequent if distribution lines are properly designed and installed. Such mortality is most common in areas with limited natural perching sites.
- Increased sediment production from active and abandoned mine sites is a common occurrence, except where effective sediment control measures are implemented and successful reclamation is achieved following cessation of mining. Impacts from increased sedimentation are most pronounced when mining activities occur in or adjacent to streams supporting major fisheries. This issue is particularly relevant to placer mining operations (McLeay et al., 1987). In some situations, however, historic placer and dredge operations were the source of channel gravels that now serve as good salmon spawning habitat (Prokopovich and Nitzberg, 1982).

#### *5.3.2.1.2 Habitat Loss/Fragmentation*

The most widespread and potentially most significant impact of mining activities, especially on terrestrial wildlife populations, is the loss or conversion of habitat associated with the clearing and subsequent reclamation of mined areas. Most surface mines and some underground operations involve physical disturbance of considerable land area, often occupied by existing wildlife habitat. Removal of such habitat results in a reduction of wildlife- carrying capacity and ultimately in a corresponding reduction in local wildlife numbers, even though the short-term effect may simply be an overcrowding of adjacent habitat. In some cases the effective loss of habitat exceeds the direct physical disturbance due to fragmentation of remaining natural areas in a pattern that precludes optimal use by local wildlife. Unless such remaining natural areas each provide the requisite food, cover, water, and space needed by the wildlife species in question, they may not individually or collectively constitute effective wildlife habitat. Habitat loss in some crucial habitat types may result in disproportionately high losses in some local wildlife populations. This effect is discussed separately below.

In terms of wildlife habitat physically disturbed by mining, the surface mining of coal and lignite probably accounts for by far the greatest area. The U.S. Office of Surface Mining (Anon., 1979c) has estimated that if all strippable coal reserves were mined in the United States, approximately 0.5% of the surface area of the country would be directly affected. Because of the uneven distribution of coal reserves, the potential disturbance could be as high as 6% in some states and nil in others. On a local basis, some counties in coal mining regions may have over 50 percent of their area disturbed during the next century. Similar major coal reserves and ongoing large-scale operations or the potential for such development exist in numerous other countries.

Another major contributor to disturbance of wildlife habitat is mining for aggregate in alluvial deposits along stream courses. While the area disturbed by individual operations is typically far smaller than for other types of surface mines, these operations are much more numerous, occurring around almost all urban areas. Ryan (1992) reported that about 5600 active sand and gravel operations existed in the United States in 1991. Collectively, this number of operations can affect a significant amount of wildlife habitat. Additionally, aggregate operations commonly occur in conjunction with stream courses, thereby leading to disruption of important habitat for fish and wildlife.

Other types of surface mining, including uranium, precious metals, and industrial minerals, may account for

major habitat disturbance within individual localities or even some regions (e.g., precious metals mining in Nevada, iron mining in northern Minnesota, copper mining in Arizona, and phosphate mining in Florida), but do not contribute the amount of disturbance nationally or globally as do coal and aggregate mining.

#### *5.3.2.1.3 Loss of Wetlands*

Wetlands are generally recognized as a unique and especially valuable type of wildlife habitat. In most ecosystems wetlands constitute a minority of the total area but provide a vastly disproportionate share of the escape cover, nesting cover, food, and water needed by wildlife. In this context, wetlands range from major marshlands along rivers and coastlines to small desert playas and narrow strands of riparian vegetation along intermittent and ephemeral streamcourses. According to Mitchell (1992), annual losses of wetlands amount to over 1200 $km^2$ within the United States, largely due to agriculture, with lesser impacts resulting from residential development, transportation routes, and industrial uses including mining.

Loss of wetlands may occur through either direct physical disturbance and removal due to mining operations or through alterations to the local hydrologic regime, which effectively remove or restrict the water source associated with the wetland.

While any type of mining may impact some local wetlands, placer and dredging operations for precious and industrial metals, aggregate mining, and phosphate mining are the dominant types of mining potentially affecting wetlands on a national or international scale. Within the United States, most types of operations affecting wetlands are regulated under Section 404 of the Clean Water Act, which prohibits the dredging or filling waters of the United States without a permit. This provision is interpreted to include filling or alteration of wetlands.

#### *5.3.2.1.4 Loss of Crucial Habitat Types*

Wildlife populations are most susceptible to external factors affecting natality and mortality rates during certain critical stress periods of their life cycles. These periods commonly include breeding and birthing seasons, winter stress periods in temperate and subpolar regions, and summer stress periods in low latitude desert regions. During these periods, wildlife species are typically dependent on specific habitat requirements for their survival. Thus, such habitats become crucial to maintenance or growth of the population and often serve as limiting factors to population size.

Throughout the western United States, wildlife management agencies have focused intensively during recent years on the avoidance, whenever possible, of such crucial habitats as grouse strutting grounds (leks), crane dancing or mating grounds, elk calving areas, big game winter foraging areas in mountainous regions, fishery spawning redds, and raptor nesting sites. Only in recent years have serious attempts been made to study the population behavior associated with disruption of specialized breeding habitats, recreate similar specialized habitat conditions, and entice wildlife populations to conduct such activities on reclaimed lands.

#### *5.3.2.1.5 Toxicities*

Among the most pervasive, least understood, and perhaps longest lasting impacts associated with mineral development are the various toxicities resulting from waste rock piles, process chemicals, and exposed ore zones. Throughout the mineralized regions of the world, mineral extraction and processing activities prior to recent decades have left a legacy of acid drainage from waste rock and exposed ore bodies, mercury toxicities from amalgam processing of precious metals, other heavy metals toxicities from residual minerals in mill tailings, and, in some instances, cyanide toxicities from early gold leaching operations. In numerous cases, these toxic reminders of past mining practices have seriously affected fish and wildlife populations for decades, and at dozens of sites throughout the United States the remaining toxicities from mining and smelting activities have resulted in designation of Superfund sites.

Mason and Macdonald (1987 and 1988) reported elevated levels of several metals in aquatic mosses growing in a rural Welsh river receiving mine drainage and suggest that the absence of otter in this particular drainage was due to the metal pollution and its effects on the food supply. Accumulation of heavy metals and resultant physiological impacts have been reported for a variety of fish and other aquatic organisms exposed to drainage from mining and smelting areas (Bradley and Morris, 1986; Singh et al., 1990; Vinot and Larpent, 1984; Somers and Harvey, 1984; O'Grady, 1981; Roline and Boehmke, 1981; Moore et al., 1991).

The recent proliferation of gold mining activities and associated cyanide leaching operations in the western states have accentuated mining toxicity concerns in the United States due to widely publicized cases of stream pollution by cyanide solution spills and waterfowl mortality on tailings impoundments and solution ponds. Eisler (1991) provides an excellent review of cyanide toxicity including lethal and sublethal effects on a wide variety of invertebrate, fish, and wildlife species. Hallock (1990), estimated that there were between 110 and 130 active mines in the State of Nevada in 1990 with possibly 300 individual ponds containing cyanide. In one of the more notable cases of waterfowl mortality associated with such ponds, approximately 800 birds died

during the first year of operation at a mill tailings pond of approximately 0.4 $km^2$ (Allen 1990). Waterfowl mortalities on impoundments are not restricted to cyanide operations. For example, similar problems have been observed on caustic ponds associated with the soda ash industry.

Cyanide spills near perennial streams can present problems for downstream aquatic resources. Prior to its recent closure and subsequent declaration of bankruptcy by the operator, one of the cyanide heap-leach gold mines in southern Colorado experienced a number of cyanide leaks into the adjacent drainage, resulting in fish kills along 27 km of the river (Peterson, 1992).

#### *5.3.2.1.6 Increased Human Activity*

Mineral development projects are commonly accompanied by significant growth in the local human population, both for direct mining employment and for secondary services. This increased population growth typically leads to increased levels of human activities in or adjacent to existing wildlife habitat. These activities may include vehicle traffic on highways and secondary roads, off-road vehicle use, hiking and sight-seeing, and rural residential development. Each of these activities contributes to the potential for direct injury or mortality discussed above and also contributes to the noise, visual distraction, and other background stress factors affecting local wildlife populations. The increased frequency of human/wildlife encounters can be a significant factor affecting wildlife population behavior and reproductive success. While some wildlife species, such as mallards, coyotes, skunks, prairie dogs, and cottontails may thrive in proximity to suburban development, many other more seclusive species will relocate or exhibit reduced reproductive success as their habitat is disrupted by human activities and presence. Outstanding examples of such behavior include the Rocky Mountain elk, which was primarily a plains animal prior to white settlement of the western United States, and the large predators that require sizeable undisturbed territories for their survival and reproduction.

#### *5.3.2.1.7 Induced Harvest Changes*

Along with the increased human activities in mining communities, it is expected that a significant portion of the population influx will consist of hunters, thus increasing the local hunting pressure and the annual harvest of game animals. Unfortunately, the legal harvest in most areas is accompanied by an often equal or even greater illegal harvest of major game species. Hence, the increased demands on wildlife populations are frequently greater than anticipated from the increased employment base alone.

#### *5.3.2.1.8 Migration Barriers*

In major surface mining areas such as the Powder River Basin of Wyoming and the Carlin Trend of Nevada, the immense size and close proximity of mining and mineral processing operations can effectively create barriers to the normal movement patterns of big game species. Such barriers may preclude use of critical habitat areas such as important winter range areas, breeding and fawning areas, or major water sources.

### 5.3.2.2 Threatened and Endangered Species

Wildlife species that are federally listed as threatened or endangered (Endangered Species Act of 1973, as amended, 16 USC Sections 1531-1543 [50 CFR 17.1 et seq.]) often share common characteristics of narrow ecological niche specialization, limited habitat availability, limited reproductive potential, vulnerability to predation or disease at a critical life stage, or susceptibility to chemical pollutants in the environment. Disturbance or removal of habitat used by one of these species may jeopardize the survival of that population.

Wildlife species of concern on this list are not restricted to the well-known mammals and birds such as the gray wolf, grizzly bear, black-footed ferret, and bald eagle, but include numerous more obscure reptiles, amphibians, rodents, and insects. For example, the American burying beetle and the valley elderberry longhorn beetle have been species of key concern on proposed coal mines in Oklahoma and California, respectively (Reed, 1992).

Federal agencies are required to ensure that any action they authorize, fund, or carry out will not adversely affect a federally listed threatened or endangered species. A Biological Assessment is required if major actions involving Federal lands or permits potentially jeopardize the continued existence of any federally listed species or results in the destruction or adverse modification of its designated "critical habitat." The Biological Assessment is prepared in consultation with the U.S. Fish and Wildlife Service in compliance with Section 7(a)(2) of the Endangered Species Act. In addition to Federal regulations, additional State guidelines may be applicable for protection of state-listed species (e.g., the Mohave ground squirrel in California).

#### *5.3.2.2.1 Raptors*

Within the United States, all raptors and their nesting sites are protected under either the Bald and Golden Eagle Protection Act, 16 USC Sections 668-668d (50 CFR Parts 13 and 22) or the Migratory Bird Treaty Act, as amended, 16 USC Sections 703-711 (50 CFR 10.13).

Primary impacts of mining operations on raptor populations include disturbance to nesting individuals,

removal of active nest sites (trees, cliff faces, and ground sites), removal of hunting areas for prey species, and electrocution from distribution lines serving the operation.

#### *5.3.2.2.2 Migratory Waterfowl*

All migratory bird species including waterfowl are protected under the Migratory Bird Treaty Act. The objective of the U.S. Fish and Wildlife Service in administering this act is to eliminate bird losses associated with mining operations, since the concept of acceptable losses does not apply (Hallock, 1990).

## 5.4 HYDROLOGIC EFFECTS

### 5.4.1 SURFACE WATER QUALITY – SEDIMENT
**by S. W. Johnson**

#### 5.4.1.1 Mine Land Disturbance and Sediment

Sediment production from lands disturbed by mining operations causes an increased potential for erosion that can increase sediment loading to surface waters. Areas with high erosion potential at mines include tailings piles, waste rock dumps, spoil piles, roadways, and other land areas disturbed during and shortly after the construction phase of a mining operation (Kunkle et al., 1987). Abandoned mines that were in operation prior to current regulatory mining laws have little or no sediment controls in place and, therefore, are some of the most significant sources of sediment loading to surface waters.

Prior to mining operations, undisturbed streams are in a semiequilibrium between streamflow and sediment transport. A given stream reach is stable if the geometry of the channel cross section and the channel slope remains essentially unchanged from year to year. Many stream channels are bedrock-controlled or controlled by a combination of both bedrock and alluvial channels. Any disturbance imposed on a watershed (due to natural events or human activities, such as mining) can influence the stability of a watershed. Watershed disturbances from mine activities can be in the form of 1) mining through a channel, 2) decreasing stream flows (possibly due to impoundments) or increasing stream flows, especially peak flows, to a stream, 3) diverting flows, and 4) changing the slope, bank stability, or elevation of a stream channel. All of these disturbances have the potential to modify the erosive and sediment characteristics of a stream, thereby decreasing its stability. In response to a disturbance, the gradient, channel geometry, channel pattern, and slope of the stream adjust to new equilibrium conditions that affect stream runoff and sediment transport. If the watershed disturbance causes the streambed to be eroded, the stream bottom elevation decreases (channel cutting), and the stream channel degrades. If the watershed disturbance causes increased sediment deposition to occur in the streambed, the stream bottom elevation increases, and the stream channel aggrades. Channel degrading and channel aggrading both result in sediment process changes that can adversely affect the water quality of a stream.

#### 5.4.1.2 Sediment Characteristics

Sediment loading can adversely affect fish and other aquatic life through sedimentation in the streambed and through the suspension of sediment in the water column (Anon., 1986a). Sediment loading can damage fisheries by smothering bottom invertebrates (reducing the availability of food for fish) and by smothering gravel spawning beds containing fish eggs that require sufficient exchange of oxygen and carbon dioxide from the overlying water column to remain viable. Bottom sediments containing organics can also reduce oxygen levels in the water column through the biochemical oxygen demand of organic material decomposition. Bottom sediments containing nutrients (especially phosphorus) and heavy metals can release these contaminants into the water column in toxic amounts. The suspension of sediment in the water column contributes to increased turbidity, which diminishes light penetration, and hence, photosynthetic activity of the primary producers (such as algae) which are a source of food for many aquatic organisms including fish. Suspended sediment also adversely affects fish that require low-turbidity waters to locate food, to mate, or to migrate. If the suspended solids are abrasive, as are many mineral wastes from mines, the sediment can act directly on fish by either killing them, reducing their growth rate, or decreasing their resistance to disease.

#### 5.4.1.3 Sediment and the Hydrologic Regime

The timing of runoff as well as the pathways followed by runoff from lands disturbed by mining has a large influence on the potential for sediment to cause degradation to surface waters. Streamflow and natural stream sediment levels are seasonal. Dry weather flows and flows during snowfall events are associated with low sediment levels in streams, while snowmelt runoff and storms that produce runoff are associated with high stream sediment levels. Uncontrolled stormwater and snowmelt runoff from land areas disturbed by mining often have considerably higher sediment loads than runoff from undisturbed watersheds. Mining activities conducted without hydrologic controls have been found to increase peak flows by a factor of 3 to 5 in small drainage basins (Poe and Betson, 1983). Mining operations, which may not change significantly between seasons, have the

potential to degrade stream water quality year-round from sediment discharges. Point source discharges of sediment-laden water during stream low flows typically have the greatest impact on stream water quality. The timing of sediment loading to surface waters can be critical to (1) the survival of fish during the more sensitive lifestage (i.e., juvenile), (2) successful mating and migration of fish, and (3) the production of fish hatches.

Surface water runoff containing suspended sediments is filtered, or clarified, by vegetation that traps large particles and by any water detention methods or flow-reduction methods. This filtering is caused by the loss of energy that is needed to keep the sediment in suspension (i.e., in the water column) (Curtis et al., 1986). The sediment level of runoff can also be lowered if the sediment infiltrates the ground surface and percolates through the ground water system due to the filtration of large suspended solids by soil and weathered rock.

#### 5.4.1.4 Sediment and Designated Uses of Waters

The transport of suspended sediment is a natural stream process that can be influenced by mining practices that disturb lands and increase erosion. The standard measure of whether sediment (or other water quality parameter) levels are considered pollution-causing is based on the degree to which water supports the uses for which it has been designated. Designated uses for streams include cold-, cool-, or warm-water fisheries; contact (swimming) and noncontact (fishing and boating) recreation; livestock watering; irrigation; and domestic water supply.

Based on past State surface water quality assessments submitted to the U.S. Environmental Protection Agency (EPA), siltation, or the smothering of stream beds by sediments (typically from increased soil erosion), is considered the most prevalent cause of nonsupport on the Nation's streams and affects over one-third of all impaired river miles (Anon., 1992). Resource extraction, which includes mining, is considered one of the many sources of sediment impairment to streams (Anon., 1992).

#### 5.4.1.5 Water Quality Criteria/Standards for Sediment

The EPA publishes and periodically updates criteria on acceptable ambient water quality limits for the protection of aquatic life and human health (Anon., 1986a). There are EPA water quality criteria for total suspended solids (TSS) as turbidity for the protection of domestic and industrial water supplies, and for TSS and settleable solids (SET) for the protection of aquatic life. SET refers to suspended solids that will settle within an hour (under quiescent conditions), which is often too short a time to settle fine particles, such as clay (Greenberg et al., 1992). These criteria are intended to be used to derive State water quality standards and national pollutant discharge elimination system (NPDES) permit limitations. TSS refers to essentially all solids in suspension, including clay, sand, silt, particulate organic matter, and microorganisms (e.g., algae and plankton), but it does not include dissolved substances, some of which impart color to the water (Greenberg, et al., 1992).

State water quality standards for sediment can be used to determine whether point or nonpoint discharges to receiving streams from a mining operation have the potential to degrade the water quality. Point source discharges from a mine to a stream are regulated under the NPDES and typically have permit limitations for both TSS and SET. The NPDES limitation for point source discharges of TSS from active hardrock mines is typically 30/20 mg/L (1-day maximum/30-day average) and 70/35 mg/L for active coal mines. The SET limit, if imposed, is typically 0.5 mL/L as an instantaneous maximum. These effluent limits are also considered adequate to maintain a water clarity for aesthetic purposes (clearer water is aesthetically favored) and to protect water-contact users by allowing detection of submerged hazards during such activities as swimming and diving. Stormwater runoff from mines is also regulated under the NPDES using best management practices to prevent or minimize sediment loading to surface waters.

Although it is difficult to establish a sediment criterion protective of all fish, a TSS limit of 75 mg/L is considered protective against potentially abrasive sediment (Down and Stocks, 1977). As a general criterion to protect aquatic life from elevated levels of suspended matter, the EPA has established a guideline for TSS and SET concentrations based on not reducing the depth of light penetration in water (for photosynthetic activity) by more than 10% from the seasonally established norm for aquatic life in a surface water (Anon., 1986a). Sediment water quality standards to protect industrial water supplies are industry-use specific, while standards to protect domestic water supplies are based on human health and welfare concerns. Sediment in domestic water supplies decreases the effectiveness of chlorine in disinfecting waters containing potentially harmful microorganisms and, due to turbidity, sediment diminishes the aesthetic quality of drinking water and water used for washing. The domestic water standard for turbidity is 1 nephelometric turbidity unit (NTU) (based on effective chlorine disinfection), while 5 NTUs is typically the visual threshold for detecting turbidity in drinking water (Anon., 1986a).

### 5.4.2 SURFACE WATER QUALITY – CHEMICAL EFFECTS
**by K. Johnson**

The chemical effects of mining on surface water quality

are from acid mine drainage; leaching of metals and other constituents from ore, waste rock, and processing wastes; and release of effluent from milling and heap leaching. The primary means by which surface water is impacted from mine operations and wastes include (1) discharge or overflow of wastewater; (2) runoff from rainfall or snow melt; (3) drainage from the toe of waste piles; and, (4) discharge of impacted ground water to streams and springs. Metals and other constituents from mine wastes may be transported in surface water as dissolved or as suspended material.

### 5.4.2.1 Acid Mine Drainage

Acid mine drainage (AMD) is produced by the exposure of sulfide minerals, most commonly pyrite, to air and water, resulting in the oxidation of sulfur and the production of acidity and elevated concentrations of iron, sulfate, and other metals (Sengupta, 1993). Pyrite and other sulfide minerals are generally contained in coal, overburden, sulfide ore, and the associated waste rock and processing wastes. Acid mine drainage may issue from underground mine workings as runoff from open pit workings, runoff and leachate from waste rock dumps, mill tailings, and ore stockpiles; and as effluent and spent ore from heap leach operations. Metals normally present in natural water at zero to trace concentrations, including copper, lead, zinc, arsenic, cobalt, mercury, nickel, molybdenum, and antimony, which are associated with sulfide mineralogy, may be present at significant concentrations in acid mine drainage.

The reactions of acid generation are illustrated by the oxidation of pyrite ($FeS_2$). Pyrite reacts with oxygen and water to produce ferrous iron, sulfate, and hydrogen ions.

$$FeS_2 + 7/2O_2 + H_2O = Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad (5.4.2.1.5)$$

In a sufficiently oxidizing environment with pH conditions of greater than about 3.5, ferrous iron will oxidize to ferric iron, and the ferric iron will precipitate as iron hydroxide, $Fe(OH)_3$. This reaction reduces the concentration of soluble iron and lowers the pH by the additional generation of acid.

$$Fe^{+2} + 1/4O_2 + H^+ = Fe^{+3} + 1/2H_2O \quad (5.4.2.1.6)$$

$$Fe^{+3} + 3H_2O = Fe(OH)_3 + 3H^+ \quad (5.4.2.1.7)$$

The ferric iron remaining in solution will serve as an oxidant for additional oxidation of pyrite.

$$FeS_2 + 14Fe^{3+} + 8H_2O = 15Fe^{2+} + 2SO_4^{-2} + 16H^+ \quad (5.4.2.1.8)$$

Although oxygen from the atmosphere is the oxidant which begins this reaction, dissolved ferric iron serves as the oxidant which keeps the reactions going by directly attacking the pyrite surface. The rate of oxidation of sulfide to sulfate is dependent upon the concentration of ferric iron, which depends upon the rate of oxidation of ferrous iron, the pH, and the oxidizing potential. As the pH decreases, the extent of precipitation of ferric hydroxide decreases, resulting in greater soluble concentrations of ferric iron, and subsequently a faster rate of sulfide oxidation (Eary and Schramke, 1990).

The formation rate of ferric iron is so slow, even under ideal conditions, that AMD would not commonly occur if the acidophilic iron-oxidizing bacterium Thiobacillus ferrooxidans was not present (Sengupta, 1993). These bacteria catalyze the reaction and increase the rate 5 or 6 orders of magnitude. This bacterium can grow in the absence of light and requires only a minimal amount of available oxygen. The production of AMD is thus a rapid, self-perpetuating process catalyzed by bacteria which continues as long as air, water, and pyrite are available. The bacterium may also accelerate the oxidation of sulfides of copper, cadmium, lead, zinc, arsenic, cobalt, nickel, molybdenum, and antimony.

Acid mine drainage is characterized by low pH, high TDS, and elevated concentrations of iron and sulfate as well as other metals. The acidity dissolves carbonate minerals and other acid-consuming minerals such as aluminum and manganese hydroxides which may be present, as well as other metal oxides which are present in the rocks or soils. These reactions add calcium, magnesium, aluminum, and manganese to the acid mine drainge. The precipitated iron hydroxide minerals are often visible as orange, red, and yellow stain along the flow path of acid mine drainage. Common minerals that precipitate are ferric hydroxide, $Fe(OH)_3$; geothite, FeO(OH); and jarosite, $KFe_3(SO_4)_2(OH)_6$ (Nordstrom et al., 1979). Also, as acid mine drainage is released into the environment, neutralization reactions occur between the acidic solution and the carbonate minerals, such as calcite ($CaCO_3$), in the sediment and surface water. As calcium is released by the neutralization reaction, the calcium pairs with sulfate and precipitates as gypsum.

$$CaCO_3 + 2H^+ + SO_4^{-2} = CaSO_4 + H_2O + CO_2 \quad (5.4.2.1.9)$$

### 5.4.2.2 Chemical Leaching of Metals

Chemical leaching of metals occurs when precipitation from rainfall or snow melt infiltrates through ore or waste materials and dissolves or desorbs metals from the solid material. The potential for leaching metals from ore and waste materials is dependent upon the chemical character of the water leaching through the solid material and the form of the metals in the solid matrix (Ritcey, 1989). Within the solid material, metals may be (1) adsorbed to the surface of the solid material; (2) in salts such as metal sulfates, carbonates, and hydroxides; (3) in

sulfide minerals; or, (4) incorporated into the silicate or oxide matrix. The ability of water to leach metals from solid material is controlled primarily by the pH and Eh of the solution and the anions available for complexing the metals (Stumm and Morgan, 1970).

In general, the pH affects the leaching potential by increasing the solubility of metals in carbonate, hydroxide, oxide and silicate minerals as the pH decreases, i.e., acidity increases. The hydrogen ions present in water at acidic pH conditions may also exchange with the metals adsorbed to the surface; thus, increasing the leaching of metals. Acidity in the leachate may result from acid rain, acidic effluent from a milling process, or be generated by the oxidation of sulfide minerals. Assessment of the resultant decrease in pH of the leachate from the addition of acid must also consider the ability of the solid material to neutralize the acid by reactions with carbonate minerals.

The oxidation potential as measured by the Eh (Volts) affects the leaching of metals which can exist as both oxidized and reduced states in a solid matrix at ambient conditions (Brookins, 1988). Metals such as arsenic, chromium, molybdenum, selenium, vanadium, and uranium are much less soluble in their reduced states than in their oxidized states. Oxygenated water which infiltrates through the solid material may oxidize metals present in their reduced state and allow leaching.

The anions present in the water infiltrating through the solid material affects the leaching potential by the complexing between the anions and metals in the water (Ritcey, 1989. For example, the concentrations of soluble lead dissolved from a lead-bearing compound such as lead carbonate is enhanced by the complexation of dissolved lead with sulfate ions to form soluble species such as lead sulfate ($PbSO_4$). Other examples in which complexation of metals enhances leaching are found in milling processes. Uranium leaching is accomplished by complexation of the oxidized form of uranium with either sulfate, $UO_2(SO_4)$ or carbonate, $UO_2(CO_3)_2^{-2}$. Gold is leached by formation of cyanide complexes, $Au(CN)_2^-$.

The soluble concentrations of metals which can exist in leachate at specific chemical conditions of pH, Eh, and composition can be determined by geochemical thermodynamic calculations of the dissolution and precipitation reactions involving the minerals in the solid material. Thermodynamic calculations account for the solubility parameters but generally do not include the reaction kinetics and adsorption.

### 5.4.2.3 Processing Wastes

Processing wastes include waste rock, slag, and tailings. Runoff over waste piles may transport dissolved constituents as well as particles of waste material. Precipitation may also infiltrate through piles of wastes and result in seepage out the toe of waste piles or into the subsurface soils (Robertson, 1986).

Slag and waste rock are composed primarily of metal silicate and oxide minerals. The reactions which break down the oxide and silicate matrices and dissolve metals generally occur slowly under ambient surface conditions. However, if sulfide minerals are present, the oxidation of metal sulfides will produce acid, sulfate, and metals, and may accelerate the leaching of metals from silicate and oxide minerals. Other minerals which may be present in small quantities in slag and waste rock and which readily dissolve by infiltration are metal sulfate and carbonate minerals.

Tailings, produced from milling operations, have undergone physical and chemical treatment which caused the breakdown of ore and rock minerals to release the metal of value. Tailings are produced by the processing of various elements including gold and silver, uranium, copper, and other base metals, phosphate, potash, alumina, and taconite (Williams, 1975). Hydrometallurgical milling of gold, uranium, and base metals is done by the addition of large quantities of chemicals, which include acid, carbonates, and cyanide. Reactions between the chemicals and the ore and rock minerals create either acid or alkaline tailings with easily soluble salts and metals.

Ores of phosphate, potash, alumina, and taconite are processed with water without the addition of large quantities of chemicals. Tailings from these processes are typically fine-grained sand, silt, and clay-sized particles with a composition similar to the ore material. The primary impact of releases to surface water from these types of tailings is high levels of dissolved solids. Metals may be present if they are associated with the ore.

Uranium tailings are derived from either a sulfuric acid or alkaline carbonate leach process (Johnson, 1986). The process of uranium extraction is the oxidation of uranium and complexing the oxidized form as sulfate or carbonate complexes according to the following reactions.

$$UO_2 + 2Na_2CO_3 = UO_2(CO_3)_2^{-2} + 4Na+ + 2e^- \qquad (5.4.2.3.10)$$

$$UO_2 + H_2SO_4 = UO_2(SO_4) + 2H^+ + 2e^- \qquad (5.4.2.3.11)$$

The pH of sulfuric acid tailings is generally less than 4, whereas the pH of the carbonate tailings is generally greater than 9. The vigorous chemical conditions of the milling process create tailings with high concentrations of soluble salts and metals as well as radionuclides of radium and thorium. In the case of sulfuric acid tailings, the acid dissolves the carbonate minerals that are present in the ore, such as calcite ($CaCO_3$), releasing calcium which pairs with the sulfate and forms gypsum. Certain uranium ore contains pyrite which continues to oxidize

in the presence of oxygen and generate acid long after the tailings are produced.

Gold and silver tailings are generally produced by an alkaline cyanide leach process. Gold ore commonly is comprised of an iron-magnesium silicate and carbonate minerals with traces of iron sulfide minerals such as pyrrhotite, pyrite, and arsenopyrite. Trace metals such as copper, lead, nickel, silver, and zinc are often present. The release of arsenic, iron, and other trace metals occurs upon oxidation of the sulfide minerals. In tailings from ore containing a significant carbonate content, the acidity from the sulfur oxidation is neutralized, which raises the pH and reduces the rate of sulfide oxidation and release of metals. Cyanide from the milling process may also be present in the tailings.

Base metals including copper, molybdenum, nickel, lead, and zinc are generally recovered from sulfide ores. Milling involves the addition of organic reagents as flotation agents to "collect" the mineral concentrates. The tailings contain pyrite and other metal sulfide minerals remaining after the flotation circuit. Thus, the tailings are a source of acid, sulfate, iron, and trace metals as oxidation of the sulfide minerals occurs.

#### 5.4.2.4 Toxic Effluents

Effluents from milling and heap leaching can impact surface water as discharge or seepage. The design of waste management systems often includes a controlled discharge to surface water. In addition, inadvertent discharge may occur if the ponds overflow during precipitation events. Seepage from heap leaching pads, ponds, or waste piles may flow into surface water. Gold and copper heap leach operations are the most widespread.

Gold heap leaching uses an alkaline solution containing cyanide to extract the gold and other precious metals from the ore (Van Zyl, 1985). The alkaline cyanide solution dissolves gold by the formation of very stable complexes between the metals and the cyanide ions.

$$4Au + 8NaCN + O_2 + 2H_2O = 4Au(CN)_2^- + 4OH^- + 8Na^+ \qquad (5.4.2.4.12)$$

Alkaline cyanide solution is leached through the ore. After removal of the gold, the barren solution is recirculated for additional leaching. The spent ore is neutralized by rinsing with fresh water or barren cyanide solution that has been treated with hydrogen peroxide or chlorine to oxidize the cyanide. The spent ore is disposed after rinsing to achieve the standards for pH, cyanide, and other disposal standards in the insterstitial water.

The cyanide solutions and rinse solutions may contain free cyanide ($CN^-$ and HCN), alkali cyanides such as potassium cyanide (KCN) and sodium cyanide (NaCN) and metal cyanide complexes of copper, iron, nickel, and zinc, as well as reaction products of sulfur and nitrogen (Anon., 1986b). Arsenic, antimony, and silica may also be soluble in the alkaline solutions. The alkali and metal cyanide complexes dissociate to produce free cyanide species. The ratio of the concentrations of cyanide ion ($CN^-$) to hydrogen cyanide (HCN) is a function of the pH of the water. The cyanide ion will be the dominant free cyanide species at alkaline pH conditions. The free cyanide species are generally more toxic than the metal cyanide complexes.

Heap leaching of copper oxide and sulfide ores is done with an oxidizing sulfuric acid leaching solution. The recirculation of the leach solution through a given heap of ore may go on for many years. The chemical composition of the leach solution will change through time because of the varying rates of reaction between the different minerals in the ore and the leach solution. As acid is consumed by reactions with copper and noncopper-bearing minerals, acid must be added to maintain a pH of less than 2.5 for efficient dissolution of copper oxide minerals. The leach solution will contain elements that have dissolved from the ore, such as iron, copper, cadmium, nickel, manganese, and total dissolved solids. The low pH and highly oxidizing conditions allow for significantly elevated concentrations of soluble metals.

### 5.4.3 SURFACE WATER QUANTITY
**by R. Spotts and J. K. Burrell**

#### 5.4.3.1 Introduction

The consequences of mining on surface water hydrology can be detrimental and extensive if watershed characteristics and control technologies are inadequately considered during mine design. On the other hand, many effects can be prevented by a team approach that involves engineers, hydrologists, geologists, and environmental specialists in mine planning and development. During planning, alternative configurations can be analyzed to minimize potential hydrologic effects and allow space for mitigative measures. Such teamwork is best begun early in a project and carried on through operation and reclamation.

To mitigate the potential effects of mining on water resources, it is important to adopt a hydrologic systems approach. Impacts may extend far beyond the local boundaries of a mining operation, in both space and time. The hydrologic systems approach incorporates both surface water and ground water disciplines, their interrelationships, and other watershed factors such as climate, topography, soils, and geology. The systems view toward hydrologic cause-and-effect and toward potential impacts and mitigation is both local and regional. This section considers the potential effects of

mining on surface water quantity, as a part of the systems approach.

### 5.4.3.2 Runoff

Runoff from a watershed is influenced by two major groups of factors: climatic and physiographic factors (Chow, 1964). Climatic factors primarily include the effects of various forms and types of precipitation, evaporation, and transpiration. These factors typically exhibit seasonal variations in accordance with the climatic environment. Physiographic factors mainly include watershed size and shape, drainage slopes, depression storage, soil moisture conditions, soil types, infiltration capacities, and vegetative cover. Mining activities can significantly affect the physiographic factors controlling runoff.

A recent study of hydrologic issues related to mining operations across the United States (Britton et al., 1989) indicates that mining can cause both increases and decreases in runoff depending on the timing and type of mining activity. For example, the early phases of a mining operation typically involve the removal of vegetation, salvaging of topsoil, removal of overburden or waste rock, and the construction of roads. These activities can result in a significant localized increase in runoff caused by the following variety of mechanisms (MacDonald et al., 1991):

- An increase in impervious surfaces from road building and the interruption of subsurface lateral flow.
- Reduction of infiltration rates and soil moisture storage capacity by compaction (overburden and waste rock moved either by scraper or truck tend to be compacted and will likely exhibit higher runoff rates than the undisturbed site (Curtis et al., 1986)).
- Reduction in rain and snow interception due to removal of the vegetative canopy.
- Higher soil moisture levels due to the reduction of evapotranspiration.

As mines are developed, the dewatering of pits and underground mine workings can contribute large quantities of flow to surface runoff, particularly with regard to natural baseflow conditions. For example, dewatering operations at some large ongoing and historic hard-rock mining operations have adit flows or ground water pumpage rates on the order of several hundred cubic feet per second. Many of these operations discharge this water into ephemeral or intermittent drainages, or into perennial streams with prior average flows less than a few cubic feet per second.

Alteration in flow regimes can affect the timing and amount of surface runoff. Surface disturbance from mining and reclamation activities often results in the need for mine water control systems that modify stream flows and surface runoff patterns, including changes in drainage areas and the combination of streamflows.

Significant decreases in localized runoff can result from activities that produce cast spoil that is full of voids, thereby increasing material permeability, infiltration, and water-holding capacity; and from the construction of open pits, tailings impoundments, heap leach operations, or other process and mine water control facilities that intercept precipitation and surface runoff.

Mining activities can affect surface runoff that enters a mining operation from upstream, that originates within the mining area, and that receives downstream inflow from the area of disturbance. The effects can occur both on and off the mine site. These changes in runoff quantity and timing can change the frequency, magnitude, and duration of floods and natural baseflow conditions, and lead to adverse effects downstream such as scour and sedimentation in stream channels, disruption of aquatic habitats, and changes in both the quantity and quality of the water supplies to public or private users (Curtis et al., 1986).

### 5.4.3.3 Consumption

Water consumption is inherent in all types of mining operations. Water is consumed through evaporation associated with ore processing activities such as heap leach operations, flotation circuits, tailing ponds, process water ponds, and coal washing facilities. Seepage into open pits from pit bottoms and walls can significantly contribute to evaporative losses. Evaporative losses occur from sediment ponds, diversion channels, dust suppression activities, and irrigation of reclaimed areas.

Mining operations can require water consumption rates of several thousand gallons per minute. Potential effects of water consumption are dependent on the source and occurrence of water. Wells might be installed as a water supply, or water might be obtained from pit inflow pumpage or the diversion of surface water. These water withdrawals can directly affect both ground water levels and stream flows. Consideration must be given to the potential effects of water consumption on wetlands, riparian habitats, springs and seeps, streamflows, aquatic habitats, and levels of ground water in alluvial and hardrock aquifers. Mine water consumption losses can directly impact downstream or downgradient domestic, agricultural, and industrial water users.

### 5.4.3.4 Diversion

Diversion and retention structures are built to collect and drain overland flow or to alter the path of an existing channel around mine operations. Typically these create beneficial effects by maintaining surface water yields, controlling erosion and sediment yield, and minimizing the exposure of flows to mining components (Curtis et

al., 1986).

Mining activities may increase runoff at certain phases by changes in topography, surface detention, and infiltration. Ditches, culverts, and retention structures must be sized and aligned to accommodate increased peak flows and sediment transport that commonly occur during construction and operation. Undersized systems, when breached, can lead to flooding, erosion, and sedimentation (Barfield et al., 1987). These may be worse in a failure than if no structures had been placed. Improper alignment and channel protection at transitions may lead to scour and structural failure. Flow momentum effects are frequently ignored in configuring transitions and locating diversions with respect to project components. Washouts may result. Such oversights have caused topsoil stockpiles to end up in process ponds, as an example.

Stable channel design plays a significant role in diversion works. Concentrated, directed flow occurs along the diversion pathway and must be dissipated at outlets. Inadequate consideration of flow magnitude, velocity, and sediment transport characteristics in diversions can lead to aggradation or degradation both within the diversion and the associated channel system. Where an existing channel is to be modified or used as a receiving water, the channel reaches and tributaries upstream and downstream should be characterized for stability, gradient, and other hydraulic features. A combined geomorphic and engineering approach can be used to design a diversion to fit with the sediment transport characteristics of the neighboring channel network (Simons, Li & Associates, 1982b; Rathburn et al., 1993). This approach may also be used in reconstructing a postmining drainage network (Lowham and Smith, 1993).

Haul roads and access roads frequently act as inadvertent diversion structures (Carpenter, 1990). Compacted surfaces increase sheet flow and velocity over the road, and rills and gullies can ultimately result. These conditions present a hazard to mine traffic as well as to surface water resources. Undersized culverts and unprotected transitions and outfalls may cause flooding and washouts, with subsequent sedimentation downstream.

Maintenance must be a part of a diversion system, as it is for any other mining component. Sediment deposition, bank caving, and scour at culverts and transitions can all lead to failure if left unchecked or not otherwise incorporated into design. Postmining stability and related hydrologic issues present both short- and long-term considerations for reclamation (Joyce and Ryan, 1990). The parties involved in administering a reclaimed mine site need to provide inspection and maintenance as long as diversion and retention systems play a significant role in water and sediment management.

#### 5.4.3.5 Flooding

Another potential effect of mining on hydrologic systems is its influence on flooding. Mining may have minimal effect or may considerably alter the flood characteristics of a watershed. In some cases, the changes to runoff hydrographs have been insignificant (Martin et al., 1988). The same mining components can act either beneficially or detrimentally, depending on their location, design, and structural capacity and integrity, as well as on the weather. For example, reclaimed areas that have higher rainfall infiltration capacities may decrease downstream flooding, but useful moderate-to-low flows may also be decreased (Wilson and Cannon, 1989). Changes in near-surface aquifer characteristics as a result of mining may increase or decrease baseflows depending on local conditions (Anon., 1985; Shampine, 1989; Stannard and Kuhn, 1989). Sediment basins at one site may substantially reduce siltation impacts. Placed elsewhere, the same installation may promote downstream scour and bank erosion by releasing water that does not carry enough sediment initially.

Potential flood effects from mining operate on a drainage basin scale, hence the value of a hydrologic systems approach to their analysis. Storm or snowmelt events may occur in remote headwaters. Subsequent runoff can accumulate behind embankments at local mine facilities. If these are not designed as retention structures, or if capacities are exceeded, overflows and breaches can lead to catastrophic floodwaves propagating far downstream in the system. Perhaps the most tragic example of this is the coal-waste dam collapse on Buffalo Creek, West Virginia, in early 1972. After rainfall approximating that of a 2-year recurrence interval, the sequential collapse of three coal-waste embankments caused a 10- to 20-foot-high floodwave to travel downstream through several communities. Extensive loss of life and property resulted (Davies et al., 1972). Mine-related dam and embankment failures still cause impacts on surface waters and adjacent areas.

A number of other flood events have been attributed to mining, in particular to coal strip mining in the Appalachian region (Anon., 1977c). Whether or not mining was the direct cause of several of these incidents remains uncertain and controversial. In some cases mines are only a part of extensive regional development that has overall effects on runoff, sedimentation, and floodplain geometry. Mining activities may reduce flood risks by retaining runoff in benched topography, sediment ponds and pits, and porous waste piles and stockpiles (Curtis, 1977). This can be especially true when watershed characteristics and potential hydrologic effects are addressed to a reasonable level of risk throughout project activities. Typical considerations involve the configuration and sizing of drainage and sediment control systems, avoiding encroachments on

channels and floodplains, and constructing waste piles, heaps, and impoundments to provide stability and drainage. Even moderate reclamation efforts can reduce potential flooding impacts (Banaszak, 1989).

Mining may have beneficial effects on flooding and stream sedimentation in certain instances. An example of this would be where multiple land uses occur within a watershed, and mining practices (such as revegetation and sediment controls) partially mitigate other activities (such as overgrazing, logging, off-road vehicle recreation, or poor agricultural practices).

Abandoned mined lands have the potential to increase flood-related hazards through floodplain encroachment and a continuing contribution of sediment and debris to channel networks. This is particularly true of former hydraulic and placer mining sites, where floodplain disturbance was common. Current Federal law, particularly the Clean Water Act, governs present disturbance on floodplains to minimize such impacts.

Accumulations of sediment and debris within the channel and at bridges and other channel structures will constrict the flow area, with resultant overflow of storm runoff into adjacent areas and scour around foundations exposed to the flow. Sand and gravel mining, especially within active channels, has contributed extensively to such problems. Significant sediment transport imbalances may be created by mining in or across channels. This often rejuvenates degradation and aggradation in the watershed system, particularly if highwalls intersect streams. In addition to the potential effects already mentioned, increased erosion and sediment in-filling can significantly limit the operating life and cost-effectiveness of downstream reservoirs, lakes, and other features in the river environment (Anon., 1977c).

In modern-day coalfields, common sediment sources from surface operations include cleared areas, haul roads, spoil piles, and newly reclaimed land (Appel, 1989). However, State and Federal regulations require the containment of sediment and runoff within the project sites, generally minimizing off-site effects (Crosby and Armstrong, 1989). Successful reclamation generally controls runoff and erosion to near premining conditions, but this can be difficult to achieve in arid parts of the country.

Alluvial valley floors are an important resource, particularly in the western United States. Protection of the hydrologic balance is necessary to maintain current or potential uses of such areas. Surface irrigation potential and associated land uses may be affected by changes in flood levels, channel scour, and bank erosion. Existing State and Federal regulatory programs are intended to minimize or eliminate potential mining effects in alluvial valley floors and wetlands.

#### 5.4.3.6 Dewatering

Mine operators must frequently dewater pits, underground workings, waste piles, slurry, and tailing facilities to provide stability and allow further operations. Both surface and ground water resources may be affected by this activity. Major implications for surface waters include land surface subsidence, affected springs, changes in alluvial valley floors and wetlands, and water quality impacts from discharges.

Dewatering active underground mines can intercept streamflow, since frequently stream channels contribute the heaviest inflows to underground operations (W.A. Wahler and Associates, 1979). Often surface drainage networks are controlled by underlying geologic structures and fracture systems. Pumping from aquifers can impede surface drainage as a result of subsidence and may interrupt flow from springs.

Open pit or underground dewatering may significantly affect the hydrologic regime of alluvial valley floors and wetlands. Prior to recent regulatory programs, such areas were often drained, with significant impacts on agricultural productivity, wildlife habitat, and other functions. Current State and Federal laws are designed to minimize or eliminate such effects.

In some cases, disposal of dewatering flow can create flooding, saturated ground, and temporary wetland habitat. Complex issues may be raised by this, particularly in the arid West, when the functions of existing drainage bottoms are changed by mine dewatering and then modified again at the cessation of mine-related flows.

Tailing deposits, industrial clay wastes, and coal-refuse slurry and waste piles are dewatered to provide stability, access, and additional space (Smelley et al., 1980; Backer and Busch, 1981; Kelsh, 1990). Resulting discharges of clean, treated water may affect sediment transport and flow duration in channel systems. These effects may be either beneficial or detrimental depending on site specifics. Failure to drain and stabilize such mine components could have much more impact on surface water systems if saturated materials were accidentally released.

In conclusion, the potential effects of mining on surface water quantity may take many forms and degrees of severity. Beneficial effects can also result. Predicting and managing the consequences of mining requires a systems approach to hydrology, considering upstream and downstream factors. This involves understanding of climate and watershed characteristics on both a site-specific and a local or regional basis.

### 5.4.4 SURFACE WATER PATTERNS
**by D. B. Simons**

#### 5.4.4.1 Introduction

Identification of responses of surface water systems to various mining activities is best approached by utilizing

the concepts of fluvial morphology, hydrology, hydraulics, and river mechanics. Fluvial geomorphology treats the morphology of rivers and river systems. As geology is concerned with the history of Earth through billions of years, the geomorphologist views the fluvial landscape in a historical perspective and utilizes the concept of unlimited time during which the landscape evolved to its present configuration. The engineer may question the relevance of the historical approach to river mechanics, but its significance should not be ignored. The investigation of river and stream channel response to the climatic changes, mining activities, water resources development, and diastropic events of Earth's evolution provides information and insight into both short- and long-term stream channel adjustment to altered hydrologic and hydraulic conditions imposed by development within the basin, such as mining.

### 5.4.4.2 Stream Form and Classifications

Rivers and streams can be broadly classified in terms of channel pattern based upon configuration as viewed on a map or from the air. Patterns include straight, meandering, braided, or some combination of these channel types.

#### *5.4.4.2.1 Straight Channel*

A straight channel can be defined as one that does not follow a sinuous course. Leopold and Wolman (1957) have pointed out that truly straight channels are rare in nature. Although a stream may have relatively straight banks, the thalweg, or path of greatest depth along the channel, is usually sinuous. As a result, there is no simple distinction between straight and meandering channels.

The sinuosity of a stream channel, the ratio between thalweg length to down-valley distance is most often used to distinguish between straight and meandering channels. Reaches of a stream channel that are relatively straight over a long distance are generally classified as unstable, as are divided flow reaches, and those in which bends are migrating rapidly. Straight reaches can also be artificially induced by placing of contraction works such as dikes and revetment to control channel alignment and sinuosity.

#### *5.4.4.2.2 Braided Channel*

A braided channel is generally wide with poorly defined and unstable banks, and is characterized by a steep, shallow water course with multiple channel divisions around alluvial islands. Lane (1957) concluded that, generally, the two primary causes that may be responsible for the braided condition are (1) overloading, that is, the stream may be supplied with more sediment than it can carry, resulting in deposition of part of the load, and (2) steep slopes, which produce a wide, shallow channel where bars and islands form readily.

Another cause of braiding is easily eroded banks. If the banks are easily eroded, the stream widens at high flow and at low flow bars form which become stabilized, forming islands. In general then, a braided channel has a steep slope, a large bed-material load in comparison with its suspended load, and relatively small amounts of silts and clays in the bed and banks. The braided stream is difficult to work with in that it is unstable, changes its alignment rapidly, carries large quantities of sediment, is very wide and shallow even at flood flow and is, in general, unpredictable.

#### *5.4.4.2.3 Meandering Channel*

A meandering channel consists of alternating bends, giving an S-shape appearance to the plan view of the channel. More precisely, Lane (1957) concluded that a meandering stream is one whose channel alignment consists principally of pronounced bends, the shapes of which have not been determined predominantly by the varying nature of the terrain through which the channel passes. The meandering channel consists of a series of deep pools in the bends and shallow crossings in the short, straight reach connecting the bends. The thalweg flows from a pool through a crossing to the next pool, forming the typical S-curve of a single meander loop.

Alluvial channels of all types deviate from a straight alignment. The thalweg oscillates transversely and initiates the formation of bends. In general, the river engineer concerned with channel stabilization should not attempt to develop straight channels. In a straight channel, the alternate bars and the thalweg change continuously; thus, the current is not uniformly distributed through the cross section but is deflected toward one bank and then the other. Sloughing of the banks, nonuniform deposition of bed load by debris such as trees, and the Coriolis force have been cited as causes for meandering of streams. When the current is directed toward a bank, the bank is eroded in the area of impingement, and the current is deflected away and may impinge upon the opposite bank further downstream. The angle of deflection of the thalweg is affected by the curvature formed in the eroding bank and the lateral depth of erosion.

As a meandering stream channel system moves laterally and longitudinally, the meander loops move at an unequal rate because of the unequal erodibility of the banks. This causes a tip or bulb to form, and ultimately this tip or bulb is cut off. After the cutoff has formed, a new bend may slowly develop. Its geometry depends upon the local slope, the bank material, and the geometry of the adjacent bends. Over time the local steep

slope caused by the cutoff is distributed both upstream and downstream. Years may be required before a configuration characteristic of average conditions in the channel is attained.

### 5.4.4.3 Continuum of Channel Patterns

Because of the physical characteristics of straight, braided, and meandering streams, all natural channel patterns intergrade. Although braiding and meandering patterns are strikingly different, they actually represent extremes in a continuum of channel patterns. On the assumption that the pattern of a stream is determined by the interaction of numerous variables whose range in nature is continuous, one should not be surprised at the existence of a complete range of channel patterns. A given reach of a channel, then, may exhibit both braiding and meandering, and alteration of the controlling parameters in a reach can change the character of a given stream from meandering to braided or vice versa.

Lane (1957) investigated the relationship among slope, discharge, and channel pattern in meandering and braided streams, and observed that an equation of the form

$$SQ^{1/4} = K \qquad (5.4.4.3.13)$$

fits a large amount of data from meandering streams. Here S is the channel slope, Q is the water discharge, and K is a constant. Lane's equation shows that when

$$SQ^{1/4} \leq .0017, \qquad (5.4.4.3.14)$$

a sand-bed channel will tend toward a meandering pattern. Similarly, when

$$SQ^{1/4} \geq .01, \qquad (5.4.4.3.15)$$

a stream channel tends toward a braided pattern. Slopes for these two extremes differ by a factor of almost six. The region between these values of $SQ^{1/4}$ can be considered a transitional range where streams are classified as intermediate. Many streams and rivers of the United States fall in this intermediate category. If a channel is meandering, but with a discharge and slope that borders on transitional, a relatively small increase in channel slope could initiate a tendency toward a transitional or braided character.

### 5.4.4.4 Longitudinal Profile

The longitudinal profile of a stream shows its slope or gradient. It is a visual representation of the ratio of the fall of a stream to its length over a given reach. Since a stream channel or system is generally steepest in its upper regions, most channel profiles are concave upward. As with other channel characteristics, shape of the profile is undoubtedly the result of a number of interdependent factors. It represents a balance between the transport capacity of the stream and the size and quantity of the sediment load supplied.

Shulits (1951) provided an equation for the concave horizontal profile in terms of distance along the stream:

$$S_x = S_0 e^{-\alpha x}, \qquad (5.4.4.4.16)$$

where $S_x$ equals the slope at any station a distance x downstream of a reference station, $S_0$ equals the slope at a reference station, and $\alpha$ equals a coefficient of slope change.

As implied by the definition of the parameter $\alpha$, Shulits assumed that grain size decreases in a downstream direction, a fact confirmed by field observations on many rivers. The change in particle size with distance downstream can be expressed as

$$D_{50x} = D_{50o} e^{-\beta x}, \qquad (5.4.4.4.17)$$

where $D_{50x}$ equals median size of bed material at distance x downstream of a reference station, $D_{50o}$ equals median size of bed material at the reference station, and $\beta$ equals a wear or sorting coefficient.

The longitudinal profile of an alluvial stream is not static. It adjusts to continually changed input conditions of water and sediment discharge, particularly at major confluences. Adjustments to input conditions change the channel geometry, roughness, and other parameters including channel gradient. A simplified analysis of this response results if it is assumed that a stream adjusts only its gradient.

If a stream is unable to move its load below a given point on the profile, it will build up the channel bed, causing an increased slope below the point and thus an increased ability to transport. At the same time deposition results in a decrease in gradient and transport capacity above the point, and a wave of aggradation moves upstream.

If a stream develops an excess ability to transport and can carry more sediment than is supplied in a given reach, the flow will scour its channel at the point of excess capacity. This decreases the slope and transport capacity below the point, but steepens the slope above the point. A wave of erosion or headcutting will then move upstream.

### 5.4.4.5 Qualitative Response of Stream Systems

Many streams have achieved a state of approximate equilibrium throughout long reaches. For practical engineering purposes, these reaches can be considered stable and are known as "graded" streams by geologists

and as "poised" streams by engineers. However, this does not preclude significant changes over a short period of time as a consequence of episodic events or over a period of years. Conversely, many streams contain long reaches that are actively aggrading or degrading.

Regardless of the degree of channel stability, local mining activities may produce major changes in stream characteristics both locally and throughout an entire reach. All too frequently the net result of imposing the impacts of mining on a watershed and its drainage system is a greater departure from equilibrium than that which originally prevailed. This is often of great concern when such changes may adversely impact the geomorphology and the ecology of the system. Good engineering design must invariably seek to enhance the natural tendency of the stream toward poised conditions. To do so, an understanding of the direction and magnitude of change in channel characteristics caused by the actions of humans and nature is required. This understanding can be obtained by (1) studying the stream channel in a natural condition, (2) having knowledge of the sediment and water discharge, (3) being able to predict the effects and magnitude of future mining activities, and (4) applying to these a knowledge of geology, soils, hydrology, and hydraulics of alluvial streams.

Predicting the response to channel watershed and stream development and utilization is a very complex task. There are a large number of variables involved in the analysis that are interrelated and can respond to changes in a stream system and in the continual evolution of stream form. The channel geometry, bars, and forms of bed roughness can all change with changing water and sediment discharges. Because such a prediction is necessary, useful methods have been developed to predict both qualitative and quantitative response of channel systems to changes imposed by changing land use and increased utilization of available water.

### 5.4.4.6 Prediction of General Channel Pattern Response to Change

Quantitative prediction of response can be made if all of the required data are known with sufficient accuracy. Usually, however, the data are not sufficient for quantitative estimates, and only qualitative estimates are possible.

The response of channel pattern and longitudinal gradient to variation in selected parameters has been discussed in previous sections. In more general terms, Lane (1955) studied the changes in stream morphology in response to varying water and sediment discharge. Similarly, Leopold and Maddock (1953), Schumm (1971), Santos and Simons (1972), and Simons, Li & Associates (1982a) have investigated channel response to natural and imposed changes. These studies support the following general relationships.

1. Depth of flow y is directly proportional to water discharge Q.

2. Channel width W is directly proportional to both water discharge Q and sediment discharge $Q_s$.

3. Channel shape, expressed as width-to-depth W/y ratio is directly related to sediment discharge $Q_s$.

4. Channel slope S is inversely proportional to water discharge Q and directly proportional to both sediment discharge $Q_s$ and grain size $D_{50}$.

5. Sinuosity $_s$ is directly proportional to valley slope and inversely proportional to sediment discharge $Q_s$.

6. Transport of bed material $Q_s$ is directly related to stream power $\tau_0 U$ and concentration of fine material $C_F$, and inversely related to the diameter of the bed material $D_{50}$.

A very useful relation for predicting system response was developed by Simons and Sentürk (1992) establishing a proportionality between bed-material transport and several related parameters. This relation is derived from the stream-power transport relation for which

$$Q_s \sim \frac{(\tau_o U) W C_F}{D_{50}} \qquad (5.4.4.6.18)$$

where $\tau_0$ equals bed shear, U equals cross-sectional average velocity, and $C_F$ equals concentration of fine material load. This equation can be modified by substituting $\gamma y_0 S$ for $\tau_0$, and

$$Q = AV = WdU \qquad (5.4.4.6.19)$$

from continuity, yielding

$$\frac{Q_s D_{50}}{C_F} \sim \gamma y_o S W U \qquad (5.4.4.6.20)$$

If specific weight $\gamma$ is assumed constant and the concentration of fine material $C_F$ is incorporated in the fall diameter, this relation can be expressed simply as

$$QS \sim Q_s D_{50} \qquad (5.4.4.6.21)$$

This equation is essentially the relation proposed by Lane (1955), except fall diameter, which includes the effect of temperature on transport, has been substituted for the physical median diameter used by Lane.

**Table 1** Evaluation of Tendency of Channel to Braid or Meander

| Equation | Tendency to Braid or Meander |
|---|---|
| $Q^{+}{}_{s}D_{50}/C_{f}\sim S^{+}U^{+}y_{0}W^{+}$ | M → B |
| $Q^{-}{}_{s}D_{50}/C_{f}\sim S^{+}U^{+}y_{0}W^{+}$ | B → M |
| $Q_{s}D^{+}{}_{50}/C_{f}\sim S^{+}U^{+}\ y_{0}W^{+}$ | M → B |
| $Q_{s}D^{-}{}_{50}/C_{f}\sim S^{-}U^{-}\ y^{+}{}_{0}W^{-}$ | B → M |
| $Q_{s}D_{50}/C^{+}{}_{f}\sim S^{-}U^{-}\ y^{+}{}_{0}W^{-}$ | B → M |
| $Q_{s}D_{50}/C^{-}{}_{f}\sim S^{+}U^{+}\ y_{0}W^{+}$ | M → B |
| $Q^{+}{}_{s}D^{+}{}_{50}/C_{f}\sim S^{+}U^{+}\ y_{0}W^{+}$ | M → B |
| $Q^{-}{}_{s}\ D^{-}{}_{50}/C_{f}\sim S^{-}U^{-}\ y^{+}{}_{0}W^{-}$ | B → M |
| $Q^{+}{}_{s}D^{+}{}_{50}/\ C^{-}{}_{f}\sim S^{+}U^{+}\ y_{0}W^{+}$ | M → B |
| $Q^{-}{}_{s}\ D^{-}{}_{50}/\ C^{+}{}_{f}\sim S^{-}U^{-}\ y^{+}{}_{0}W^{-}$ | B → M |
| $Q^{+}{}_{s}D^{+}{}_{50}/\ C^{+}{}_{f}\sim$ | M → B |

One of the first engineering and environmental concerns with regard to defining stream channel response to water resources development, mining activities, etc., is to identify the tendency for change in channel form to occur. For example, if we consider a sand-bed channel and utilize the equation $Q_sD_{50}/C_F \sim \gamma Y_oSWU$, one can identify this tendency for change in channel form, as indicated in Table 1. For example, in this table, the equation as subjected to changes in variables is identified in the first column and the tendency for the channel to shift from a braided form to a meandering form or a meandering form to a braided form is indicated in the second column. In the first line in Table 1, it is indicated that the sediment discharge has been increased as symbolized by a plus sign adjacent to the variable. Further reference to the equation shows that an increase in sediment discharge would tend to increase slope, would tend to increase velocity, would tend to decrease depth, and, because of potential instabilities, would tend to increase width. The conclusion, observing these responses indicated in the equation, verifies that if a meandering channel existed, there would be a tendency for that channel to shift from a meandering plan form to a braided plan form. Other lines in Table 1 can be interpreted similarly.

To further illustrate the application of the preceding concepts to estimate river response when subjected to a variety of types of developments, next refer to Table 2. The headings in this table identify, first of all, the variable, then the change in the magnitude of the variable (i.e., + indicates an increase in magnitude and - indicates a decrease in the magnitude of the variable). Thereafter, subsequent columns identify the effects of change in variable on regime of flow, channel form, resistance to flow, energy slope, stability of the channel, cross-sectional area and river stage. More specifically, utilizing the same equation from Table 1, the response of the stream system to a change in gradient is as indicated opposite channel flow. For an increase in channel gradient, we would expect an increase in the energy level from the viewpoint of regime of flow. There would be a tendency if the stream were originally meandering to shift to a braided form. Resistance to flow could either increase or decrease depending upon the characteristics of the channel, that is, size of bed material, initial channel form, etc. The energy slope would increase, the stability of the channel would decrease, the cross-sectional area required to convey the flow would decrease, and stream stage would decrease. In a more general sense, there would be an increase in sediment transport in the downstream direction resulting from the perturbation of changing channel slope.

### 5.4.4.7 Potential Channel Response to Various Mining Activities Imposed on the System

Utilizing the preceding information, it is possible to assess watershed and river response based upon geomorphic, hydrologic, and hydraulic principles for any type of mining activity that may be imposed on the hydrologic system. To illustrate a point, consider the impacts of instream sand and gravel mining. The local effects imposed by sand and gravel mining, as indicated by the preceding type of analysis, are as follows:

The channel gradient will be reduced.

There will be local degradation.

The flattening of the gradient caused by mining may change the form of the channel from, for example, a braided system to a meandering system.

The reduction in channel gradient will be accompanied by a reduction in velocity and an increase in the local stability of the system, with the possible exception that as the channel degrades bank erosion and bank caving may be accelerated.

**Table 2** Geomorphic Response to Changes in Significant Variables

| Variable | Change in Magnitude of Variable | Effect on | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | Regime of Flow | River Form | Resistance to flow | Energy Slope | Stability of Channel | Area | Stage |
| Channel Slope | | | | | | | | |
| (a) | + | + | M → B | ± | + | - | - | - |
| (b) | - | - | B → M | ± | - | + | + | + |
| Discharge | | | | | | | | |
| (a) | + | + | M → B | + | - | - | + | + |
| (b) | - | - | O | - | + | O | - | - |
| Bed Material Size | | | | | | | | |
| (a) | + | + | B | + | + | - | + | - |
| (b) | - | - | O | - | - | O | - | + |
| Bed Material Load | | | | | | | | |
| (a) | + | + | M | + | + | + | + | + |
| (b) | - | - | O | - | - | O | - | - |
| Wash Load | | | | | | | | |
| (a) | + | + | M | + | - | + | + | + |
| (b) | - | - | O | - | + | O | - | - |
| Viscosity | | | | | | | | |
| (a) | + | + | - | + | + | - | + | + |
| (b) | - | - | M → B | - | - | + | - | - |
| Seepage Force | | | | | | | | |
| (a) | outflow | - | - | - | - | + | - | - |
| (b) | inflow | + | M | + | + | - | + | + |
| Vegetation | | | | | | | | |
| (a) | + | + | M → B | + | + | - | + | + |
| (b) | - | - | - | - | - | + | - | - |
| Wind | | | | | | | | |
| (a) | downstream | - | - | - | + | + | - | - |
| (b) | upstream | + | M → B | + | - | - | + | + |

The lowering in elevation of the channel bed will increase the drainage from adjacent lands to the stream, possibly affecting water table in adjacent lands, wetlands, etc., and may initiate degradation in tributaries.

The initial mining activity may require the clearing of vegetation, as the mining activity proceeds.

As we look in the upstream direction from the assumed mining activity, the channel would experience an increase in channel gradient; an increase in velocity; the extension of degradation upstream from the mined reach, possibly exhibited in the form of a nick point or a headcut moving upstream, and, of course, a reduction in channel stability.

As we look in the downstream direction from the mining activity, there would be a reduction in supply of sediment due to the increase in trapping efficiency for sediment in the mined reach. This reduction in the supply of sediment could initiate channel degradation, possibly a change in channel form, and could initiate degradation in the tributaries, which would tend to balance the deficit in sediment load from upstream.

There are many different types of mining activities that may impact the watershed and channel system. Major mining activities include accessing minerals through open pit mining operations; quarrying to produce minerals, rock, aggregate, etc.; underground mining; tunneling associated with hydropower and transportation systems; and mining of ground water.

Considering these types of mining, resultant impacts on the watershed and surface water system depend upon the volume of spoil produced, the quality of spoil, and methods of disposal. All mining activities require quantification of waste materials that must be accommodated. The concepts presented in this section and highlighted in Tables 1 and 2 provide a basis for identifying potential impacts upon the watershed and stream channel environment, as illustrated for the sand and gravel mining scenario.

#### 5.4.4.8 Summary

With the present concern for possible adverse impacts resulting from mining and the methods to mitigate these impacts, it is essential to thoroughly understand the physical system within which such activities reside. Utilizing the geomorphic concepts presented in this section to distinguish stream form, assess possible changes in channel gradient, and identify such impacts on sediment supply, sediment transport, velocity and velocity distribution, it is possible to qualitatively and, to some degree, quantitatively establish the magnitude of future impacts that may be imposed by any particular type of mining activity.

### 5.4.5 GROUND WATER QUALITY
**by A. Lewis-Russ**

Mining can impact ground water quality because mining can change ground water flow paths and the geochemical environment. Mining can increase permeability of rock units, expose fresh rock surfaces, or cause water flow between previously unconnected units or between surface and ground water. The result is a disturbance of established geochemical systems that can cause rock dissolution/precipitation reactions that can affect ground water quality. The impact of these changes on ground water quality depends on the presence of flow paths that result in movement of surface water to ground water; soluble minerals; and geochemical barriers.

This section discusses mechanisms resulting in ground water quality changes and the operation of these mechanisms in different mining situations.

#### 5.4.5.1 Altered and New Water Flow Paths

Mining, by removing rock, creates new water flow paths or alters old flow paths. Water in mined areas may initially be poor quality, but relatively contained because of low permeability of the rock units. Mining opens flow paths and may allow this water to enter previously unconnected aquifers. For example, open pit mining may cut across geologic units, allowing water within one aquifer unit to mix with water in other units.

The impact of new flow paths depends on water chemistry. If the water entering is chemically similar to preexisting water, the effect on ground water quality will be minimal. Open-pit mining creates an area of ingress for surface runoff to ground water and may expose ground water to the surface. The surface water generally contains more oxygen than ground water and may have lower total dissolved solids. When this water enters the ground, it is not in equilibrium with the rock units, and rocks will dissolve or precipitate to achieve equilibrium.

#### 5.4.5.2 Changes in the Hydrologic System

In addition to changing passive flow paths, mining-related pumping may actively reroute water. Pumping includes dewatering and reinjection wells and pumps for open-pit mines (Tyler and Beale, 1991) and underground mines, injection and recovery wells for *In situ* mining, and water quality/quantity monitoring wells. Pumping induces changes in water flow direction. Water may be pulled from one area to another, causing contact of water and rock that are not in equilibrium.

#### 5.4.5.3 Increased Exposed Surface Area

Increased exposed rock area provides fresh, large surface areas for interaction of water and the rock fragments. The fresh surfaces are produced by blasting, and the smaller the particle size, the larger the surface area exposed for interaction with water. For example, mine drifts open fresh rock surfaces to contact with ground water seepage; however, these surface areas are small compared to surface areas in waste rock and tailings piles. Increased rock surfaces multiply the sites for water/rock interaction, thereby increasing dissolution rates and increasing loading of the water and changes in water quality.

#### 5.4.5.4 Oxidation of Materials

In addition to exposing fresh surface areas to water, mining also results in exposing fresh surfaces to oxygen. If reactive minerals such as pyrite are present, oxidation and acidification can occur that result in drastic lowering of pH and increase in soluble metals loading. These reactons are discussed in Section 5.3.1.

#### 5.4.5.5 Geochemical Barriers

Although virtually all mining has the potential to affect ground water quality, the actual effect depends on the magnitude of geochemical reactions and the transport of reaction products. In arid or semiarid environments, there may be insufficient precipitation and water percolation to transport reaction products. Additionally, native materials may provide a geochemical barrier that inhibits metals movement.

Soils often contain components that react with metals. Beneficial soil components include clays, limestone, caliche, iron oxide or manganese oxide coatings, or organic matter. Clays can provide a physical barrier to percolation of surface water to the ground water table and can remove metals from solution by adsorption or cation exchange. Limestone and caliche react with low pH solutions, causing a pH increase that can result in metals removal by precipitation and adsorption reactions.

Iron oxide and manganese oxide coatings provide adsorption surfaces for metals. Manganese oxide can catalyze oxidation of arsenic, thereby leading to arsenic removal through adsorption or precipitation (Oscarson et al., 1983). Organic matter can form a reducing layer that results in the precipitation of metals and inhibits further movement. The effectiveness of a geochemical barrier depends on the quantity of barrier minerals present and the relation to flow paths (Popielak et al., 1992).

### 5.4.5.6 Backfilled Pits

Open-pit mines change water flow paths by creating large areas where surface runoff can percolate into the ground water or ground water can contact the atmosphere. During active mining, this water is controlled by perimeter pumping, in-pit pumping, or both (Tyler and Beale, 1991). After cessation of mining, ground water levels will return to equilibrium in the pit, and surface runoff, if uncontrolled, can percolate through the pit floor into ground water or directly contact ponded water (Garlanger and Shrestha, 1991).

Backfilling open-pit mines can eliminate the formation of an open pit lake; however, the effect on ground water quality depends on the backfill material and permeability. Ground water eventually will return to equilibrium levels. If the water is flowing through reactive rock, the increased surface area will result in increased water/rock reactions which transfer rock components to the water. If the equilibrium ground water level is below the pit bottom, the effect on water quality will be limited by the amount of surface runoff entering the filled pit and the permeability of the material. The impact of the percolating water will be proportional to the flux of the seepage and seepage quality. If permeability is small compared to underlying aquifer material, the percolating water will have less impact than if permeability is relatively high.

An example of an open-pit mine that intersected the water table is the Berkeley Pit in Montana. During mining, the pit reached a depth of 548.6 m (1800 ft) and it has been filling with ground and surface water since mining and pumping ceased in 1982. Ground water currently is not being impacted, however, because the pit acts as a large ground water sink, and water flows toward the pit.

The impact of surface coal mining on ground water quality was studied in three Ohio watersheds (Bonta et al., 1992). Water quality before mining was compared with water quality after mine reclamation. Table 3 lists occurrences of some of the ions that were significantly larger after mining as compared to premining conditions.

**Table 3** Effect of Surface Coal Mining on Ground Water Quality. Number of Significant Increases of Concentrations of Listed Constituents

| | Upper (Mined) Zone | Middle Zone | Lower Zone |
|---|---|---|---|
| Aluminum | 1 of 1 | 1 of 1 | InD |
| Ammonium | 1 of 1 | 1 of 1 | InD |
| Chloride | 2 of 3 | 1 of 3 | 0 of 2 |
| Iron | 3 of 3 | 1 of 3 | 0 of 2 |
| Manganese | 3 of 3 | 3 of 3 | 1 of 2 decreased |
| Sulfate | 3 of 3 | 2 of 3 | 0 of 2 |
| Total Dissolved Solids | 2 of 2 | 1 of 2 | InD |

InD indicates insufficient data

Numbers indicate the number of basin that had significant increases of concentrations of listed constituents per number of basins studied (or with sufficient data). Note that there was a significant decrease in manganese for one lower zone.

(data from Bonta et al., 1992)

### 5.4.5.7 Underground Workings

Underground workings provide a channel for water and air that did not previously exist. Seeping water can contact fresh (unweathered) rock surfaces that have minerals that may be reactive and soluble under the new conditions. The chemistry of ground water entering the mine is often unstable under the changed conditions. The result may be dissolution/precipitation reactions that change ground water quality.

Water entering the mine may be low in oxygen but may have large quantities of iron in solution. The contact of such ground water with the oxygen-rich mine environment results in precipitation of iron and coprecipitation of other metals, such as copper, lead, or radium. The precipitate is generally a soft floc which is easily disturbed by mechanical contact, such as sampling. Therefore, water samples from such locations can have highly variable water quality depending on sampling method and filtration.

Water entering mine workings often has large metals concentrations because it has passed through highly mineralized rock and may have been in contact with the rock for long periods of time. This water drains into the mine during operations. The effect of the seepage water on ground water quality depends on point of discharge and treatment.

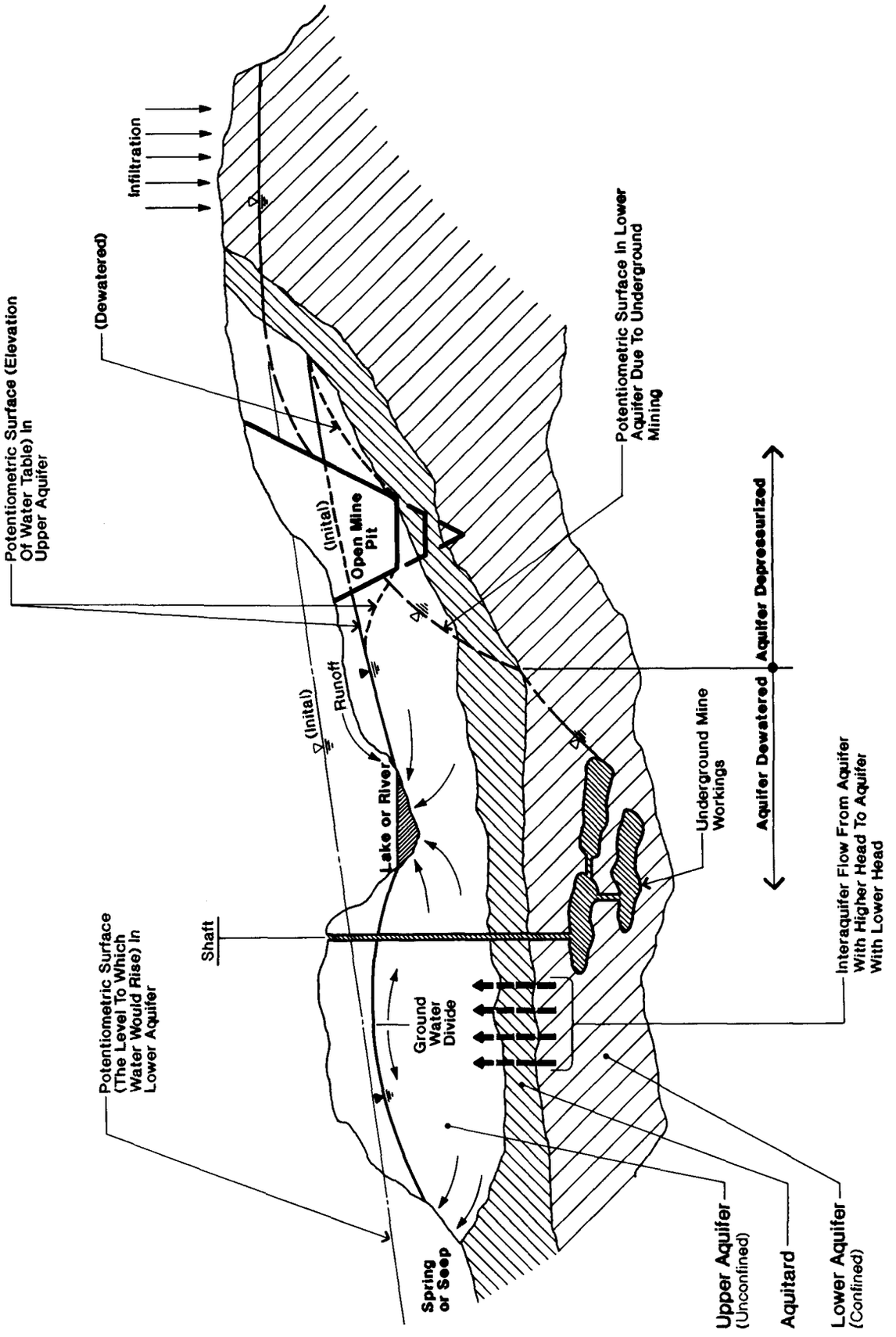



**Figure 1** Ground Water Flow Systems Affected by Mining.

#### 5.4.5.8 *In situ* Mining

*In situ* mining affects ground water quality by introduction of chemicals during mining and by pumping that alters flow paths and changes the local hydrologic system. *In situ* mining is used when a mineral is soluble under natural or induced geochemical conditions. Solutions are pumped to the ore strata that dissolve the target mineral, and the pregnant solution is removed.

The effects on ground water quality depend on the chemicals added (lixiviant) to solubilize mined metals. Additions of strong acid or basic solutions as lixiviants for uranium mining in Texas resulted in massive alteration of ground water quality. Another lixiviant, ammonium bicarbonate, resulted in contamination of ground water by ammonium. This type of contamination was eliminated by addition of sodium bicarbonate or dissolved carbon dioxide in place of ammonium bicarbonate (Montgomery, 1987).

#### 5.4.5.9 Tailings and Tailings Ponds

Tailings leachate forms because tailings consist of fine particles of reactive minerals such as pyrite. Oxidation of pyrite results in acidic, metal-laden leachate that may evaporate in arid climates or enter surface or ground water if precipitation and permeability are suitable. The effect of tailings ponds on ground water quality depends on the geochemistry and permeability of the tailings material and of the underlying soils. If tailings are placed on soils with lower permeabilities than the tailings, or if tailings are underlain by drain systems, percolating tailings leachate will follow the path of least resistance and not enter ground water. Tailings ponds generally consist of low permeability areas (slimes) and higher permeability areas (sands). Interbedded sands can form preferred pathways for leachate migration.

A study in the northern Black Hills of South Dakota examined the impact of abandoned gold mill tailings on underlying ground water (Fox, 1984). Geochemical mechanisms within the tailings had limited metals movement to underlying ground water. According to Fox (1984), metals mobilization within zones of acidification seemed to be retarded by reaction with carbonate material in the tailings, precipitation of metals as metal hydroxides, and adsorption of metals on solids.

#### 5.4.5.10 Waste Disposal

Waste disposal during mining presents the same problems as disposal for other industries. Potential wastes can include waste rock with potentially reactive minerals that can release metals and sulfate; petroleum products, lubricants, hydraulic fluid and waste drums; chlorinated organic compounds such as pesticides and PCBs from electric condensers; and process and laboratory chemicals including cyanide, acids, bases, surfactants, and flocculants. Disposal that exposes waste to precipitation can result in ground water contamination.

While disposal of concentrated wastes such as PCBs requires special handling, disposal of large volumes of low concentration waste rock presents a continuing challenge. Waste rock often contains small quantities of metal-bearing minerals that are unstable under atmospheric conditions. Percolation of water through waste piles can result in formation of acid leachate that may percolate into ground water. Other gangue minerals may also cause contamination; for example, gypsum dissolution can add sulfate to ground water.

### 5.4.6 GROUND WATER QUANTITY
**by J. Siegel**

Dewatering required by mining operations affects ground water quantity by depletion of aquifer(s) when mine features extend below the water table and become a drain. Depressurization required to lower hydraulic heads in geologic units at depth, whether or not these units are to be mined, also results in ground water depletion. Mining operations which result in ground water depletion can include open pit mining, underground mining, and *in situ* mining. Boreholes and shafts also can cause ground water depletion. Ground water within unconfined and confined aquifers can be affected by mining operations.

The basic features of ground water systems, with potential mine features superimposed are shown on Fig. 1. The figure indicates how mining may influence ground water resources, and is a simple representation of the hydrologic cycle (see Davis and DeWiest, 1966; Freeze and Cherry, 1979).

Ground water systems have recharge and discharge areas. Recharge comes from precipitation, surface water bodies, and interaquifer flow. Surface recharge to aquifers occurs at topographic highs. Discharge from an aquifer may occur as inflow to streams, rivers, or lakes, springs and seeps, extraction from wells, interaquifer flow, and drainage from excavations or mining operations. Rate of ground water movement through an aquifer is controlled by aquifer features such as hydraulic head, porosity, and permeability. Ground water velocity ranges widely in subsurface materials, generally being lowest for clays and intact rock, and highest for the coarse-grained sediments, karst systems, and fractured rock.

When an excavation is made to saturated ground, operational concerns dictate that the water be removed to keep working conditions dry and safe. The pumpage creates a hydraulic gradient and induces flow to the mine, and ground water levels are depressed (Fig. 1). Several factors affect the magnitude and distance to which ground water levels will decline. The depth of mining in relation to the static water level can be thought of as the strength

of the "drain"—in general, the deeper the mine, the more water levels will decline. The location of the mine both aereally and vertically relative to recharge/discharge sources also influences the distance to which water levels will decline. Properties of the mined formation, specifically transmissivity and storage, will influence how much water levels will decline as a function of distance from the mine, and how quickly the water table depression will spread. Low transmissivity formations will yield steep cones of depression in an aquifer, and water table lowering will be large over a short radial distance. Conversely, in high transmissivity aquifers, the ground water decline will be less on average but extend over a larger area. As already presented, mining may influence ground water quantity by connecting previously isolated water-bearing units, allowing them to communicate by yielding water from one to the other.

Predictions of water table lowering, or drawdown, are generally based on the assumption that geologic materials are isotropic (they transmit water equally in all directions) and homogeneous (they are the same over a great distance from the mine). These conditions are generally not the case. In hard-rock formations, structural features may magnify and extend drawdown in selected directions.

One other general effect of mining is the potential for ground water depletion in an unmined aquifer due to depressurization or dewatering of the mined unit. Ground water flow is induced to the mined aquifer. Ground water levels may be significantly reduced in the unmined aquifer. Spring flows may be reduced. Streamflow depletion may occur, though it may not be obvious.

Though ground water depletion is the most obvious and immediate effect of mining on ground water, there are longer term effects which may be equally important on the environment. Subsidence can either be caused by, or result from, underground mining. Redistribution and/or change in ground water recharge rates may affect the time and degree to which aquifers will recover to a static condition. These phenomena are covered later in this section.

### 5.4.6.1 Open-Pit Operations

Generally, open-pit mines are more apt to encounter unconfined water (that is, water not under hydraulic pressure) than ground water under confined conditions, due to the limited depth of excavation and/or removal of confining units. The source of ground water to the mine in this case is, initially, storage released from the pore space of the aquifer, and at later times, water transmitted from recharge areas.

Water table lowering in unconfined aquifers may occur at distances up to a few miles from the mine, typically 1 to 3 miles (Anon., 1981). Springs, seeps, and ephemeral drainages fed by a surficial aquifer whose water levels are depressed by open-pit mining can be dried up. Drawdown may also locally reduce streamflow or reverse stream segments from gaining to losing.

Ground water lowering may not always occur to the degree and distance from the open pit that might be anticipated based on observations during exploration drilling. Some deposits will have enhanced permeability due to the nature of their formation. In these cases, the ore zone is the exception rather than the rule with regard to formation permeability. The mine operation may drain this volume of water at rapid rates consistent with the high permeability, and then produce water at rates consistent with a lesser permeability of the host formation. Ground water removal may resemble the draining of a "bathtub." When reverse circulation methods are used for exploration, the drill string may blind the ground water from the borehole and disguise this, or for that matter, any other appreciable permeability contrast between the ore zone and host materials.

Ore horizons, such as coal seams, may themselves be the aquifers, or at least the more permeable zones compared to the horizons that divide the individual units. Mining may then remove a part of the aquifer, particularly if the ore units outcrop on ground surface. The National Academy of Science (Anon., 1981) presents a comprehensive document on the impacts of coal mining on ground water in the United States.

### 5.4.6.2 Open-Pit Reclamation

When open pits are completed, they may be backfilled with mine material. Ground water will fill the pit, and with time an equilibrium water level will be established approximating the premining ground water elevation, depending on the regional ground water flow and the recharge pattern to the aquifer. The time to reach equilibrium is also dependent upon these hydrogeologic conditions. Generally, ground water reestablishment will occur within a few years. Backfill material will become a part of the aquifer. Overall ground water flow is usually impacted only locally, as the backfill is generally more permeable than the mined zones. The exact response of the water table within the backfill is not easily predicted.

Backfill material may also affect recharge to the ground water system. These effects are usually small in magnitude and may result in increased or decreased recharge to the water table, depending on a number of factors including revegetation and backfill compaction and grade. The National Academy of Sciences presents a comprehensive assessment of the effect of mining on ground water recharge (Anon., 1990). Stone (1990) describes a case study on procedures and results of a recharge study in New Mexico, and concludes that for practical purposes, mining there affected recharge negligibly if at all.

If the pit is left open, then evaporation, surface water run-on, and ground water inflow have increased significance as to how long and to what elevation the pit water level will rise. In the arid western United States, for example, evaporation potential on a year-round basis often exceeds rates of inflow to the pit, and a permanent depressed pool is established. The time for water to recover into the pit at the end of mining may take tens of years in the absence of significant surface water run-on. Wells in the mine vicinity will experience incomplete recovery, or may be fully depleted.

#### 5.4.6.3 Underground Operations

Underground mines will impact ground water in the same way as open pit mines. The effect on ground water elevations may be more severe, as the final "drain," or dewatering elevation in an underground mine will often be deeper and of larger areal extent than an open pit. Underground mines have a greater chance of removing water from a confined aquifer in which the source of water is from expansion of the water within the pore space rather than from drainage of the pores. This generally means that ground water depressions will occur over a much larger area in comparison to an equally permeable unconfined system, as more of the aquifer volume is required to produce the same inflow to the mine. Ground water depletion can occur for several miles and has the potential to impact more areally extensive aquifers, particularly when extensive mining operations are occurring or have occurred.

Subsidence may result from underground mining and associated dewatering operations. The vertical distance to which tension cracks above the mine roof develop depends on the depth of mining, the open span of the mine, and the strength of the materials above the roof. Fracturing of the overburden material can enhance vertical recharge to the mine and result in drainage of an upper aquifer. If the fractures spread to the ground surface, permeability increases may lead to increased ground water recharge, which could include streamflow depletion. Whittaker et al., (1979) present a case study of permeability changes above the roof and near the ground surface for longwall mining. They found appreciable permeability change up to 40 meters above the roof of a 630-meter-deep mine, and up to 25 meters down from ground surface for a 54-meter-deep mine. Ground water flow from zones above the shallow mine was increased.

If mechanical breakage does not occur, dewatering can still cause subsidence through drainage of compressible clays and peats. Subsidence, in turn, can result in widespread damage to roads, utilities, and structures. Subsidence may take years to develop for materials that are slow to consolidate and may occur over a long period of time. Noguchi, et al., (1969) reported on widespread subsidence in an alluvial valley extensively undermined for coal. Though the operation occurred over 28 years, highly compressible seams of peat and clay began to consolidate after mining. The authors concluded that consolidation might occur for many years due to both ongoing drainage of water to the workings and the consolidation characteristics of the peat and clay. Another type of subsidence relates to development of sinkholes in karst terrains. Through dewatering, solution cavities erode and enlarge via ground water movement to the mine. Sinkholes can cause damage as severe as that due to consolidation of compressible layers. Bezuidenhout and Enslin (1969) summarize sinkhole development above gold-bearing dolomite in South Africa due to dewatering.

#### 5.4.6.4 Underground Reclamation

Water level recovery in underground mines occurs in two stages. In the first stage the relative rate of water level recovery is small, because the mine voids are being filled. After this occurs, the relative rate of recovery increases as the ground water fills only the natural pore spaces of the material. In most cases, ground water will stabilize at the level where it intersects a daylight point, such as an access tunnel or adit. When this occurs, ground water discharges from the mine, and a new equilibrium is established. Ground water levels in the mine vicinity may be depressed relative to the regional levels. Mine discharge may be of poor quality relative to the ground water system and the water in the surface drainage it enters.

Tunnel sealing is sometimes undertaken. This will raise ground water in the mine and may establish the premining equilibrium. However, the water table may rise into zones of naturally fractured rock, or rock that has been disturbed by the mining operation. In this case, more diffuse springs and seeps will appear on hillsides. Excessive hydraulic pressures may develop, affecting the integrity of the mine seal.

#### 5.4.6.5 *In situ* Mining

*In situ* mining does not significantly reduce the ground water resource, because the *in situ* system is essentially "closed" except for a small amount of overpumping and process evaporation loss. During the restoration phase, overpumping may become more aggressive, or ground water may not be returned to the aquifer at all, in attempting to return ground water to premining conditions.

The primary effect of *in situ* mining on ground water quantity is the possibility that the operation penetrates confining layers, thereby allowing previously isolated aquifer(s) to transmit water from one to the other. Ground water quality may also be affected in one or more of the aquifer(s). The effect of ground water

communication between aquifers caused by unplugged borehole or improperly completed wells may be seen from the results of aquifer pumping tests. These will demonstrate abnormally high "leakage" through a confining bed, which is actually water being drawn from an adjacent aquifer. When the boreholes are plugged, a similar pumping test would demonstrate less significant leakage effects. The extent and integrity of the confining zone(s) above and below an ore zone aquifer to be mined are important from the standpoint of ground water quantity.

#### 5.4.6.6 Boreholes

Unplugged boreholes have long been recognized as a potential for widespread ground water contamination, but even in current times boreholes are often left unplugged. If they are not marked or surveyed, locating these boreholes may be a problem at some later time. The definition of boreholes is extended here to include access shafts and air vents.

Two of the more noticeable effects with regard to boreholes on ground water quantity can result from penetration of an artesian aquifer and penetration of an aquifer which is then drained to a lower mining horizon. Artesian boreholes allowed to flow may cause local erosion and depress ground water levels in the area.

In many cases, exploration boreholes provide conduits for ground water flow from shallow to deeper aquifers. This may not be apparent until the mine extends under such exploration areas. An upper aquifer may drain, and in some cases the drainage may be permanent. This could be the case when the upper aquifer is unconfined, and the catchment area for recharge to the aquifer is small. Shallow aquifers relied upon for stock water in the western United States have been depleted by interaquifer flow along improperly completed wells and/or unplugged boreholes.

#### 5.4.6.7 Other Situations

Placer mining, or in-stream gravel mining, can have a relatively large impact on shallow aquifers. When streambeds are lowered, water levels in adjacent ground water systems will also decline. This phenomenon has been noted in Yolo County, California. Lloyd (1978) presents a summary of the potential impacts of in stream gravel mining upon ground water systems.

## 5.5 EFFECTS ON AIR QUALITY
**by J. H. Desautels**

### 5.5.1 INTRODUCTION

This section provides a general overview of the effects of mining and its attendant activities and processes on air quality. Coal, hard rock, and industrial minerals mining by surface, underground, and *in situ* methods, as well as attendant beneficiation and other associated activities, all affect air quality and will be discussed in this section. Effects from coal crushing and emissions from coal preparation plants and loadouts are included in this discussion. However, this section does not include effects from coal combustion. Air quality impacts from milling, tailings deposition, crushing, and grinding associated with hard-rock mining are included in the discussion, while impacts from smelting, retorting of oil shale and tar sands, uranium milling, and other downstream activities are not covered.

The section includes a discussion of many of the ancillary activities associated with mining and beneficiation which also impact air quality. Exhaust produced by diesel and other vehicles, emissions from a variety of onsite equipment, and air pollutants produced during equipment maintenance and cleaning are included. All phases of mining are addressed, including exploration, planning, and production processes, as well as mine shutdown, decommissioning, and reclamation.

The section is organized according to mining method, i.e., underground, surface, and in-situ mining. For each major mining method(s) employed, products and activities associated with each method, and phases of the mining process are discussed. To avoid needless repetition, once a particular activity is covered with respect to a mining method or product, a similar activity for a different mining method or product will be summarized or referenced in subsequent discussions.

This section is related directly to the air quality section of Chapter 6 dealing with control strategies. Chapter 6 deals with strategies to control the impacts described in this section, for different aspects and types of mining operations. Thus, the reader may refer to the discussions in Chapter 6 to determine what mix of potential control strategies is relevant to the particular type of mining being planned.

The individual pollutants of concern will be reviewed briefly. The discussions of pollutants and effects are based largely on the concepts contained in U.S. law, which is quite comprehensive in its regulation of air pollution. Finally, this section is intended for general reference and use. The information it contains is intended to provide the general reader with the broadest reasonable coverage of the subject matter. Specific details and performance standards for control strategies are discussed in some detail in Chapter 6, but are set forth in much more detail in legislation and regulations, and should be consulted for answers to specific questions.

### 5.5.2 POLLUTANTS OF CONCERN

Air quality has been a primary concern of U.S.

environmental law since the early 1960s. Over time, a series of Federal and State statutes of increased complexity has been enacted. The principal study and coordination effort is directed by the Federal government, but the individual States have primary authority to conduct air pollution control programs. The overall purpose of the programs is to achieve levels of ambient air quality that do not pose a threat to human health or to environmental values.

Pursuant to the Federal Clean Air Act (CAA), the United States Environmental Protection Agency (EPA) has promulgated national ambient air quality standards (NAAQS) for certain "criteria" pollutants. The criteria air pollutants generally associated with mining include particulates, sulfur oxides ($SO_x$), nitrous oxides ($NO_x$), and carbon monoxide (CO). Mining releases varying quantities of other pollutants, including carbon dioxide ($CO_2$), volatile organic compounds (VOCs), methane, lead, and other hazardous air pollutants (HAPs), including radiological constituents. Reactive VOCs are considered precursors to ozone, another criteria pollutant subject to a NAAQS. Certain of these airborne pollutants may increase the incidence and seriousness of a number of diseases, especially those related to the respiratory tract, as well as impact the physical environment. Environmental impacts may include effects on visibility, acid deposition, and global climate.

NAAQS comprise the foundation of the 1970 and 1977 versions of the CAA, as well as the most recent amendments to the statute passed by the U.S. Congress in 1990. NAAQS are not directly enforceable against individual sources of air pollution. Rather, NAAQS represent the maximum permissible concentration of criteria pollutants in the ambient air, thereby providing the standard for setting emissions limitations for individual sources. Generally, it is the emissions limitations that are subject to direct enforcement.

There are two types of NAAQS, described as primary NAAQS and secondary NAAQS. Primary NAAQS prescribe maximum allowable concentrations of a criteria pollutant in the ambient air, leaving an "adequate margin of safety" to protect human health. Secondary NAAQS are set at the maximum level of a criteria pollutant that will protect the public welfare (i.e., protection of crops, environmental values, etc., not related to human or health). Most significantly, primary NAAQS are set to protect not only the majority of the population, but sensitive subgroups as well. Protection of human health is the sole factor upon which primary NAAQS are based, and factors like cost and technical feasibility of attaining a primary standard are not to be considered when the standards are developed and periodically reviewed by EPA.

Since NAAQS are not directly enforced against individual sources of air pollution, the Clean Air Act requires the States to promulgate State implementation plans (SIPs) to provide for the implementation, maintenance, and enforcement of NAAQS in each designated air quality control region of a State. SIPs may regulate sources generically or establish particular requirements applicable to individual sources. Most SIPs employ both strategies as a means of attaining and/or maintaining NAAQS. If sources in an area are in compliance with their individual emissions limits, but there are exceedances of air quality standards, it is the State's responsibility to revise its implementation plan to meet the NAAQS. Such revisions may make individual emissions limitations more stringent.

#### 5.5.2.1 Particulates

By far the most ubiquitous concern to the mining industry is particulate matter, which is emitted in relatively large amounts in almost all aspects of mining operations. In addition to mining, major sources of particulate matter include stationary fuel combustion, various industrial processes, road construction and use, other construction projects, and agriculture. Particulate matter is also generated in major quantities by a variety of natural processes such as forest fires, wind, and volcanoes.

Particulates can affect human health adversely, as well as damage animals and crops. At high enough levels, particulates can contribute to chronic respiratory illnesses such as emphysema and bronchitis and have been associated with increased mortality rates from some diseases. In addition, particulate matter may cause irritation of the eyes and throat, and it can impair visibility.

Prior to 1987, particulates regulated by the U.S. Clean Air Act included all material measured as "total suspended particulate matter" (TSP). The TSP standard, however, included large particles that tend to settle out of the air very quickly and that generally are not considered harmful to public health or the environment. Many areas of the United States were unable to achieve attainment of the particulate matter NAAQS.[1] Consequently, in 1987, EPA amended the particulate matter NAAQS and replaced the TSP standard with a $PM_{10}$ standard. The $PM_{10}$ standard is considered a more accurate measure of particles that affect human health and welfare. Under this standard, particles with an aerodynamic diameter of 10 microns or less are regulated by the particulate matter NAAQS.

#### 5.5.2.2 Other "Criteria" Pollutants

Other "criteria" pollutants regulated under the CAA

[1] Some of the arid and semi-arid regions of the United States exceeded the TSP-based particulate matter NAAQS because of background levels of *fugitive dust*.

include $SO_x$, $NO_x$, VOCs (as ozone precursors), and CO. Sulfur oxides are corrosive gases produced when sulfur-containing fuel is burned. Sulfur-oxides include *sulfur dioxide* ("$SO_2$"), sulfur trioxide ("$SO_3$"), and their derivatives. They are natural contaminants in coal and are released in the combustion process, primarily from electric utilities and industrial plants. Thus, the majority of issues associated with the sulfur oxides are beyond the scope of this section, although relatively small quantities of $SO_x$ are emitted by diesel vehicles and onsite fuel combustion at mining operations. Exposure to high levels of $SO_x$ and their transformation products, which help form acid precipitation, can interfere with respiratory tract functions and result in permanent harm to lung tissue, as well as damage vegetation and exterior paints.

Nitrous oxides are emitted when fuel is burned at high temperatures, for example in stationary combustion plants and transportation vehicles. Nitrous oxides may lead to the formation of smog or ground-level ozone and acid precipitation. Nitrous oxides at high levels can reduce plant growth, cause lung damage and exacerbate some respiratory diseases. As with sulfur oxides, this section will deal only with relatively minor sources of nitrous oxides from mine-related transportation and onsite fuel combustion.

Carbon monoxide is a colorless, odorless, poisonous gas produced by the incomplete burning of fuels, and is emitted primarily from motor vehicles and in all fossil fuel combustion processes, including utility and other boilers. Carbon monoxide can combine with $NO_x$ to produce smog. At high levels, carbon monoxide can impair the blood's ability to transport oxygen, affect cardiovascular, nervous, and pulmonary systems, and impair mental functions. In addition, it can cause eye and lung irritation, damage vegetation, and, as smog, can produce an offensive odor and haze that impairs visibility.

VOCs are generated at mines chiefly by transportation related sources. In addition, VOCs are generated at industrial facilities, by fueling operations, and by a variety of commercial operations such as dry cleaning and painting. VOCs react with $NO_x$ in the presence of sunlight to produce smog.

### 5.5.2.3 Lead and Other Metal Hazardous Air Pollutants

A number of naturally occurring metals are classified as hazardous air pollutants (HAPs) under the U.S. CAA. In addition, radionuclides generally are considered hazardous air pollutants. Emissions from most mining activities, therefore, contain hazardous constituents, depending on the concentrations of the metals in the overburden or ore being mined. Because of the widely varying concentrations of these constituents in rock, it is impossible to quantify a generally applicable emission level of pollutants for mining operations.

Naturally occurring radiological constituents such as uranium or thorium may be emitted as particulates during mining operations. Disturbing the land surface will release certain amounts of radon gas, another naturally occurring radiological constituent of natural rock and soils. Radon emissions from mining operations are minor compared with radon emissions resulting from agricultural and general construction activities.

### 5.5.2.4 Regional Air Quality Issues

Air pollution is at once a local, regional, and global concern. Certain air pollutants can cause regional health and visibility impacts beyond the immediate area of release. The vast majority of total emissions from mining and beneficiation operations are relatively heavy particulates, which settle out quickly and thus are of only local concern. However, when smaller particles and some gaseous substances become airborne in large enough quantities to be transported from the immediate areas in which they are emitted, they can have regional or even global impacts.

#### *5.5.2.4.1 Visibility*

Particulate matter, $NO_x$, $SO_x$, VOCs, and CO contribute to the production of smog and haze, and thereby impair visibility. While smelting and refining of metal ores, and coal combustion can contribute significantly to such problems in specific areas, mining itself as discussed in this section is not a substantial contributor.

#### *5.5.2.4.2 Global Warming*

A significant scientific controversy surrounds the question of whether human industrial activities are contributing to rapid climatic change, especially warming of global temperatures. So-called "*global warming*," to the extent it may be taking place, is understood to be caused at least in part by heat-trapping chemicals present in the atmosphere. These chemicals may trap sufficient heat transmitted as infrared rays from the Earth to cause a net warming of the Earth's surface. This phenomenon is known as the *greenhouse effect*. Although climatic monitoring and modeling studies are inconsistent and subject to intense differences in interpretation, there is concern that, although climatic fluctuations have been common throughout the Earth's history, the climatic and ecological changes that have until now taken place over millennia are currently occurring in the span of a century or less. If these effects are rapid and severe enough, the effects may be substantial.

The pollutants that potentially contribute most

significantly to the greenhouse effect include *carbon dioxide* ($CO_2$), *chlorofluoro-carbons* (CFCs), and *methane*. Mining is a very minor contributor to carbon dioxide and CFC emissions.

Methane released from coal mines contributes to the total methane loading in the upper atmosphere that may play a role in the greenhouse effect and global warming. While estimates vary, methane from coal mines may account for up to 8 to 10 percent of total methane emissions worldwide.

## 5.5.3 EMISSIONS FROM SURFACE MINING

All three mining methods addressed in this subchapter, surface, underground, and *In situ* mining, are utilized to extract coal, hard-rock minerals and industrial minerals.

The products of hard-rock mining described in this section include uranium, solid hydrocarbon deposits, primarily oil shale, and metals, including copper, gold, iron, lead, silver, and zinc.

"Industrial minerals" include all valuable minerals other than fuel or metallic minerals. Minerals that are considered "industrial" include building materials, such as clay, cement-rock, limestone, sand and gravel, fertilizer minerals, and other miscellaneous minerals.

The air quality impacts associated with surface mining of each of the major products, and the ancillary activities associated with such surface mining, are discussed below. Although a number of mining methods qualify as surface mining, this discussion is limited to strip mining and mountain-top or "contour strip" mining.

In surface mining for coal, hard-rock minerals, and industrial minerals, the soil and rock that overlies the deposit being recovered (overburden and interburden) are removed, and the mineral is extracted. In coal mining, the overburden may be redeposited in the cavity and the area graded and revegetated. The combination of stripping, removing, redeposition, and reclamation are undertaken simultaneously in different portions of the mine proper.

Mountain-top mining or "contour strip mining" for coal is a variation of conventional strip mining that is often used to mine coal in mountainous areas. In mountain-top mining, the top of the mountain is removed and conventional strip mining is carried out. When removal of the top of the mountain as overburden is not feasible, "contour strip mining" is utilized. In this type of mining, the overburden is stripped around the contours of the hill, the exposed coal is removed and the overburden is replaced. Then, as with conventional strip mining, the area is graded and revegetated.

Hard-rock minerals are often located in ore bodies that cannot be strip mined in the same manner as coal seams. Instead, the ore bodies are mined in a single or multiple pit operation. Overburden is placed in waste rock dumps and is not normally returned to the mine. In open pit mines such as this, reclamation of the main pit does not occur. Depending on regulatory requirements, the overburden dumps may or may not be reclaimed.

### 5.5.3.1 Mining Activities

Surface mining occurs in several distinct phases of activity. The first is exploration and development. A drilling program determines the depth, thickness, areal extent, and quality of the deposit. The drilling program contributes to the production of air pollutants, chiefly dust, as does the creation of roads to access drill sites.

During the development stage, the mine and its ancillary facilities are constructed. Just as nonmining construction sites produce particulate matter due to disturbance of the ground and soil, these mining construction sites similarly cause particulate emissions. In addition, vehicular traffic and construction equipment contribute mobile source emissions, chiefly carbon monoxide and nitrous oxides.

Overburden or waste rock is stripped or removed using heavy equipment such as draglines, shovels, and heavy haul trucks. Excavation often involves blasting as a preliminary step. Coal, hard-rock ore, or industrial minerals are removed from the area of the mining operation. In coal mining, overburden from the next area is placed in the cavity created. All of the drilling, blasting, removal, storage, and rehandling of topsoil, overburden, and ore contribute to emissions of particulates. Much of the dust consists of large particles that settle out quickly, and are nonrespirable. A small percentage of the dust, which varies according to the makeup of the overburden and coal, is generally comprised of small, respirable particles that travel further before settling.

The greatest production of fugitive emissions occurs when the overburden is stripped from the site and stored. By removing the vegetation at the deposit site and exposing soil to the elements, particulates become airborne through wind erosion. Coal, hard-rock ore, or industrial minerals removal and storage also result in a similar release of particulates into the air.

Surface mining results in the production of other "criteria" pollutants in addition to particulate matter. The machinery and equipment used to extract coal from the deposit site emit $NO_x$, $SO_x$, VOCs, and CO, thereby contributing to the quantity of pollutants present in the air. Strip mining of coal also results in some methane emissions from the coal seam.

Some percentage of the topsoil, overburden, and the ore itself consists of metals that are classified a hazardous air pollutants, for example lead, arsenic, cadmium, and nickel. Generally, the concentrations of these metals are so low that the amounts actually emitted during earth-

moving operations are minor. In addition to these substances, radon and other naturally occurring radiological materials will be liberated as particulates (or gases, in the case of radon).

#### 5.5.3.2 Transportation Activities

Conduct of the mining process requires a variety of transportation-related activities. Because many mines are located in remote regions, access to the mine itself and transportation of the coal from the mine is likely to require that haul roads be built and maintained. Coal, hard-rock ore, or industrial minerals are transported from the pit to crushing facilities, often by truck, and to truck or train transportation facilities. If coal is washed, waste is transported to waste disposal sites. Loadouts and transfer points are erected and operated. Haulage is most commonly accomplished through the use of trucks and other vehicles, trains, and conveyors. These methods of transportation also require construction of roads, tracks, and conveyor systems.

Each of these transportation activities is a source of air pollutants. The construction and maintenance of access roads and of loadouts and transfer points disturbs the ground and discharges particulate matter into the air. Utilization of the roads and loadouts for transport releases particulates as a result of disturbance of the ground. The engines of the trucks, trains or conveyors used to transport the ore also produce $NO_x$, VOCs, $SO_x$, and CO.

#### 5.5.3.3 Processing Activities

If coal is cleaned, the process includes a variety of activities that produce air pollutants. Construction of surface facilities used to clean coal entails disturbance of the site chosen for the processing plant and the use of construction equipment. Coal crushing will emit particulates, as will transportation, whether by truck or conveyor. In addition, the use of transportation transfer points will result in particulate emissions. Not all coal mining operations include preparation plants. Preparation plants wash and screen the ground coal to remove impurities. The waste material produced in this process is generally disposed of in a waste disposal area. Transport to disposal areas will result in further minor particulate emissions, as will the disposal process. Wind erosion can create further particulate emissions from the disposal site.

Processing of hard-rock ore often occurs on a larger scale than beneficiation of coal. Because hard-rock minerals are normally found in low concentrations in ore, the recovery of usable product requires beneficiation of a larger quantity of ore. This may be accomplished by flotation, washing and screening, gravity separation, magnetic separation, chemical extraction, or a combination of these processes.

Extracted industrial minerals are crushed and ground to the appropriate size. However, normally no further milling or other preparation of the minerals is required. The crushing and grinding of the ore result in releases of particulate matter.

#### 5.5.3.4 Ancillary Activities

In addition to mining, and the beneficiation processes and transportation activities associated with them, ancillary activities that are vital to the operation of a mine also have air impacts. All transportation vehicles and machinery used in the extraction of ore require fuel, generally in the form of diesel or gasoline. Not only must these vehicles be refueled, but the fuel itself must be stored onsite. In addition, these vehicles and other equipment used in the mining and beneficiation processes must be maintained. Thus, maintenance and repair shops are also required onsite.

Both gaseous and liquid material is lost during refueling. Thus, both directly and through evaporation, the VOC, $NO_x$, and CO components of gasoline and the $SO_x$ component of diesel are emitted. These air pollutants are also discharged into the air from evaporation and loss of fuel from fuel storage tanks. In addition, the maintenance and repair of the machinery and vehicles utilized onsite entail the use of solvents, resulting in the emission of VOCs.

### 5.5.4 EMISSIONS FROM UNDERGROUND MINING

The air-quality impacts of underground mines are much less significant than those of surface mines. There are a variety of underground mining methods, all of which generate some air pollutants. However, there is generally much less earth disturbance in underground mining and, therefore, significantly reduced emissions, especially of fugitive dust and other particulates. In addition, utilized power is usually in the form of either electricity or compressed air.

#### 5.5.4.1 Surface Operations

As with surface mining, underground mining operations require exploration drilling, construction of exploration and haul roads, construction of surface facilities, transportation of mined minerals, construction and use of transfer points and loadouts, crushing, grinding, and milling of minerals, waste disposal and storage, fueling of vehicles, fuel storage, and construction and operation of maintenance and repair shops. (*See* discussion at Section 5.5.3)

As with surface mines, the most significant pollutant in underground mining is particulate matter, albeit in far lower amounts during underground mining. Underground

mining surfaces are not exposed to the outside air. Most of the particulates that do become airborne within the mine settle before the mine air is vented to the outside.

Pollutants produced by the surface operations of underground mines include particulate matter, $NO_x$, $SO_x$, VOCs, and CO emitted by vehicles and equipment, solvents, and VOCs released incident to fueling, fuel storage, and use of maintenance and repair shops. Emissions from transportation vehicles at an underground mining operation are likely to be lower than those at surface mines because typically less waste rock is involved. At mines that utilize a conveyor system to transport the mined mineral from the mouth of the mine to a preparation plant and/or loadout, relatively few mobile source emissions will be produced.

Industrial minerals mining does not generally include complex milling or waste storage and, thus, does not produce the air pollutants associated with these activities. Crushing, grinding, and sizing of the mineral will produce some particulate emissions. (*See* discussion at 5.5.3)

### 5.5.4.2 Underground Operations

The air emissions from underground operations result principally from mine ventilation. As noted above, the ventilation system will contain minor amounts of particulates emitted during mining that stay suspended long enough to exit with the ventilation air. However, engineered dust control measures such as water sprays and other controls required for mine safety and health purposes substantially reduce those emissions. Methane also is emitted from underground coal mines through the ventilation system. As with surface mining for uranium, underground uranium mining produces radon gas that is transmitted to the surface through the mine ventilation system.

In an underground mine, the amount of material moved, and therefore the number of vehicles and the amounts of $NO_x$, $SO_x$, and CO that are emitted are lower than that produced at a surface mine of similar size. Much of the machinery, including shovels and draglines, that is utilized to excavate overburden in a surface mine is not necessary in underground mining. Furthermore, some of the machinery used in underground mines is electrical rather than diesel powered. Thus, the quantity of mobile source emissions within the mine, including $SO_X$, $NO_X$, VOCs, and CO, is relatively low.

## 5.5.5 EMISSIONS FROM *IN SITU* MINING

*In situ* mining can be utilized to extract hard-rock and industrial minerals. *In situ* mining of coal is achieved through *In situ* coal gasification, in which gas is extracted from the coal bed and brought to the surface.

Hard-rock and industrial minerals may be mined using either one of two types of *in situ* mining methods. *In situ* solution mining is often utilized to extract low-grade or deep mineral deposits that contain soluble minerals, such as uranium and copper deposits. *In situ* processing of solid hydrocarbon deposits may be used to produce and extract liquid hydrocarbons by underground retorting of oil shale and tar sands.

### 5.5.5.1 Surface Support Operations

For the most part, the surface activities associated with *In situ* mining are similar to those associated with surface and conventional underground mining. Road construction, sample drilling, construction of surface facilities, the use of vehicles for transportation purposes, repair and maintenance of equipment and vehicles, fueling of vehicles, and fuel storage are common to all three types of mining. *In situ* mining, in addition, utilizes gas gathering or recovery systems at the surface.

The air pollutants emitted as a result of the activities common to all three types of mining include particulate matter emitted during sample drilling, hauling, and construction of roads and facilities, production of $NO_x$, $SO_x$, VOCs, and CO by vehicles used for transportation, and VOCs emitted during refueling, in fuel storage, and in equipment and vehicle maintenance.

The natural gas produced by the ignition of coal deposits in *in situ* coal gasification includes methane, nitrogen, and $CO_2$. In the event of a leak in the gas recovery system at the surface of the mine, methane and the other components of natural gas may escape. However, during normal operations such emissions should be minimal.

Depending on the hard-rock or industrial mineral being mined, there may be limited emissions of certain chemicals through system leaks and from storage and transfer of the leach solution. Incidental leaks from the system may result in reactions with chemicals present in the ambient air if the leaching compound that is used and ultimately released is volatile in nature.

### 5.5.5.2 Underground Operations

Gasification of coal deposits requires combustion activity. Combustion of coal emits pollutants into the environment. Nitrous oxides are produced when fuel is burned at high temperatures and are a byproduct of coal gasification. Carbon monoxide is also produced by the incomplete burning of the carbon present in coal. As a contaminant of coal, sulfur is also released as SOx during such activities. Methane and the other components of natural gas are produced as well. These products are recovered through the gas-gathering system and may be released into the air outside the mine through leaks in that system.

At present, *in situ* solution mining is predominantly

used to extract deep uranium deposits. The extraction is accomplished by injecting a leach solution under pressure into the deposit. The solution and the dissolved uranium is then pumped to the surface and processed. This underground process does not produce any significant air contaminants unless there are leaks in the gathering system.

## 5.6 SOCIETAL EFFECTS

### 5.6.1 AESTHETICS
**by C. Taggart and T. Keith**

#### 5.6.1.1 Introduction

This discussion of aesthetics will be confined to visually related issues and will be frequently referred to as visual resources. Public opinion and policy, as well as case law, increasingly demand that visual resources be adequately considered in project planning and design (Smardon et al., 1986). An assessment of visual resource effects must address two separate considerations: first, how the landscape will be affected, and second, how these effects will be perceived by the viewer (Anon., 1980b). Mining activities can affect the landscape in a number of ways and can be grouped into three primary areas of consideration: effects to the landform, vegetation, and/or structures, i.e. built environment. The second component of the assessment is concerned with how changes to the landscape will be perceived by potential viewers. This includes consideration of both visibility (the physical, measurable conditions under which the project will be seen) as well as consideration of how potential viewers will react to visible changes to the landscape (based on their expectations, understanding, and familiarity with the site) (Smardon et al., 1986). This section is, therefore, organized as follows: first, an overview of landscape principles; second, a categorization of mining practices and how they affect the landscape; and finally, some considerations on how these modifications may be seen and interpreted by affected viewers.

#### 5.6.1.2 Landscape Principles

All landscapes can be described and evaluated by addressing their individual features -- landform (as well as water), vegetation, and structures. It is helpful to identify the conditions of these features in terms of their form, line, color, and texture. As discussed in the following sections, an awareness of these landscape variables is important in project planning. A project that is able to mimic or repeat the existing form, line, color, and texture of the landform, vegetation, and structural elements present in a landscape will usually be judged to be much less visually intrusive than one that strongly contrasts with existing landscape characteristics (Anon. 1980b; Anon., 1977a).

Landform is one of the basic landscape elements and a key consideration in mine project assessment. A failure to blend with existing landforms may result from the creation of steep slopes or other topographic forms that are not present in the existing landscape, creation of color contrasts through the exposure of bright rock materials that do not match the color of weathered materials naturally outcropping near the site, or the creation of relatively rigid lines that define the limits of mining and that do not otherwise occur in the landscape.

Removal of vegetation is another major way in which the landscape can be modified by mining activities. In almost any setting, including projects located in grassland or shrub communities, the contrast between disturbed areas and existing vegetation is a strong indicator of project effects until successful reclamation can be achieved. These contrasts may result from a number of factors, including a change in vegetative patterns (form); color differences; the creation of strong lines resulting from clearing of vegetation at the mine site or for ancillary features, such as roads or electric transmission lines; and textural changes, such as the difference between a mature plant community and newly reclaimed areas. Once again, an effort to reflect existing vegetative patterns in mine development and reclamation planning will significantly reduce visual effects. These efforts may include creating irregular clearing patterns and the utilization of plant species for revegetation that blend with surrounding vegetation.

The introduction of structures, including buildings, utilities, roads, and other support facilities also has the potential to greatly modify the landscape. In a relatively natural landscape, the introduction of any building may create strong contrast. The degree of contrast can be reduced through the use of materials and colors that are characteristic of the landscape.

Landscapes that have a simple and uniform character can be easily disrupted by the introduction of new elements. Just as stains on a plaid shirt are less noticeable than on a plain white shirt, landscape modifications in a simple landscape usually create greater contrast than the same activities would in a complex landscape. Simple landscapes, such as those with weak or regular landforms, vegetation of uniform type, and lacking structures are those where a mine is likely to create the greatest contrast. Conversely, a landscape with strong, irregular landform and vegetative patterns and some existing structures has a high visual absorption capability; it takes a modification of greater relative scale and extent to create a noticeable contrast with existing landscape patterns.

#### 5.6.1.3 Mining Practices

For ease of discussion, the various types of mining can

be grouped into two general categories: underground/*In situ* operations, and those involving surface or pit extraction. While administrative, maintenance, load-out, and stockpile facilities are generally visible in each case, the actual extraction operations and the majority of disturbance associated with it are much less visible in underground operations. In addition, greater flexibility often exists for siting the support facilities of an underground operation in a way that will reduce visual impacts. Virtually all mining activities, from exploration to closure, will result in modifications to the landscape which may be seen by people and which, by definition, will result in some level of visual effect (Anon., 1979a; Anon., 1979b). By no means are all mining-related activities extensive or disruptive enough to be judged as offensive by a majority of viewers. However, even small levels of disturbance may be judged as objectionable in sensitive settings. For this reason, the following general guide is provided regarding the nature and extent of landscape modifications associated with various mining phases for both above- and below-ground operations.

#### 5.6.1.4 Mine Planning

*Exploration* – Exploration activities typically involve creation of roads, drill pads, dozer holes, and sometimes exploration camps. Often the most noticeable effects of such activities are the presence of people and equipment and the resulting vegetative modification. Occasionally, landform disturbance is visible where site conditions are steep and/or sparsely vegetated. The pattern of disturbance for such activities tends to be angular or linear, which most often is in contrast with natural patterns in the landscape. The increased activity over the short term and the residual vegetative disturbance over the long term tend to be the most contrasting and therefore noticeable visual elements. This contrast can be rather limited and insignificant in flat to rolling forested landscapes where disturbance can be minimized and adequate screening is in place. On the other hand, landscape modifications associated with exploration can be quite extensive and highly visible in steep and arid landscapes or where access to each drill pad, and the pad themselves, require cut-and-fill slopes and there is little to screen views.

*Feasibility/Operating Plans* – There is typically little landscape modification associated with the mine planning phase beyond those associated with exploration activities. However, this is the best time to develop a clear understanding of the visual implications of alternative mine layout and development plans and to take appropriate actions to avert unnecessary problems. Reducing disturbance before it happens is far more effective and cost efficient in reducing visual impacts than spending money and effort to restore the landscape after the fact. Siting and layout of support and ancillary facilities should be given specific thought in this regard.

#### 5.6.1.5 Mining Operations

*Development* – Depending upon the type of mine and mineral, mine development may include construction of access roads, buildings/structures and utility infrastructure, as well as other site preparation tasks including grading, topsoil stripping and stockpiling, placement of protective liners and monitoring systems, creation of diversion structures, etc. In the case of underground mines, development may include excavation of large amounts of waste material for staging, access, and ventilation. Under certain circumstances, development may also include construction of worker housing and associated service facilities. Mining development results in a substantial amount of activity and can create a large amount of surface disturbance. Unnatural colors and lines (linear or angular patterns of disturbance) introduced through vegetative modification and the addition of structures are likely to be the most visually evident signs of disturbance. The proportion of overall disturbance attributed to landform modifications will increase under this phase.

*Mining* – During the mining operation, landform disturbances typically increase substantially for surface mines and often become the greatest source of visual contrast. The unnatural form of pits, tailings piles, leach pads, high walls, waste rock piles, etc., and the bright, unnatural colors which result are strong indicators of disturbance. These form and color contrasts in conjunction with the large scale of most mining operations are the primary reasons for their high visual contrast. When located in an otherwise natural setting, these contrasts are particularly noticeable and often objectionable. For underground mines, the mining operations themselves may not measurably contribute additional visual contrast at the surface. Typically, a stockpile at or near the loadout facility will be created early in the process and remain throughout the life of the mine. Depending upon the type of operation, waste deposits may also be created over time. These features have similar color and form contrasts as a surface mine. The smaller size of visible portions of an underground operation and its greater flexibility in siting and layout are characteristics that can be used to great advantage in reducing visual impacts if understood in advance at the planning stage.

*Reclamation* – The purpose of reclamation is to create a stable and productive postmining landscape. This increasingly involves not only revegetation, but landform reconfiguration as well. It is also increasingly

common to require incremental reclamation throughout the active life of the mine. Thus, meaningful progress in reducing visual contrasts created during mining can be made during the life of the mine. Incremental reclamation can both shorten the overall duration of mining disturbance and reduce the extent of visible area disturbed at any one time.

### 5.6.1.6 Mine Abandonment

*Closure* – Closure involves removal of buildings/structures and other infrastructure, and initiation of reclamation on the yet unreclaimed portions of the mine. The elimination of structure contrasts takes place almost immediately, and any planned reduction in landform contrasts can be accomplished very rapidly as well. The reduction of vegetative contrasts is the most lengthy process, particularly in arid climates.

*Postmining* – Some types of operations, such as gravel and certain types of coal mines, as well as most underground mines can be reclaimed with virtually complete success from a visual perspective (Anon., 1978). Others may have substantially high walls or pits of a scale that make visual amelioration infeasible and inevitably result in very long-term landform and vegetative contrasts on site. The degree to which these features create long-term visual problems is a function of their degree of visibility from public viewpoints, accounting for variables such as vegetative or topographic screening, orientation, angle of view, distance, etc.

### 5.6.1.7 Viewer Perception and Interpretation

It is important to develop an early understanding of under what conditions the on-site modifications will be seen by the public at various viewpoints. A high degree of modification on site does not necessarily equate to high visual impact. There are a number of variables associated with our physical relationship to the project in view which influence how a modification is both seen and interpreted (Anon., 1974). A basic understanding of these concepts can help not only to anticipate how a potential project may be viewed by the public, but how these principles of perception may be taken advantage of in the mine planning process to reduce or avoid visual impacts.

*Distance* – Color-value plays the primary role in our recognition of objects, whether it is the letters on this page, a car ahead of us on the highway, or a landscape modification. As distance increases, color value decreases toward uniformity. The distance at which an object can no longer be identified depends on two factors: its size and its degree of contrast with the surroundings. At any distance, reducing color contrasts of structures and early revegetation of freshly disturbed areas is particularly effective in minimizing visibility of mining operations.

*Angle of View* – How clearly we see objects also has to do with the angle of view. Size relationships in plan view (above, looking down) often have no size or shape correlation to the same area seen in perspective. From a viewpoint above a landscape modification (viewer superior), we see its full extent more directly. As our viewing position drops in elevation and we approach a level viewing relationship (viewer normal), the object appears compressed in height as views are foreshortened.

*Scale* – Scale is the proportionate size relationship between an object and the surroundings in which it is placed. Modifications that remain within a "reasonable" scale to the overall landscape are much more likely to be acknowledged as acceptable. No definitive guidelines can be offered to define what may be considered reasonable to the general public, but generally it equates to a scale of operations that occupies a relatively small percent of the overall landscape in view. Where the landscape is generally intact, without other major modifications, a mine can easily become the dominant feature if it grows out of scale with the overall landscape. As indicated previously, the character and complexity (strength) of the existing landscape will have a great deal to do in determining the level at which a mining operation becomes at first noticeable, then evident, then dominant because of its scale relationship to the overall landscape in view.

*Screening* – Screening a proposed project from view essentially eliminates the visual impact to that viewpoint. Screening can be provided by vegetation or topography. Vegetative screening may be temporary in nature due to unforeseen events such as disease, fire, or cutting. If not already present, creating a vegetative screen can take a long period of time. Planting near the mine may take many years to reach an effective height, and in arid landscapes, may result in unnatural patterns. There are many commercially available software programs that allow development of topographically based seen-area plots. This tool can be used to identify unseen areas where ancillary facilities could be located without causing a visual impact.

*Backdrop* – Facilities on the skyline are much more noticeable than when seen against the backdrop of trees or a hillside. Large structures are particularly susceptible to easy detection from this kind of prominent landscape position; however, unnatural landforms (cuts or piles/pads) and timber modifications are also often more easily detected when placed on the skyline.

*Duration* – Viewing duration relates directly to observer conditions in evaluating dominance. If a viewer spends even a few minutes at a stationary viewpoint, he

recognizes not only major contrasts in the scene but also secondary or more subtle contrasts. A busy highway viewpoint then will afford much less time for a viewer to scan and process visual information regarding a landscape modification than a residential area where people spend extensive periods of time. When it is not possible to avoid many of the viewing conditions identified above, including prolonged viewing time, a project sponsor can often benefit by providing an interpretive site at a prominent or heavily used viewpoint to explain the nature of the disturbance they will undoubtedly have already noticed. Information is the first step to understanding and acceptance. Having no information almost always generates greater skepticism and antagonism. Even a simple and inexpensive facility can provide the basis for a company to promote a positive image by indicating (among other things) what is being mined, the need for the project, how the mineral is processed and used, the jobs it creates, and how the company is planning for a productive postmining landscape following operation.

*Viewer Sensitivity* – The previously discussed variables affect how we perceive objects in the landscape. How we interpret them is another matter. There can be wide differences of opinion in what we see and what it means. Often referred to as viewer sensitivity, viewer interpretation of what we see in the landscape is related to our expectations and experience. This is why relatively small change in one landscape can create greater controversy than large change in another. Landscapes used mostly for recreation purposes and without obvious modifications create an expectation of naturalness and sometimes remoteness. A mine proposed in such a setting is certain to create greater public concern because of predetermined expectations about the appropriateness of uses in this type of landscape. Areas with special features or designations, whether historic, scenic, natural, primitive, or cultural, will be more valued landscapes. Perceived and actual incompatibility of a mine in such areas is certain to be raised directly or indirectly as a visual resource concern. Familiar landscapes, or those seen as their "backyard" by locals, are often sensitive settings for a mine. The landscape here is known in significant detail and a change from "the way it has always looked" will typically be resisted. Proper attention and time spent in accurately anticipating sensitivities will provide important information regarding an appropriate and responsible course of action.

## 5.6.2 LAND USE
**by E. F. Harvey**

Land use effects of mining are readily identifiable and by definition unavoidable. Land uses are generally referred to as surface uses, although subsurface land use typically is the focus of mineral extraction.

### 5.6.2.1 Affected Resource

Land uses are defined by the human application of active enterprise or the preservation of land in an inactive state, usually for a premeditated purpose. Not only is land a factor of production, most economists would argue that some value of land is reaped by all land uses however small or distant in the future that use or value might be. For many land use administrators, existence values of land in a pristine setting suggest that nonmonetary returns to land have merit in certain instances.

In practical terms, Federal, State and local resource planners and land managers have defined categories of land use under their respective domains. The categories of land use are not sacrosanct, but usually include residential (defined as dwelling units per acre), commercial, light industrial, heavy industrial (mining is usually here), agricultural, open space, recreational, and so on. Each jurisdiction will develop its own definition for these categories.

Land uses are not permanent in the true sense. That is, agricultural land uses might, over time, revert to residential uses. In theory, the owner of a land tract could transform a land use at his discretion. Further, the evolution of land use in a given area is driven by the marketplace interaction, which is driven, in turn, by economic forces. Sometimes public land use administrators interject preconceived public values into this evolution, restricting its course of change. For example, public-sector planners, in response to public desires, have put aside particular land tracts for preservation in their natural state; these are usually considered off-limits for mining or other types of development (i.e., national parks, wilderness areas, etc.).

In sum, land uses are monitored and influenced by governmental planning efforts at the local, State and Federal levels. Except where Federal lands are involved, most land use regulation occurs at the local level. The bulk of mining activities occur in rural areas and deal with surface land uses and county regulations regarding those land uses.

### 5.6.2.2 Causes of Land Use Effects

Mining's effect on land use represents a *change* of land use from some previous use to mining. The change of land use associated with mining often begins with a change of ownership, or an option for change of ownership, or right of exploration which is normally purchased from the land owner. Interestingly, public regulators of land use are almost never involved with land ownership changes, although changes of ownership commonly raise the prospect of a change of use.

From a land use regulator's standpoint, exploration is

the initial premining activity. This may consist of drilling, seismic data gathering, small excavations, or other surface examinations. The exploration stage is considered a temporary change of land use and receives different treatment from public land use regulators as compared with longer term changes associated with actual mining operations.

The change of land use process takes on added import when a proposed mine development and extraction process occurs over a number of years. These long-term changes mean that the existing land use will be eliminated for an extended period. The magnitude of such a change will often spark comprehensive permitting or review procedures from public land use regulators.

Reclamation plans should focus on future land uses during the postmining phase. Land use planners among public agencies will often seek reclamation plans that return the property to its previous land use prior to the advent of mining. Perhaps surprisingly, this might not be the best use of these lands in the postmining era.

The causes of land use changes vary considerably by the type of mining operation. Surface mines almost always result in a long-term suspension of the previous land use, unless that land use was mining. Underground mines might have certain surface facilities such as processing or refining plants, but these mines are considered more easily revertible to previous land uses than a surface mine. Regardless, the mining activity below ground may affect the range of land uses which might occur on the surface. *In situ* mining operations typically create the least land use impacts. Even so, public sector land use administrators will typically view any mining operation as an intensive land use.

### 5.6.2.3 Land Use Effects of Mining

Mining results in a decrease of certain prior land uses over time with a commensurate increase in mining land uses. The importance of that change of land use depends upon:

*The amount* of lands held in that previous land use, compared with the lands converted to mining.

*The public* or private sector view of the value of that previous land use.

*Legal proscriptions* allowing for a change of land use.

*The compatibility* of mining with the surrounding land uses.

*The retrievability* of the previous land use.

An evaluation of change in the value of the land or a "best and highest use" analysis of lands will usually indicate that mining is favored. It is important to recognize, however, that this evaluation criterion will carry limited weight in land use decisions made in the public arena. Compatibility of mining with surrounding land uses and consistency of mining with previously identified, desirable changes in land use will typically represent more important decision criteria for public land use administrators. Land use impacts of mining are deemed greater, in general, if the mine is located in or near a population center; the mine is located in or near a national park or forest; or there are special or unique characteristics of the current land use.

It must be emphasized that land use changes and the effects of mining are a function of time; the reversion of lands to their previous use once mining is complete and the time period for the disturbance and extraction are major considerations.

Land use changes are not necessarily a function of the type of mineral commodity extracted. However, certain minerals are more amenable to surface mining than underground mining or *in situ* operations. Coal mines, for example, are often surface operations and therefore result in greater land use changes.

Land use changes associated with mining are often tied to other types of effects. For instance, concerns about the compatibility of nearby land uses suggest that noise, traffic, dust, or lower property values might extend from mining. On the other hand, nearby land owners might perceive a financial benefit with the prospect of additional mining and therefore support such land use changes. Flexibility in future land uses and changes in property values are important considerations.

## 5.6.3 CULTURAL RESOURCES
**by R. L. Spude**

Mining firms should always take into consideration their impact on cultural resources, otherwise major losses may occur to a nation's patrimony. Mining impacts are direct or indirect. Simply by removing large acreage of the surface, an open-pit mine can obliterate all evidence of use of the land by peoples, their artifacts, evidence of habitation, or graves. The impacts of underground mining are more limited, but can be as severe. Culutral resources can be irreperably impacted by the development of support facilities and roads. Indirect impacts include the destruction of cultural resources, such as prehistoric artifacts or pioneer cabins that are near a worksite and may be unintentionally damaged. Development of an area may attract vandalism or looting of archeological or historical sites.

The first steps in understanding the potential impact to cultural resources is to identify the types of resources and then survey and inventory those resources. The importance of a historic property may include the cultural values of Native or indigenous groups. The property may contain artifacts or structures that date from the first settlement of a region or may be representative of a technology that was significant and commonplace,

but no longer in use. Often the last remaining example of a 19th century industry is on the exact locale of a modern mining operation. The information about a culture or society, the settlement of an area, or the technology of an era may be lost if, first, professional methods of identifying and inventorying those resources are not undertaken.

To identify cultural resources, one must understand the broad definition of that term. Standard definitions of cultural resources include archeological properties, historic buildings and engineering structures, and places where significant historic events occurred, such as battlefields. Miners may neglect their own history as significant. Examples of cultural resources include the remains of a former mining camp that represented the settlement of an area, such as Virginia City, Montana or Silver City, Idaho, or a mine owner's historic home such as the Empire Mine manager's home, California. Even industrial remnants are important, such as the steel headframes of Butte, the open-pit method of mining as developed by Daniel Jackling at Bingham, Utah, which is representative of the work of a master mining engineer, and parts of a water flume system in the Black Hills that fed placer mines along Rapid Creek. The ruins of a mining operation can tell us about the history of technology; through history and archeological survey and salvage, the ruin at Cortez, Nevada offered new information about metallurgy.

Today, cultural resources have come to mean more than just a prehistoric ruin or historic home. Cultural resources encompass many subtle, less easily recognized properties. The traditional values of a Native society may be based upon land features. An elder can delineate the beliefs of a people through specific land formations or "special places," now defined as "traditional cultural properties." Similarly, cultural resources can be defined as the landscape shaped by a people; this landscape goes beyond formal gardens to lands that can help us understand a historic farmland, a battlefield, or even a historic mining area. Historic mining-related properties may have less obvious components, but are just as significant. These may include the cultural landscape – spoils piles, ditches, tailings, and other people-modified elements – and ethnographic elements.

One of the more challenging tasks in cultural resources today is identifying traditional cultural properties. This takes the skill of someone able to work with Native groups, especially to earn their trust in order to identify sites that are sacred. This can be a difficult job because of the long tradition of a dominant culture's desire to destroy such sacred sites in order to subdue indigenous peoples throughout the world. Once the site is identified, special care must be taken to honor the wishes of Native peoples to limit access or information about such sites. Misunderstandings between Native groups and the mining community have developed in such disparate regions as the Black Hills of South Dakota, where the Sioux continue their claim to the land, to the isolated upper Amazon region, where the Yanomano are under pressure from recent mining. It is important to understand what a people values in order to best identify and care for a resource. The literature or oral tradition of a people often first defines values, while actions of respect or reverence are also indicators. When dealing with cultural resources, it is always best to err on the side of preservation no matter in what part of the globe one operates.

Specialists can help in the identification of resources. The traditional experts have been archeologists, historians, and architectural historians. Each can place into context the significance of a pot sherd, pioneer's cabin, or historic home. A mining firm, however, should be aware that specialists in a broad field may need more specialized training in order to assess a region's resources. A firm opening a copper mine would not seek an expert on coal to build its flotation mill; thus, the firm might seek someone other than their prehistoric archeologist to evaluate a 19th century industrial ruin located in the middle of their potential open pit. For sensitive Native issues, an ethnographer is best utilized.

The literature on how to survey and inventory cultural resources is extensive. The methods used include two broad components: 1) a literature search or background data collection, and 2) field work. The Homestake Mining Company, for example, hired historians, architectural historians, and historic archeologists to complete the survey and identification of cultural resources in the area of Lead, South Dakota, where the company is expanding its open-pit mine. The specialists compiled historic data – photographs, documents, and oral histories – then inventoried the structures and landscape. The background information helped date properties and apply some criteria of significance to the resource prior to recording, removal, or, if the property lacked significance, demolition.

The survey and inventory of archeological resources requires extensive field work. The smallest artifact – a point, a sherd, a sign of ash – may prove critical in understanding the significance of a resource. The systematic collection of field data is essential as well as the follow-up lab work and report preparation, placing the resource in context. The information gained in field surveys adds, sometimes greatly, in understanding the lifeways of earlier peoples.

In the United States, the Federal government and a majority of States have defined cultural resources and established inventories of significant properties. Other Western countries have similar requirements for identifying and inventorying cultural resources, some countries systems more rigorous than others. These laws, such as the National Historic Preservation Act of 1966, as amended in the United States, require certain

regulations be met prior to operation on Federal lands or receiving a permit from the Federal government to proceed with mining. Some countries promote economic development and are less restrictive, while an increasing number of other countries require more regulations be met prior to mining. Thus, it is incumbent for any mining firm to include in the plans for development a parallel timeline for identifying and inventorying cultural resources. The obvious next phase, after a cultural resource has been identified, is to develop a plan to avoid or mitigate the loss of the resource *In situ*. It is best to have this work well underway, if not finished, prior to mining. If a significant resource is found, mining may be delayed while a plan for avoidance or mitigation of the loss of the resource is completed. Mitigation of cultural resources is discussed in Chapter 6.

### 5.6.3.1 Competition and Conflicts for Community and Economic Resources by E. F. Harvey

Among the societal effects of mining, the competition for community and economic resources is arguably the most enigmatic. Mining's effects can range from isolated nuisance factors recognized only by a limited number of individuals to a pervasive impact and transformation of the very socioeconomic fabric of a community or region. The effects on community and economic resources can be extraordinarily sensitive from a political standpoint because the layman understands these issues more easily than technical ones, and these issues can be "very close to home" (jobs, income, home values, etc.). Public sector regulators are not immune to the political interest in such issues. Unlike most other environmental effects, however, these can be either positive or negative on balance.

### 5.6.3.2 Identification of Potentially Affected Community and Economic Resources

The resources in question can be summarized as all attributes of a community or a region that are utilized by human inhabitants or visitors. While correct, this definition offers little use for practical application since the socioeconomist or mine planner must isolate the specific aspects that are affected, the measure of change, and assess the significance and direction (positive or negative) of that change. Which resources to focus on can be determined by playing out the sequence of events. The following hypothetical case is an example:

Mine A is developed and goes into operation 3 miles outside of Community B. Community B is a small and stable community whose work force is limited in size and focused primarily on the service industries as a regional, retail trade center. Mine A may result in an influx of workers and families, causing a shortage of housing, an increase of housing and land values, a rise in prevailing price levels, an increase in income, a shortage of water, an increase in traffic, and an overall loss of stability for existing residents.

The characteristics of the mining operation and the characteristics of the community and economic resources are the primary determinants indicating which resources will be most affected and should be the focus of attention. The most common community and economic resources affected by mining include housing, private sector retail and service businesses, public sector services, public sector facilities, and infrastructure. Within each of these broad categories, there can be a number of subcategories; public facilities can include roadway condition and capacity, tourism and recreation facilities, sewer system capacity, hospital space, number of fire trucks, etc.

The range of resources in the community or economy that are actually affected by mining has evolved over time because of the changing societal values and viewpoints about mining and personal well-being. Traditional conflicts included housing shortages, rising prices, and falling levels of services due to competition brought on by an influx of mining employees. An increasing recognition of health risks associated with hazardous wastes and toxic substances, coupled with a growing mistrust and lack of understanding of industry in general, has produced new concerns. These concerns might be categorized as personal security, which is perceived to be threatened by mining in some instances from a health or safety standpoint. Also in recent years, a growing dichotomy of viewpoints concerning affected resources has been born, depending on the distance one's household or job is from the mine itself. Noise, traffic, dust, toxicity or contamination fears, or employee misconduct can be perceived as conflicting with one's living conditions. This phenomenon has been referred to as NIMBY (not in my backyard). These proximity-type conflicts can often be subsumed in changes to property values of nearby homeowners. As society's values, knowledge, and overall perception of well-being change, the perception of mining's "effects" will continue to evolve.

### 5.6.3.3 Causes of Competition and Conflict

The causes of competition and conflict for community and economic resources stem from the development and the initial operation of the mine itself. These effects actually begin during the construction phase of the facilities and the preliminary stripping, grading, or shaft drilling activities. In fact, these effects can begin during the exploration phase if it requires new road development, extensive employment, or a substantial increase in traffic.

**Table 4** Community and Economic Effects of Mining

| Community/Economic Resource | Potential Negative Effects | Potential Positive Effects |
|---|---|---|
| Housing | Incoming miners purchase all available housing so movement and housing costs for existing residents become constrained. Temporary employees live in cars or mobile homes scattered indiscriminately in a community. | Influx of miners stimulates moribund housing market, absorbing surplus homes, stabilizing housing costs, improving land values for existing residents, stimulating home building. |
| Private sector services and facilities | Higher paying jobs at mines rob community of available work force, rapid increase in demand for goods and services drives up prices, brings in competition, reduces service level for long-time customers. | New payroll in community stimulates retail sector, keeping businesses alive. Larger economic base brings in greater diversity of facilities and services, improving shopping opportunities for long-time residents. |
| Public facilities and services | Increased demand for facilities and services results in inability to meet demand. Water is rationed, customer response declines, adequacy of public services diminishes. | Governmental entities are able to keep up with demand increases so that service levels do not decline and larger operational base produces better service for everyone. Absorption of capacity produces more viable entities. |

It is interesting to note that the effects of mining on community and economic resources do not stem from the operation itself except in rare instances (e.g., Anaconda's underground mine beneath Butte, Montana; Homestake Mining Company's Open-Cut Mine in Lead, South Dakota). Off-site or indirect effects are usually more relevant. The effects of mining in most instances stem from:

*The size and duration* of the exploration, construction, or mine development work force.

*The time period* for buildup and ultimate size of the operational work force.

*The degree of perception* as to hazardous output of materials, hazardous byproducts, or hazardous ingredients.

*The volume* of output as a function of time.

*The mode* of transportation of the output.

*The duration* of the active mining phase.

The competition and conflicts come into play when these mine characteristics are superimposed on the characteristics of the region in which the mine is located. Hence, the above causes may be viewed as stimuli which may or may not produce competition and conflict.

### 5.6.3.4 Mining's Effects on Community and Economic Resources

The effects of mining result in either shortages in community and economic resources or an absorption of excess resources. During the 1960s and 1970s, the rapid increase in the number of mines and total mining activity in a given region would often produce an overburden on the available community and economic resources that existed. In recent years, the smaller number of mines, coupled with stagnant economies or declining circumstances of many regions, has resulted in a perception of positive effects, on balance, as the mine absorbs excess capacity in various sectors and upgrades the economic and financial base of a region. Creative mine planners point out mining's benefits as an offset to other environmental concerns. Under the current circumstances, the threat of mine closure and the loss of the economic base represents a more noticeable risk than its ongoing operation. Table 4 below indicates the effects a mine can have on community and economic resources.

The community and economic effects are in part a timing issue. The marketplace is often able to rectify shortages given enough warning and degree of certainty about future mining operations. Public entities generally expand capacity and improve service levels once increased tax revenues begin to expand local capability. These tax revenues might lag several years behind actual effects, however, and jurisdictional conflicts (e.g., the mine is in

one county but the workers live in another) may pose serious fiscal problems. In general, construction impacts and the effects of the first 2 or 3 years of operation have the potential to cause the greatest impacts. The forces of supply are usually able to respond over time, and existing residents typically gain greater comfort once newcomers have remained in the community for a period of years.

Proximity effects are rarely, if ever, positive. Increased noise, increased traffic, and more dust can produce lower property values, frustration, and an overall "unwanted neighbor" viewpoint. Sensitivity to these proximity effects appears to be growing.

### 5.6.3.5 Differences in Effects by Type of Mining Operation

The type of mining operation (e.g., surface, underground, or *in situ*) may or may not relate to its effects upon the community. *In situ* operations tend to be smaller and lower in scale so that the potential for conflict is reduced. Underground mines are more labor intensive, typically, than surface mines, tending to increase their effects. Surface mines can increase noise and dust concerns, although individual mine characteristics vary widely on this measure.

The type of mineral commodity produced does not typically define the magnitude or direction of effects. If the mineral commodity is consumable or otherwise considered important to the local community (e.g., supplies other local industries with commodities), the degree of acceptance of certain impacts or impositions will be tend to be greater. Gold, for example, might not be viewed as having important utilitarian value and so may be scrutinized more closely than a potash mine which provides fertilizer for nearby farmers. However, the industrial processes associated with refining, milling, or preparing the mineral production for sale can also create serious conflicts with the community. For instance, cyanide discharges from heap leach operations into stream courses can be viewed quite negatively in certain circumstances.

## 5.6.4 DAMAGE
**by D. E. Siskind**

### 5.6.4.1 Blasting

There are four environmental effects of blasting: 1) Flyrock, 2) Ground vibrations, 3) Airblast, and 4) Dust and gases (Dick et al., 1983).

Flyrock is a potential cause of death, serious injury, and property damage. Ground vibrations and airblast are potential causes of property damage and human annoyance, but are very unlikely to cause personal injury. Flyrock, ground vibrations, and airblast all represent wasted explosive energy. Excessive amounts of these undesirable side effects are caused by improper blast design or lack of attention to geology. When excessive side effects occur, part of the explosive energy that was intended to give the proper amount of rock fragmentation and displacement is lost to the surrounding rock and atmosphere. A larger than normal amount of dust may be caused by a violent shot. Noxious gases, normally oxides of nitrogen or carbon monoxide, are the result of an inefficient explosive reaction. Because of its sporadic nature, blasting is not a significant source of air pollution.

#### *5.6.4.1.1 Flyrock*

Excessive flyrock is most often caused by an improperly designed or improperly loaded blast. A burden dimension less than 25 times the charge diameter often gives a powder factor too high for the rock being blasted. The excess explosive energy results in long flyrock distances. On the other hand, an excessively large burden may cause violence in the collar zone, especially where an inadequate amount or an ineffective type of stemming is used. This situation is compounded when top priming is used, as opposed to center or toe priming.

Zones of weakness and voids are often causes of flyrock. These potential problems can sometimes be foreseen through consultation with the drill operator and through past experience in the area being blasted. An abnormal lack of resistance to drill penetration usually indicates a mud seam, a zone of incompetent rock, or even a void.

#### *5.6.4.1.2 Ground Vibrations*

Blasting produces ground vibrations as acoustic or seismic waves which travel outward from the source at propagation velocities determined by the media elastic constants and density. Points in the ground are disturbed by the wave passage which can be expressed as a time-varying kinematic motion of particle displacement, velocity, or acceleration (a time history of varying amplitude and frequency). Blasts as vibration sources are complex, extending in both space and time. The transmitting medium (ground) is also typically complex both in composition and structure. Consequently, vibration records which are initially characteristic of the source are then strongly altered by the transmitting medium, including both their amplitude and frequency.

At every interface, compression and shear body waves produce both transmitted and reflected counterparts according to Snell's law and acoustic impedance matching. This gives rise to complex vibration records at large distances. Also, surface waves of specific frequency are generated. Rock is dispersive, that is the waves spread

with time and the high frequencies propagate faster. Attenuation is also frequency-dependent, being greater for the high frequencies, also enhancing low frequencies. The long period tail of vibrations measured beyond a few hundred meters are usually Rayleigh waves. At even larger distances, the high frequency beginning will be further attenuated and the seismic record will show little source influence but only reflect the transmitting medium. Where such low-frequency waves exist (4-8 Hz) either through low-velocity and wave-trapping surface layers or simply large distances, vibrations will be relatively noticeable and disappropriate in their response effects on structures. Usually and fortunately, amplitudes for these cases are well below damage thresholds (Siskind, 1980b).

#### *5.6.4.1.3 Airblast*

Blasting produces an airblast disturbance which travels as an overpressure wave in air at a propagation velocity dependent on air density. At sea level and temperate conditions, this velocity is about 330 m/s (1080 ft/s). Airblasts, being far slower than ground-borne waves (ground vibrations), arrive about one second later for each 1000 ft of source-to-receiver distance. Airblast waves are only compressional, that is, particle motion is only radial. Therefore, they do not require three components of measurement. They also do not exhibit the variety of wave types as with ground vibration (compression, shear, and surface) because air, being a fluid, does not support shear stresses.

#### *5.6.4.1.4 Frequency Characteristics*

As with ground vibrations, time history records can be obtained for detailed analyses. Airblasts from large mining shots often have considerable low frequency, as low as 1 Hz. Therefore, a wide band system response must be used when an accurate and undistorted time record is required. In contrast to ground vibrations where low frequencies are a special concern, airblast from mine blasts with significant energy above 5 Hz are considered "high frequency" and are a potential problem for excessive structural response and impacts. The amount of such energy is related to the mechanisms of airblast generation.

#### *5.6.4.1.5 Types of Airblast*

Five significant sources of airblast have been identified for mining blasts through the work of Wiss (1979). The terminology of Wiss has been adopted here and in Bureau of Mines technical reports on airblast by Siskind (1980a) and Stachura (1981). The Bureau's studies have identified two general types of airblast, a Type I with significant high frequencies (spikey) and the predominantly 1-Hz Type II (smooth).

##### *5.6.4.1.5.1 Air Pressure Pulse (APP)*

All blasts which produce permanent ground displacement also produce an APP through a piston effect. The moving rock face pushes a pressure wave in air ahead of itself as does a loud speaker cone. Where the bench face is projected forward, the case in most blasting and particularly casting, this APP is strongest in front. In a delayed blast, each front row hole can generate an APP pulse (Type I). In addition, the face itself acts as a propagation barrier. Therefore, the APP as seen from behind, only has the low frequencies which are able to refract around the bench and/or shows up as a less uniform and lower-amplitude rarefaction phase (the Type II airblast). Some blasts produce little forward throw but do heave up the bench top. This also acts as a source of APP, however, it is less directional. In a properly designed blast, the APP will dominate the airblast.

##### *5.6.4.1.5.2 Rock Pressure Pulse (RPP)*

This is also caused by ground motion except in this case it is the cyclic ground vibration which is the source. Every point on the ground which moves vertically produces a corresponding sound pressure wave of similar wave character. This kind of source starts when the ground vibration arrives at the airblast sensor. Comparisons of airblast and ground vibration provided this relationship:

$$RPP = 4.14 \times 10^{-7} V_V \qquad (5.6.4.1.5.2.22)$$

where RPP is in MPa and $V_V$ is vertical ground vibration in mm/s.

RPP is the minimum airblast which can be expected and is typically much smaller than the APP or adverse types described below.

##### *5.6.4.1.5.3 Stemming Release Pulse (SRP)*

This is the airblast corresponding to a stemming ejection type blowout. It represents a loss of explosive energy which is supposed to be fragmenting and displacing rock. This is a special case of the gas release pulse below.

##### *5.6.4.1.5.4 Gas Release Pulse (GRP)*

Like the SRP, this is a loss of explosive efficiency with premature release of gas pressure. This can be through weak zones, developing cracks, from under burdening or overloading. It is also a kind of blowout and is usually accompanied by flyrock.

*5.6.4.1.5.5 Surface Explosive Pulse*

An explosive detonated on the surface produces the worst-case airblast. Frequencies are high and inversely proportional to the charge size. In mining, this is represented by uncovered detonating cord or a situation where underburdening or overrelief allows explosive products to detonate without the usual rock burden. Accidental explosions also usually fall in this category with minimal confinement. At sufficiently large distances, the high frequencies attenuate and again a Type II waveform results.

### 5.6.4.2 Subsidence
**by A. J. Fejes**

Subsidence is a natural result of underground mining. When a void is created, nature will eventually seek the most stable geologic configuration, which is a collapse of the void and consolidation of the overburden material. The magnitude, location, and rate of subsidence depend on various geologic and mining factors including, but not limited to depth of mining, material strength of the surrounding strata or country rock, and percent of extraction. The significance of each factor has been discussed previously and will not be belabored here. The important fact is that subsidence from any type of mining can cause damage to buildings and other fabricated structures. Damage can occur to residential and commercial buildings; infrastructure such as roads, highways, and railroads; and utilities such as power lines and oil, gas, and water pipelines.

#### *5.6.4.2.1 Hard-Rock Mining*

Subsidence damage to manmade structures is not usually an issue for hard-rock mines for several reasons: 1) mines are often located in remote areas; 2) large-volume mining methods, such as block caving, cause catastrophic overburden failure, and thus the only solutions for mitigating damage are to purchase the structure, move the structure prior to mining, or limit mining; and 3) low-volume mining methods that follow vein deposits are often located in competent rock at great depths with relatively low extraction ratios, which results in no surface expression of subsidence in the near future and possibly not for hundreds of years.

#### *5.6.4.2.2 Solution Mining*

As with hard-rock mining, the issue of subsidence damage to buildings and others structures is limited by the nature of the overburden failure. Sinkholes and piping subsidence are commonly associated with solution mining. This type of catastrophic overburden failure offers the same solution for mitigating damage as hard-rock mining, that is to purchase the structure, move the structure prior to mining, or limit mining.

#### *5.6.4.2.3 Bedded Deposits*

Bedded deposits are usually mined by two methods: room-and-pillar and longwall. A majority of subsidence research and regulations concerning mine subsidence is dedicated to these mining methods because the subsidence is relatively "controlled." In other words, these mining methods and the nature of the bedded deposits lend themselves to controlling the location, magnitude, and rate of subsidence, thus allowing regulation of the damage resulting from the mine subsidence.

Room-and-pillar mining limits the extent and magnitude of subsidence by limiting the percent of extraction. Subsidence from this type of mining is usually expressed at the surface as a sinkhole or pit subsidence, but the timing and location of its occurrence is virtually unpredictable. Subsidence over room-and-pillar mining is isolated and limited, but can be very damaging to structures because of the large vertical displacements at the edges of the sinkholes or pits.

Full-extraction room-and-pillar and longwall mining create large subsidence troughs, and the rate, extent, and magnitude of subsidence from these mining methods are relatively easy to predict. "The damage forming properties of subsidence are more commonly associated with tilt, curvature and strain. Tilt (differential subsidence) and curvature (differential tilt) are a direct consequence of the shape of the subsidence trough, while strain has two components, (1) that due to curvature and (2) that due to the lateral migration of the surface towards the centre of the excavation." (Breeds, 1976)

Tilt can affect drainage systems, the flow of creeks, the flow of liquids in pipelines, the grade of highways or railways, and the irrigation of crop lands. Tall structure with small base areas such as towers, chimneys, and power transmission towers are also extremely sensitive to tilt.

Curvature is the rate of change of slopes, usually expressed by the radius of curvature. The two types of curvature are convex (positive) and concave (negative). Concave curvature induces tensions at the bottom and compression at the top of the structure whereas convex curvature causes the reverse response. Curvature induces distortion, because of shear strain, and flexural bending to structures.

Most damage to structures from trough subsidence is caused by strain. Tensile strain occurs in the convex portion of the surface of the subsidence trough, causing tensile cracks to develop first in the lower portion of the structure and at weak points such as windows or door openings in buildings. Compressive strain occurs in the concave portion of the trough and causes squeezing or buckling of foundation slabs, brickworks, and rafts.

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# Chapter 6

# TECHNOLOGIES FOR ENVIRONMENTAL PROTECTION

edited by R. L. Lowrie

## 6.1 LAND SURFACE EFFECTS

### 6.1.1 MINING METHODS

**by M. J. Hrebar and T. J. Toy**

At every mine, the prevailing environmental conditions and chosen technology produce a unique post-mining site geography, composed of singular surface and subsurface, physical and chemical properties. While a complete inventory of possibilities is clearly impossible, it is feasible to briefly describe some general categories of mining types and the resulting milieu that constitutes "time-zero" for reclamation.

Selection of surface mining methods is largely dependent on deposit geography, geology, geometry, and depth of burial. The mining method and equipment chosen to execute the mining sequence must perform within the economic framework of the commodity being extracted. Each deposit is unique and the mining and reclamation plan are tailored to the specific deposit. However, these operations can be generally classified for purposes of defining the post-mining site geography. Prior works (Toy and Hadley, 1987, Phelps, 1990, and Sweigard, 1992) were utilized to compile this summary of open pit, quarry, and placer operations, primarily utilized in hard rock and industrial mineral deposits, and contour, mountain top and area methods utilized primarily for coal or other bedded deposits (e.g. phosphate.)

#### 6.1.1.1 Open Pit

Open pit mining is used to extract base and precious metals, iron ore, and in some cases construction materials. The economic final, or ultimate pit limit, is calculated to determine the excavation limits. The commodity value will not support the stripping, mining, processing, and reclamation costs beyond the economic limit. The final pit slopes are usually quite steep (e.g., 45-50 degrees). Mining begins with prestripping within the final pit outline to access ore; the overburden hauled to temporary or permanent external dumps, beyond the final pit limits. The initial pit is deepened and expanded, utilizing shallow working slopes, which are then steepened to the final pit slope angle as the numerous benches encounter the excavation limit. Pit expansion continues until the ore or economic limits are reached. There is little opportunity for contemporaneous backfilling and further reclamation. In addition, because the final pit slope and ore reserves are a function of current economics, the final pit slopes may be "pushed-back" to permit the mining of additional ore when commodity prices increase. Ore and waste may be encountered on each bench and are selectively mined and transported to processing facilities or external dumps. The mined-out pit is usually an inverted cone shaped opening with numerous equally spaced narrow benches forming the final slopes. Most overburden is left in external waste dumps. When processing of ore is required, process wastes are also located in external storage facilities. The mined-out pit can be very large, having dimensions of 1000's m by 1,000 m at the surface and 100's m in depth.

#### 6.1.1.2 Quarry

Quarries are utilized to mine bedded or massive deposits of limestone, granite and other construction materials from a single or few benches. Many of these products are place value (that is, low intrinsic value) commodities, limiting the amount of overburden that can be removed economically. When the product is removed from the pit, there is insufficient spoil material available to backfill the pit, leaving a steep-sided depression. If adequate overburden is available, the steep final slopes, with the exception of the active mining face, can be backfilled contemporaneously to reduce the final pit slopes. Since many of the quarries are located in urban or suburban areas, to be close to end-use markets, reclamation often includes changes in land use. Dimensions are a function of property constraints but can be large with surface dimension of thousands by 1,000 m and depths of 100 m

or so.

#### 6.1.1.3 Placer

Placer mining is employed in active or ancient stream channels or beaches to recover precious metal or heavy minerals. The mining operations can be either wet (i.e., employing dredging) or dry (i.e., employing conventional excavators) and both operations usually include in-pit or on-pond preconcentration of low-grade ores. Consequently, the mining area is backfilled as the operation progresses, which allows contemporaneous reclamation. If overburden overlies the pay zone, it can be stripped in a separate unit operation and placed on the process spoil material. Since a small percentage of the commodity is removed in processing and the mined-out area is backfilled, only a small final pit relative to the mined area remains. Dimensions are widely variable depending on the extent of the pay zone. The deposits are usually mined in a series of cuts less than 100 m in width as dictated by the economic horizontal transport distance of the dredge or excavator.

#### 6.1.1.4 Contour

Contour mining is conducted in moderate to steep topography with the pit bounded by the outcrop or subcrop and an economic limit. The coal value will not support the required stripping, mining, preparation, and reclamation costs beyond the economic limit. An initial cut of overburden is excavated and removed to an offsite head-of-hollow or valley fill. Following removal of the exposed coal, an adjacent cut of overburden is pushed across the mined-out pit or hauled back around the pit, and the process is repeated along the cropline following coal removal. Adequate spoil volume is usually available to re-establish the original topography and allow contemporaneous reclamation. Depending on coal thickness and overburden swell, additional permanent off-site spoil storage room may be required. In some non-U.S. locales, the overburden may be placed downslope, below the outcrop, although this causes significant problems with an exposed highwall and erosive, unstable downslope spoil. The mined-out area consists of the back-filled area and a small final pit relative to the total mined area. Pit width between the low-wall or outcrop and highwall depends on overburden slope but is on the order of a few 100's of m. The mined area may extend to many kilometers with an active pit length of a few 100's of m or less and a 50 m or less highwall in the final pit.

#### 6.1.1.5 Mountain Top Removal

Mountain top removal is conducted in steep terrain and is often an alternative to contour mining where economic conditions dictate. Seams frequently outcrop on the flanks of a ridge with the coal underlying the entire mountain being economically minable when considering the allowable stripping ratio. The seams are mined in a series of parallel cuts or in progressively deeper cuts following the cropline in an adaptation of area mining. A large percentage of the material is placed in head-of-hollow and valley fills and then often covered with additional spoils while retaining major drainage patterns. The final topography is reduced to a flat surface with the average elevation below that of the original ridgeline. Considerable planning of spoil placement is done to construct a topography that is suitable for a new land use, often commercial or industrial. Contemporaneous reclamation is possible to a degree, but a large area is often disturbed during operation. Dimensions of these operations depend on geology, but can be quite large in areal extent, covering a number of square kilometers.

#### 6.1.1.6 Area

Area mining is conducted in relatively flat or rolling terrain with moderate depths of overburden. Economic limits are often not a constraint in these operations until late in the project life when overburden depth may increase. Overburden is removed from an initial pit or box cut and spoiled on the adjacent original surface. Following coal removal, the next cut of overburden is removed and spoiled into the previously mined-out pit. The process is repeated until the final cut is made at a property boundary, economic limit, or outcrop. Adequate spoil usually exists within the mined-out area to raise the topography to approximate original contour. The operation consists of the boxcut spoil, a peak and vee backfilled area, and a final cut. The final cut, bounded by a steep highwall and spoil at angle of repose, is narrow and of considerable length but represents a small percentage of total mined area. The sequential nature of the operation lends itself to contemporaneous reclamation, which can be kept within a few cuts of the active pit. Each cut is 30 to 60 m wide and typically have a length of 1-2 km with depths to 50-60 m.

Postmining geography is dependent on deposit type and mining method. The severity of surface disturbance, relative to initial topography, varies widely across commodities and methods. Further detail on mining methods and equipment is provided in Chapters 13-16 of the *SME Mining Engineering Handbook, Second Edition*.

All successful reclamation plans and technologies assume a stable foundation upon which a stable surface can be constructed. Oftentimes, the integrity of the substratum is questionable whether evaluated over the short- or long-term. It is appropriate, therefore, to consider next the phenomenon of surface subsidence and its control.

Once the stability of the substratum is reasonably

assured, it is appropriate to proceed with surface treatments to achieve the desired or mandated measure of environmental protection.

## 6.1.2 SUBSIDENCE CONTROLS
**by M. M. Singh**

### 6.1.2.1 Mitigation and Abatement

Backfilling is the most common means utilized to mitigate and abate subsidence effects, using either hydraulic or pneumatic techniques. It is important to recognize, however, that the amount of subsidence is merely reduced by these techniques, not eliminated entirely. It is a constructive method of mitigating subsidence effects, since it not only minimizes the ground-deformation but also conserves the hydrologic regime. Cost effectiveness studies should consider the beneficial effect on the environment such as decreased acid-water drainage, savings in waste disposal and reforestation, prevention of refuse fires, diminished ground fissuring and escape of mine gases, as well as the advantages of attaining long-term strata stability and decline in roof support requirements. Railroads, canals, sewers, and streams experience smaller gradient changes. Hydraulic flushing may also cool the mine air, which is desirable in deep mines. Backfilling may become essential in flat regions with a high water-table to prevent flooding, and in areas reclaimed from water bodies (e.g., in The Netherlands).

The backfilling method of strata stabilization may extend over large areas (several hectares) or be restricted to support a specific structure.

#### *6.1.2.1.1 Areal*

Backfilling, grouting, excavation and fill placement, and blasting are four commonly-used systems that provide large areal coverage:

*Backfilling* - This may be conducted either hydraulically (i.e., the fill material is transported underground as a slurry) or pneumatically (i.e., the fill is conveyed with pressured air). In either case the procedure may be controlled, when the mine is accessible and barricades can be manually built or remote (blind), through boreholes when the openings cannot be entered, such as in abandoned mines.

Hydraulic stowing is usable even in water-filled mines. In dry mines, the water level may rise temporarily, acid water may be flushed out into the hydrologic system, and surface drainage may be affected by siltation, pollution, or flooding (especially in shallow mines).

The patented Dowell process is not commonly employed, but is a hydraulic blind-flushing technique, in which the slurry is pumped at a high velocity. The mixture deposits its load when the velocity drops on entering the mine cavity, forming a doughnut-shaped pile. As the pile height nears the mine roof the slurry velocity in the gap increases, keeping the solids in suspension longer, so that the doughnut grows outward.

Pneumatic stowing causes considerable sparking and may pose a hazard, because of the potential for gas ignition. However, it has been popular in Europe.

Fly ash is often used for backfilling, because of its abundance at coal-fired power plants. It can be utilized with either the hydraulic or pneumatic techniques.

*Grouting* - The technique involves injecting a cementitious mixture into the mine opening, providing a stronger support. Portland cement, pozzolanic mixtures, or organic compounds may be used as additives. Gravity grouting simply fills the mine void to whatever extent possible. Little control can be exercised, although a perimeter wall with a thick grout could be built first, which is then filled with an expansive grout to obtain good roof contact.

Pressure grouting is required if joints need to be filled or roof caving has occurred. Bag grouting entails lowering a bag through a 150-mm diameter borehole and filling that with grout until roof contact is achieved. Grouting under important buildings requires special care.

*Excavation and Fill Placement* - This is only feasible in shallow abandoned mines, when no obstructions to surface excavation are encountered. Compacted fill replaces the entire overburden and coal, that are removed. Precautions should be taken, since flooded mines could yield large quantities of acid water.

*Blasting* - Blasting of the roof and floor is a patented technique, but not commonly used. Over time, the broken rock compresses, but the movements may be expected to be gradual and evenly distributed.

#### *6.1.2.1.2 Site Specific*

These techniques are mostly used to support isolated structures. Again four methods may be distinguished:

*Grout Columns* - Such columns can be built remotely, but the variability of floor and column strengths are problems; besides, the occurrence of water impedes construction.

*Piers and Cribs* - These can be constructed if the mine openings are accessible, and the floor and roof are competent.

*Deep Foundations* - Deep foundations can be used if shallow workings exist; however, lateral shear forces,

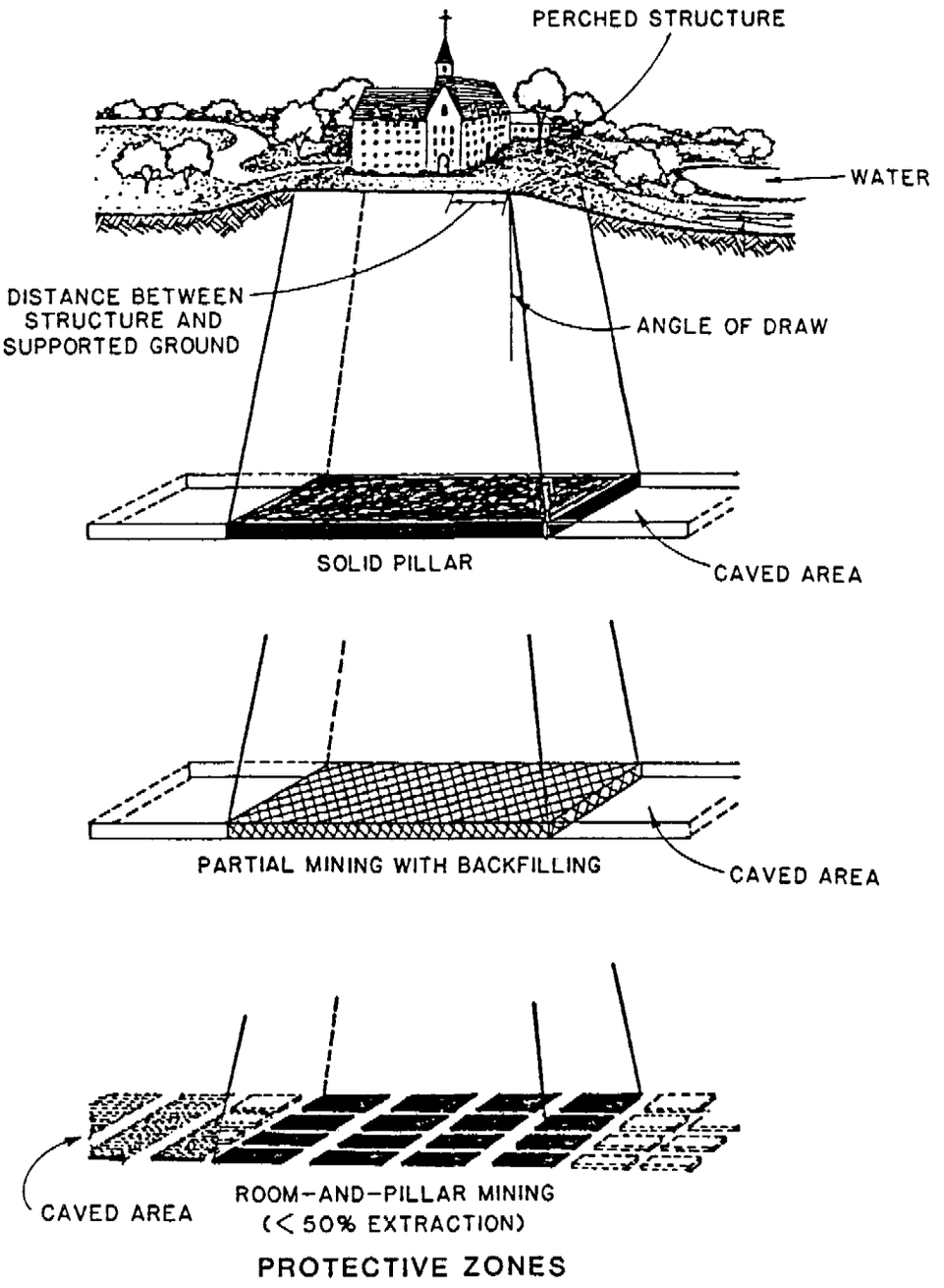



**Figure 1** Protective zones for surface structures (Singh, 1992, courtesy of Society for Mining, Metallurgy, and Exploration, Inc.)

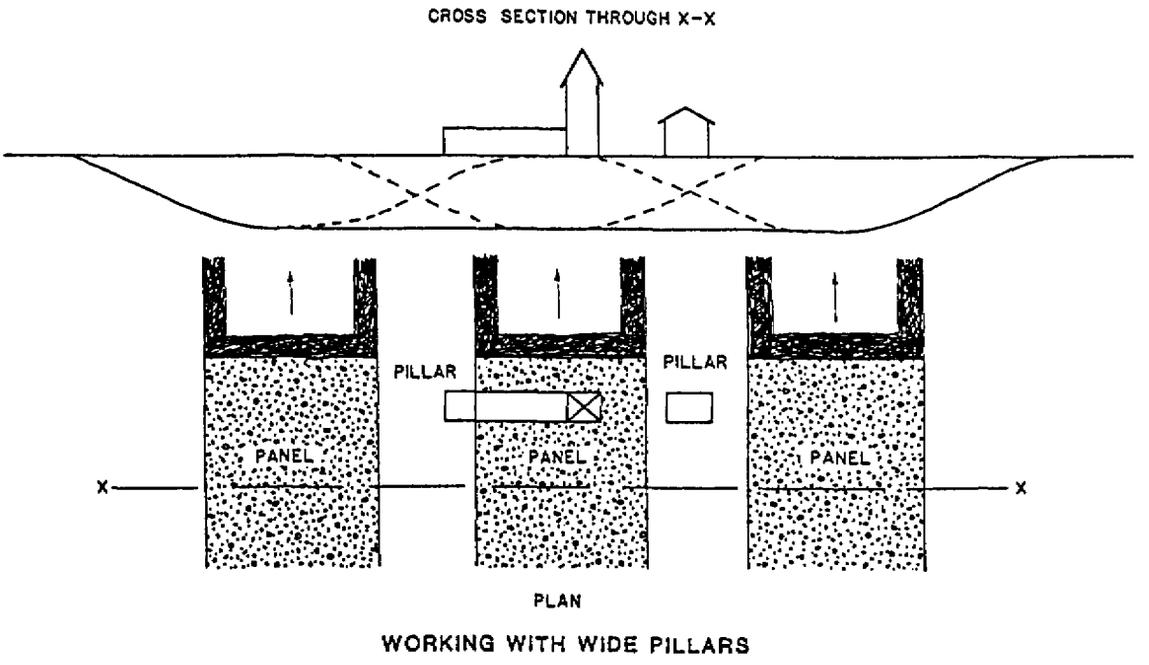



**Figure 2** Use of sized pillars for protecting surface structures (Singh, 1992, courtesy of Society for Mining, Metallurgy, and Exploration, Inc.)

that may be experienced, could cause damage.

*Groutcase Supports* - These involve placing casing between the mine roof and floor and filling it with grout, to supplement existing pillars.

### 6.1.2.2 Minimization of Subsidence Damage

Three types of measures are used to control subsidence damage (Singh, 1992): 1) changing mining techniques; 2) incorporating appropriate architectural and structural design features; and 3) comprehensive planning. Different methods may be used to effect each of these types of techniques.

#### *6.1.2.2.1 Changing Mining Techniques*

*Partial Mining* - This may be accomplished in a number of ways. Leaving protective zones is a procedure often used (Fig. 1). A zone may entail leaving the entire pillar unmined beneath structures, such as buildings, railroads, major highways, and bodies of water; partially extracting the pillar and backfilling; and room-and-pillar mining with up to 50% extraction; a practice advocated in some states (e.g., Pennsylvania) by regulation. This method does not consider the fact that pillars deteriorate with time, particularly in flooded mines.

Any structure supported by a protective zone is liable to become perched at a higher level than the surrounding ground after subsidence occurs. This may not affect the protected railroads or highways, but could interfere with the utilities (water, sewer) to a building. If the water table is high, an island could be created.

Pillars can be sized, i.e., the pillar width between panels can be adjusted so as to uniformly lower the ground surface (see Fig. 2). Subcritical widths can be mined so that the maximum subsidence encountered is reduced.

*Backfilling* - When backfilling is performed simultaneously with mining, greater resource recovery is usually possible. Other changes in the mining cycle are possible, and benefits may accrue from reduced strata control costs, or the cooling afforded by the slurry water in deep, hot mines.

*Harmonious Mining* - This technique involves superimposing compressive surface strains on the tensile strains induced by another longwall face, in a manner that they move along together. This may be accomplished by staggering two simultaneously worked faces that advance at the same rate, with 1) multiple seams, in which one face is superjacent over another, and 2) single seams, where the panels adjoin. It is evident, of course, that total cancellation of the traveling strains can only occur if the displacement curves are congruent and symmetrical (i.e., the seam thickness, influence factors, width of compressive and tensile zones, and stowage density, if backfilling is adopted, are identical). Time factors for the mining sequence must also be available from prior experience.

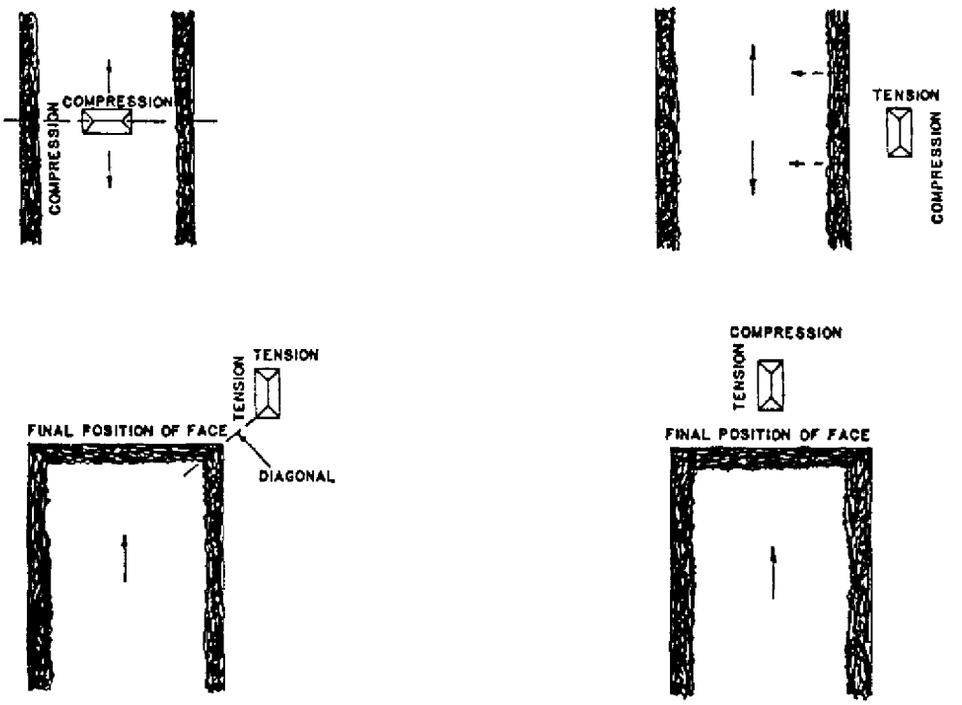



**Figure 3** Structural strains produced by basic face layouts (Kratzsch, 1983, courtesy of Society for Mining, Metallurgy, and Exploration, Inc.)

*Mine Layout or Configuration* - Layout governs the strains to which a structure is subjected. It may be possible to situate the panel with respect to the building so as to expose it to deformations that it can withstand (Fig. 3). Occasionally, it may be preferable to leave some of the mineral in place; the penalty for doing so may be tolerable for a shallow deposit.

*Extraction Rate* - In mining, face advance cannot be changed easily; besides, its range is relatively restricted with the equipment being used. In unfractured, viscoelastic strata, a faster rate is preferable, because it lowers the tensile peak and moves it closer toward the working face. However, in fractured, clastic rocks (such as over previously mined beds), rapid face advance may accentuate displacements and strains, thereby inducing greater damage.

### *6.1.2.2.2 Architectural and Structural Design*

*Orientation* - It is desirable to have the long axis of a building parallel to the subsidence contours. If a fault exists nearby, the shorter axis should be oriented perpendicular to the fault.

*Location* - Faults tend to concentrate ground strains, hence structures should be located at least 15 m away. A single building should not be constructed on dissimilar soils, owing to the possibility of differential deformations or settlements.

*Subsidence-Resistant Construction* - This technique has received considerable attention in the literature. It may be discussed under four major construction categories.

- Rigid Design - From this design viewpoint both the foundation and superstructure should be stiff. The foundations are highly reinforced concrete rafts or beams, capable of withstanding ground displacements and curvature. The structures span or cantilever over a subsidence wave. The foundations have a small footprint. Extra clearances are allowed in shafts for cages or skips, or similar structures.

- Flexible Design - This approach permits slab foundations for small buildings such as houses. It is desirable that the slab be less than 20 m along the side, poured in a single operation, without joints, finished close to ground level and, customarily, with an underlayer of granular material. The reinforcement is placed near both the top and bottom, to accommodate the tensile and compressive strains. A gap, either open or filled with a compressible or granular material, should be provided around a building with a basement. Larger buildings may have rollers or slip-joints between the superstructure and foundation. Trenches around structures absorb some of the strains. Flexible structures are designed to track the traveling subsidence wave without cantilevering, permit free ground movement below the foundation, provide sufficient superstructure

support in spite of the ground flexing, and accommodate subsidence deformations that are larger than anticipated without jeopardizing structural stability.

- Semi-flexible Design - Such a strategy may be adopted for structures that can withstand minor damage, such as some types of warehouses. These do not strictly adhere to the rigid or flexible criteria presented above. It may be more economical to perform minor repairs as required, than employ those more expensive designs.

- Releveling Devices - These are mechanisms, such as jacks, that are used to prevent tilting. Excessive tilt may cause the gap between adjacent buildings to be reduced to the extent that they touch. Gaps should be provided between all buildings to permit both compression and tilt.

Depending on design ideology, additional precautions that could be incorporated are: (a) Provide expansion joints, to accommodate ground movements and thermal expansion; (b) minimize the number of door and window openings; use flexible frames; their location should not significantly weaken the structure; do not position front and back doors opposite each other; (c) avoid weak skin materials within rooms; partitions between building segments should be strong; instead of plaster on ceilings and walls, use plaster board; (d) floors and roof should be secured to the walls; (e) allow for tensile strains at all structural connections; movements should be possible for staircases; (f) exclude masonry arches; (g) do not have corner or bay windows, or porches; (h) detach out buildings from the main building; (i) provide excessive falls for gutters; (j) do not pave immediately adjoining buildings; use bituminous type materials for paving where necessary, e.g., driveways; (k) employ flexible damp-proof courses, e.g., bitumen; (l) use light fences around properties, rather than walls; and (m) replace rigid retaining walls with earth banks.

*Modification of Existing Structures* - Appropriate changes made to a building prior to its experiencing ground movements, could appreciably reduce total repair costs. Some suggestions (Kratzsch, 1983) for this are 1) cutting out a part of a house or removing an entire house from a row of buildings; unit lengths should be about 20 m, with cuts extending into trenches, and gaps bridged with flexible materials; preferably locate cuts in connection corridors or unit divisions; 2) digging trenches around a building (and filling with compressive material weaker than the surrounding soil) to below foundation level, without disturbing the foundation; trenches may be covered, if desired, with concrete slabs that do not butt; 3) slotting rigid pavements or floors, and even superstructures (generally wood, brick, or stone do not present difficulties; concrete may); 4) introducing slip planes, especially in new buildings; 5) providing temporary supports and/or strengthening to parts susceptible to damage; support screens, partitions, and ornaments independently of the walls and floor; 6) using tie rods, if it is anticipated that the roof trusses will be pulled out from their seats; however, indiscriminate use of tie rods may needlessly disfigure the building; stress concentrations at tie-rod bearing plates may pull these through the walls; often temporary corbels provide adequate support for trusses; 7) installing pretensioned steel mesh around the exterior walls (this could be dismantled and re-used later); 8) taping windows (especially with metal frames) to avoid flying glass; 9) removing and storing stained glass windows, until subsidence is complete.

*Remedial and Restorative Measures* - Frequently, structures are constructed so as to be readily repaired after subsidence damage. Since a tension wave is usually followed by a compression wave, cracks should not be patched until all movements have stopped. Debris in the fractures should, however, be removed prior to the compression cycle. In low- lying areas, the water table may create difficulties, necessitating the installation of drains and pumps.

#### *6.1.2.2.3 Comprehensive Planning*

Ideally, both surface land use and the mine should be planned with full knowledge of their respective requirements. Deep cuts for highways, railroads, or other structures, or excavations for utility tunnels or basements, may reduce the competent overburden thickness above the old workings, thus inducing subsidence. Such a predicament can be prevented with planning.

For a plan or scheme to be successfully implemented, it is imperative that all parties affected by subsidence fully understand not only what is being accomplished, but also why it is being done in a particular manner. Hence an intensive effort of public education about the topic is required. This should not only be directed towards the general populace, but include mine operating personnel, builders and developers, government officials at all levels, and civic groups.

Four situations have been identified, each requiring a distinct strategy to planning: 1) existing subsidence potential for existing development; 2) existing subsidence potentia for future development; 3) future mining areas for existing development; and 4) future mining area for future development. All these approaches necessitate coordination or control of both the surface and subsurface development.

*Coordination of Surface/Underground Development* - Typical of the principles that should be followed include:1) avoid construction near outcrops or faults; 2) build only specially designed structures over shallow workings; surface effects are magnified as the depth decreases; 3) locate buildings above steeply dipping seams, since the strains induced are reduced; 4) erect communications or other significant structures in unmined or completely subsided areas; 5) alter routes of highways, railroads, canals, and other structures to suit coal conditions (e.g., over want areas or near fault planes); subsequent costs for lowering may be thereby reduced; 6) site linear structures (e.g., canals, railroads) so that they can be uniformly lowered along their entire length; locks may be located over unminable zones, although massive lock structures can be dropped without significant damage; and 7) avoid building important structures near mine boundaries, since coordination with several mine operators and surface land owners is onerous; also boundary pillars may introduce higher stresses.

The above list is not intended to be comprehensive, but indicative of the types of measures that should be incorporated in the plan. Collaboration between the mining companies and surface owners and developers is indispensable for regional or zonal planning, in order to forestall problems.

*Control of Land Use/Development* - Development of land areas overlying mines must be economically justifiable as well as socially and culturally acceptable. This implies that often regional plans should not only be discussed with mine and surface owners, but also be open to public comment prior to adoption. Changes in these plans also deserve an equally deliberate treatment.

Federal, state, regional, county, and local government authorities exercise substantial control over development of land that is potentially liable to damage due to subsidence, through laws and regulations such as: 1) Surface Mining Control and Reclamation Act of 1977 (SMCRA); 2) environmental impact requirements; 3) zoning and subdivision regulations; 4) building provisions (issuance of permits); 5) mining regulations; 6) safety requirements; 7) insurance needs; 8) investigative requirements for public buildings (e.g., Pennsylvania's Act 17 of 1972); 9) special local ordinances; and 10) interagency coordination.

If voluntary cooperation between mine operators and surface land owners/developers is not forthcoming in the near future, it will conceivably be mandated that mine operators prepare plans that depict predicted subsidence locations, extent, trough centers, maximum subsidence, values and directions of tilt, compression and extension zones, and other pertinent data. These plans and reports could then be circulated to building authorities, highway commissions, railroads, water supply and other utility agencies, pipeline operators, and others who may be affected, for comments and suggestions (within strict time limitations). On the other hand, these groups as well as builders/developers will be required to incorporate proper precautions in the design of their respective structures. In extreme cases, construction may be barred from particularly risky areas, and these lands used for parks, forest preserves, and open spaces.

#### 6.1.2.3 Effectiveness of the Techniques

The effectiveness of each technique varies, based on the circumstances under which it is used and the care with which it is performed. Effectiveness values are presented in Table 1, but only to serve as a rough guide as to what might be expected.

**Table 1** *Effectiveness of Techniques*

| Method | Effectiveness (%) |
|---|---|
| MITIGATION AND ABATEMENT | |
| Controlled backfilling | |
| Hydraulic | 90 - 95 |
| Pneumatic | 85 - 95 |
| Remote backfilling | |
| Hydraulic | 85 - 95 |
| Pneumatic | 80 - 90 |
| Grouting | 80 - 100 |
| Excavation and fill replacement | 95 - 100 |
| CONTROL | |
| Changing mining techniques | 60 - 95 |
| Architectural and structural design | 50 - 100 |
| Comprehensive planning | to be determined |

### 6.1.3 SURFACE RECLAMATION
**by M. J. Hrebar and T. J. Toy**

The standards for technology in this context are the goals and objectives driving the reconstruction of the land surface. Several alternatives have been proposed through the years. A first and most basic requirement should be on-site and off-site environmental impact mitigation. The National Academy of Science (Anon., 1974) defines three classes of treatment: *"rehabilitation"* - implies that the land will be returned to a form and productivity in conformity with a prior land use plan including a stable ecological state that does not contribute substantially to environmental deterioration and is consistent with surrounding aesthetic values; *"reclamation"* - implies that

the site is hospitable to organisms that were originally present or others that approximate the original inhabitants; and *"restoration"* - implies that the condition of the site at the time of disturbance will be replicated after the action.

Rehabilitation permits the greatest flexibility in planning and usually results in the least cost. Restoration affords the least flexibility and usually results in the greatest expense. Further, the National Research Council (Anon., 1981) suggests that a basic goal of reclamation should be to ensure that society does not lose important land use opportunities that were available before soil disturbance or that can be generated in the mining/reclamation process. Various specialists indicate that a fundamental intent and obligation of reclamation is to achieve soil stability through runoff and erosion control. This creates interfaces between miners, earth scientists, and the regulatory authorities.

The science of geomorphology focuses upon the character of the earth's land surface with much recent research directed toward the nature, frequency and magnitude of geomorphic processes operating on the surface through time, together with the resultant landforms. Consequently, this discipline can provide powerful assistance in the design and evaluation of reclamation programs (e.g., Toy and Hadley, 1987).

Most geomorphologists agree that under natural conditions, there usually exists a balance, variously described as an equilibrium, quasi-equilibrium, or steady state, between geomorphic processes and landforms. Geomorphic work proceeds at low to moderate rates because there is generally an approximate balance between the forces applied by processes and the resistances of soils and geologic materials. Landforms, and hence the larger landscape, are stable. Here, stability refers to a state in which slight perturbations of the variables defining a geomorphic system within a particular environment, do not lead to a progression toward a new equilibrium or steady state but a return to the previous state. From this perspective, the goal of reclamation is the re-establishment of the steady state.

Within a geomorphic context, three reclamation objectives that require increasing levels of process rate control can be considered: impact mitigation, rate replication, or geomorphic isolation. In the first case, reclamation attempts to reduce on-site process rates to the extent that serious environmental degradation does not occur while the products of processes, commonly sediment, are contained to prevent off-site environmental damage. In the second case, more extensive reclamation efforts are invested in the attempt to create a semblance of congruency between the pre-mining and post-mining process rates; this essentially constitutes the reestablishment of the steady state. In the third case, elaborate reclamation practices are employed to achieve effective geomorphic isolation of toxic material on or within the landscape. Such comprehensive measures are warranted on the basis of health, safety, and environmental protection considerations. These materials must not be exposed and dispersed through the environment by the geomorphic processes of mass-movement, water, wind erosion and transport.

Contrary to public perception, mining industries are governed by a myriad of federal, state, and local laws, regulations, and guidelines that are modified with some periodicity. Regardless of philosophy or economics, these statutes determine the substance of reclamation programs. Thus, the standards for technology can be found, frequently in rather explicit detail, within the pages of these enactments.

Few would contest the notion that pre-disturbance planning is the key to reclamation success. It is during this phase of operations that environmental conditions of the site are inventoried, the physical and chemical properties of the resource are determined, mining methods and equipment are selected, and reclamation programs are formulated. The environmental setting has a profound influence of each aspect of the planning process; certain circumstances, such as alluvial valley floors and wetlands, dramatically affect and may even preclude a mining operation as discussed elsewhere in this handbook.

### 6.1.4 LANDSCAPE RECONSTRUCTION

Once a stable, subsidence-free foundation, is a reasonable expectation, reconstruction of the landscape may proceed. First, it is paramount in importance to realize that landscapes are composed of hierarchies of drainage basins that function as open, process-response systems, governed by process thresholds and negative feedback mechanisms. Inputs of matter and energy (precipitation) cascade through the drainage basin, interacting with morphological features (hillslopes and channels), generating outputs of matter and energy (streamflow and sediment). Drainage basins, in turn, are composed of hillslopes and stream channels that themselves function as open, process-response systems integrating matter and energy cascades with morphological features.

Extensive research has documented and quantified numerous relations among the various components of drainage basins. For example, Melton (1958) contends that drainage systems are in equilibrium when

$$F = 0.694\ D^2 \qquad (6.1.4.1)$$

where F = stream frequency (number of streams/square mile) and D = drainage density (miles of streams/square mile). Strahler (1950) reports the following relation between hillslopes and stream channels:

$$S_g = 4S_c^{0.8} \qquad (6.1.4.2)$$

where $S_g$ = mean maximum hillslope gradient (degrees) and $S_c$ = stream channel gradient (degrees). Relations among geomorphic and hydrologic characteristics of drainage basin, hillslopes and stream channels have been compiled from several investigations in Toy (1984). These analyses make it clear that the reconstruction of stable landscapes requires the creation of both stable hillslopes and stream channels.

#### 6.1.4.1 Hillslopes

Hillslopes are the parts of the landscape between drainage divides and stream channels. In the short-term, hillslope form strongly influences process, but in the long-term, process strongly influences form. For reclaimed hillslopes, form is a function of backfilling and grading practices, and process rates are the consequence.

Successful reclamation requires stable hillslopes. Generally, this infers stability with respect to mass and erosional processes. Under normal circumstances, control of these two groups of processes will effectively control others that may be significant in a particular area. Likewise, effective control of erosion by water will usually provide effective control of erosion by wind. The first step in hillslope reconstruction and reclamation requires highwall reduction and backfilling of the mine pit.

#### 6.1.4.2 Backfilling

Initially in the reclamation process, backfilling must be integrated into the mine plan to ensure a rough landform that facilitates subsequent reclamation and is economical within the overall plan of operation. Rehandle of material should be minimized and required structures (e.g., diversions, drainage patterns, etc.) should be incorporated into the backfill activities. In general, backfilling can begin as soon as adequate operating space and final pit slopes have been established. This often has the effect of minimizing haulage costs as well as rehandle costs. Similarly, placement of initial box cut or prestripping spoils near final highwall may be beneficial and allow minimizing costs associated with subsequent filling of the final pit and eliminating the final highwalls.

Opportunities for efficient backfilling vary depending on topography, deposit geometry, and associated mining method. Backfilling is usually conducted by the primary stripping equipment. In area mining operations, using draglines or stripping shovels for overburden removal, spoil is placed in the adjacent mined-out pit and produces a spoil peak and vee topography suitable for grading. Care must be exercised in planning haul road placement through spoils to facilitate restoration of drainage patterns. A slight horizontal and vertical shift in topography occurs in dragline operations and additional mobile equipment may be required to adjust the surface to conform with the desired reclamation surface configuration. Area mines often use mobile equipment in conjunction with draglines. The mobile equipment (e.g., excavator and truck or scrapers) is utilized to prebench ahead of draglines to carry the prebench overburden to areas where additional spoil is required to raise the topography. In some cases, mobile equipment is utilized after stripping to adjust the rough spoil topography.

In contour and mountain top operations, backfilling is also an integral step in the sequence of operations. Overburden is hauled around the active pit and placed into spoil dumps using off-highway trucks. Use of trucks, with their capability to vary horizontal and vertical transport distance, provides flexibility in controlling spoil topography. As an alternative, large dozers are used as a primary stripping tool in continuous operation, but are more limited in their economic ability to move spoil long distances.

Backfilling in open-pit mines is more problematical, but can be done once final pit slopes have been established, usually late in the life of the project. Because of the great depths and huge quantities of material, rehandle of the external dumps for backfilling is not common practice. Consideration should be given to mine plans that allow development of the initial pit near the final pit slope. The pit can then be sequenced to allow backfilling against the final highwall and reduce the amount of material to be hauled to external dumps. There are economic (e.g., through shorter haul distances), as well as reclamation, benefits associated with such plans.

A major consideration in a backfill plan is identification and handling of toxic materials in the overburden. In this context, these are materials that inhibit plant growth and degrade surface or groundwater (e.g., pyrite in strata above coal). Once identified through the exploration and development drilling programs, these materials must be selectively excavated and placed into spoil above the pit floor, away from highwalls, and below the root zone. The materials may be further isolated from groundwater with clay caps and liners. Techniques utilized to accomplish the selective placement will vary with equipment type. For excavator and truck systems, the toxic materials are isolated on a bench to be selectively loaded and then hauled to the proper elevation in the spoil or external dump via a haul road system at the appropriate elevation. With draglines or stripping shovel systems, the toxic material is excavated and then dumped into spoil by utilizing angle of swing of the excavator to control the location of material in the spoil.

#### 6.1.4.3 External Dumps

External dumps are required for disposal of initial cut,

excess waste, prestripping, or internal waste materials. The dump site chosen must be adequate to provide structural and environmental integrity. The dumps take the form of head-of- hollow, valley, ridge sidehill, or heaped structures. In high dumps, the structure can be built in a series of benches to improve mass stability and decrease earth moving required to establish final grade. Water diversion and drainage structures are built into the structure to limit erosion and contaminant release. The mine waste rock may be utilized for construction of fine processing waste product disposal facilities in cross-valley, sidehill, or diked forms (Zahl et al., 1992). In populated areas, mine waste can be utilized in one of the external dump configurations to form visual barriers to the operation. The dump is usually further reclaimed to blend with the local environment. Bohnet and Kunze (1990) provide additional information concerning dump design and construction.

#### 6.1.4.4 Highwall Reduction

Final slope elimination or reduction can be accomplished in a number of ways depending on availability of backfill material, depth and length of slope, and land use considerations. Where adequate backfill exists, filling and return to original contours are the norm. Filling is common in area, contour, mountain top, and placer operations and utilizes either spoil from adjacent cuts, box cut spoils, material generated in final slope reduction or combinations. When land use and water quality permit, the final pit can be utilized as a water impoundment following reduction of spoil and highwall to stable angles.

When the volume of overburden available for backfill is insufficient, available material must be used for reduction of slopes at the final pit slope. The overburden is placed at the crest of the pit and graded to a stable angle to allow further reclamation. Where there is no overburden available, the final pit slope can be reduced by dozing, blasting, or combinations to produce a final stable slope. To achieve an irregular face on a straight final pit wall, selective blasting can be utilized to create a series of chutes in the highwall with a scree slope created at the bottom of the chute. A series of progressively shallower rows of blast holes parallel to the highwall crest can be used to reduce the highwall angle with the blasted material forming a scree fill on the pit floor below. Blasting can also be employed to control the final pit slopes in deeper multiple bench pits by repeating the blasting process on each of the benches (Norman, 1992).

In deep, multiple bench open pit operations, treatment of final slopes is a major undertaking. Since final slopes are usually in the 45-50 degree range, a low angle (e.g., 20 degree) spoil buttress would require post-mining movement of tremendous quantities of material and in general is not an economic alternative. A second approach involves constructing shallower final pit slopes and leaving wider remnant benches. Access is provided to the remnant benches and further reclamation, such as blasting to reduce bench angle, can be performed on them. If the upper benches are in ore, the economic consequences are not as severe as if the upper benches of the pit are in waste. In the former case, quantities of ore would no doubt be left behind the shallow final pit limit. In the latter case, additional stripping and external dumps would be required to reduce final pit slope angles. Alternative plans must be evaluated to select the most efficient and economic method for each unique situation.

Backfilling costs are primarily a function of stripping equipment type and size, material type, vertical transport distance and horizontal lift. Table 2 shows typical direct costs (i.e., labor, fuel or power, repair, maintenance, and supplies) of material movement.

#### 6.1.4.5 Grading and Shaping

Following most backfill operations, the rough surface is graded to a stable slope. Large dozers are utilized in most applications because of economies of scale. Spoil quantities are large in dragline operations where peak and vee surfaces are generated and somewhat less in excavator/truck operations where flat dumps are created. Motor graders can be used for final grading and construction of special structures but are limited by material size.

Planning of efficient mining and reclamation is aided by the use of computer software. A wide range of integrated commercial packages are available for two and three-dimensional modeling of original surface, overburden, and ore. These packages permit development and evaluation of alternative topsoil removing, stripping, backfilling, mining and reclaiming sequences. The various sequences can be evaluated on the basis of economics, total disturbed area, post- mining topography, etc.. Many of the packages have capabilities to contrast pre-mining and postmining topography in perspective. A catalog of software is presented by Gibbs (1991) in the Directory of Mining Programs.

Waste dump and backfill mass stability is a function of site topography, method of construction, geotechnical parameters of the mine waste and foundation material, and rate of advance of the dump face as discussed in detail by Bohnet and Kunze (1990). A site investigation is required to gather the information and then the stability of various spoil configurations can be analyzed, often using limiting equilibrium analysis. In principle, driving and resisting forces are estimated considering different failure surfaces and spoil shapes. Minimum factors of safety must be satisfied in selection of final spoil configuration (Sweigard, 1992). Generally, practices that minimize erosion rates produce stable hillslopes.

**Table 2** Direct Unit Costs

| Coal equipment/ systems | ($/m³) | Comments |
|---|---|---|
| Walking draglines (23-76+ m³) | 0.23-0.58 | Depends on size, manning, material, and method |
| Crawler draglines (5-12 m³) | 0 98 -1 18 | Depends on size, manning, material, and method |
| Large dozers (574 kW) | 0.14 -0.42 | Depends on material, grade, and distance 41 m @ -5.4% to 61 m @ 15.5% |
| Drilling and blasting | | |
| (17 cm) | 0.18 | Contract, ANFO, 0.24 kg/b m³ 5.2 m x 5.2 m pattern |
| (27 cm) | 0.11 | Contract, ANFO, 0.24 kg/b m³ 7.9 m x 7.9 m pattern |
| Blast casting | | |
| (17 cm) | 0.35 | Contract, ANFO, 60% emulsion, 0.71 kg/b m³, 5.2 m x 5.2 m pattern |
| | 0.43 | Incremental cost @ 39% cast benefit |
| (27 cm) | 0.26 | Contract, ANFO, 60% emulsion, 0.71 kg/b cu. m, 7.9 m x 7.9 m pattern |
| | 0.39 | Incremental cost @ 39% cast benefit |
| Loader/truck (10 m³/4.5 mt) | 0.73 -1.11 | In contour operations |
| Shovel/truck (40 m³/172 mt) | 0.34 | In modified open pit |

| Non-coal open pit* system | ($/mt) | Comments |
|---|---|---|
| >18 million mtpy ore and waste | | |
| Drilling and blasting | 0.055-0.099 | |
| Loading and hauling | 0.253-0.452 | 154-172 mt trucks, 1.1-11.3 km haul |
| 1.8-18 million mtpy ore and waste | | |
| Drilling and blasting | 0.055-0.375 | |
| Loading and hauling | 0.331-0.926 | 45-91 mt trucks, 0.8-8.0 km haul |
| <1.8 million mtpy ore and waste | | |
| Drilling and blasting | 0.165-0.463 | |
| Loading and hauling | 0.474-1.212 | 32-54 mt trucks, 1.6-4.0 km haul |

*After Mutmansky, et. al., 1992

The geomorphic stability of reclaimed hillslopes is determined by the rates of geomorphic processes operating upon them. Process rates are strongly influenced by the forms created during grading and shaping procedures. In reality, hillslopes are three-dimensional surfaces that are sometimes divided into plan form and profile form for convenience of examination. Fig. 4 illustrates various possible three-dimensional configurations. Plan form refers to the shape along the horizontal dimension or width of the hillslope. For example, the plan forms depicted in Fig. 4 show linear plans in the left column, convex plans in the middle column, and concave plans in the right column. Profile form refers to the shape along the vertical dimension or length of the hillslope. Here, the profile forms depicted in Fig. 4 show linear profiles in the upper row, convex profiles in the middle row, and concave profiles in the lower row.

The significance of these shapes rests in their effect upon the direction of surface flow. For hillslopes of linear plan and profile, characteristic of valley-side hillslopes, runoff moves in relatively parallel courses from crest to base. For hillslopes of convex plan and profile, characteristic of divide noses or spur-end hillslopes, runoff tends to diverge as it moves from crest to base. For hillslopes of concave plan and profile,

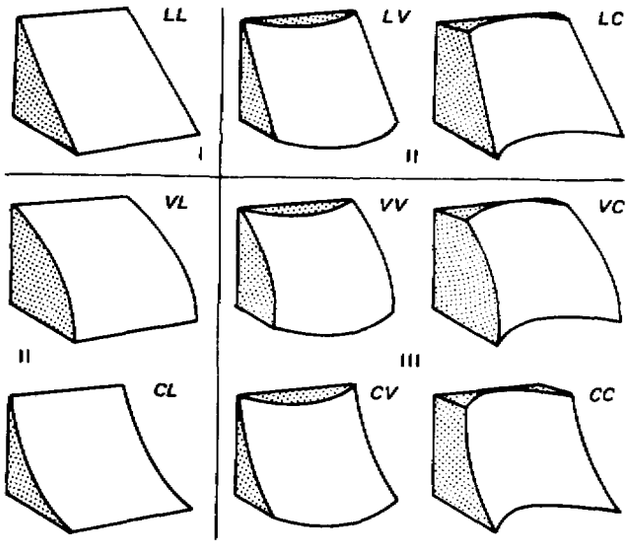



**Figure 4** Three-dimensional hillslope shapes (Ruhe, 1975).

characteristic of hollows or valley-head hillslopes, runoff tends to converge as it moves from crest to base. As a result of divergence on spur-end hillslopes, lesser flows of water and sediment pass successive points downslope than on the straight valley-side hillslopes. As a result of convergence on valley-head hillslopes, greater flows of water and sediment pass successive points downslope than on the straight valley-side hillslopes. Other things being equal,spur-end hillslopes are less susceptible to erosion and, are a preferred configuration while valley-head hillslopes are more susceptible to erosion and, hence, are an undesirable configuration.

Profile properties of gradient, length, and shape have proven to be closely related to erosion rates. Virtually every erosion prediction model includes a hillslope gradient parameter. A review by Hadley et al. (1985) found that polynomial functions best represent the relation between gradient and soil loss although the exponents range from 0.70 to 2.0, depending upon specific research conditions. The slope steepness factor of the Revised Universal Soil Loss Equation (see Equation 6.1.4.7.5) is generated through a variety of equations, depending upon steepness (above or below 9%), slope length (longer or shorter than 4.6 meters), and temperature (thawed or thawing). For example, the appropriate equation for a thawed hillslope, longer than 4.6 m, and steeper than 9% would be:

$$S = 16.8 \sin \theta - 0.50 \qquad (6.1.4.5.3)$$

where S = slope steepness factor and $\theta$ = hillslope gradient (%).

The relation between erosion and hillslope length generally assumes that runoff accumulates in the downslope direction with concomitant increases in the depth and velocity of flow, a condition sometimes referred to as Hortonian overland flow. Again, exponential functions are usually employed to represent the relation between length and soil loss; and again, the exponents vary depending upon research conditions. The slope length factor of RUSLE is estimated by means of the following equation:

$$L = (\lambda \sim /72.6)^m \qquad (6.1.4.5.4)$$

where L = length factor, $\lambda$ = slope length (ft), m = exponent related to the ratio of rill to interrill erosion.

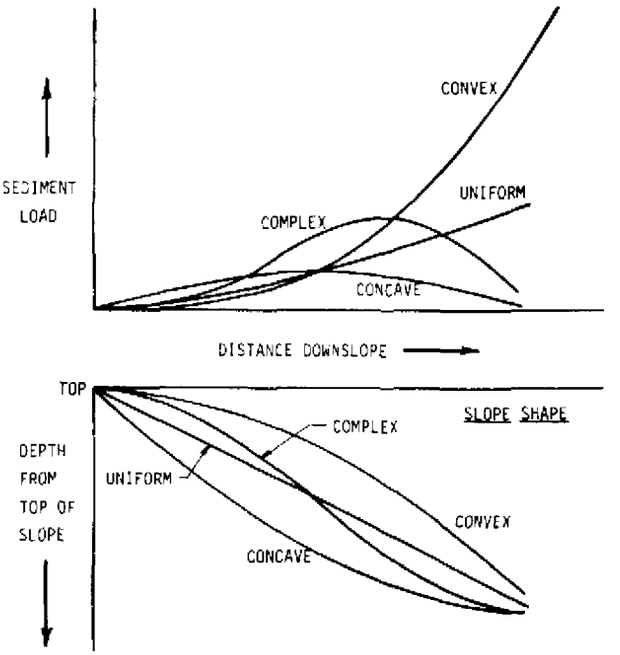



**Figure 5** Influence of hillslope shape on erosion rates.

In addition, hillslope shape also affects erosion rates. Fig. 5 illustrates the influence of convex, uniform, concave, and complex (convexo-concave) profile configurations on soil loss. Here, according to Meyer et al. (1975), erosion at successive points downslope increases gradually for uniform hillslopes. Losses for convex hillslopes are lesser near the top but increase very rapidly toward the end of the hillslope. For concave hillslopes, losses are greater near the top of the slope but decrease along the lower portions to the extent that deposition may occur. For complex hillslopes, with their upper half convex and lower half concave, sediment increases to a point approaching the tow of the hillslope, and thereafter deposition may occur. Elsewhere, Meyer and Romkens (1976) discuss the causes of these tendencies noting that a convex hillslope is more erodible than a uniform hillslope because it is steepest

near the toe where runoff is the greatest. A uniform hillslope will yield more sediment than a concave one because the concave hillslope is steepest where the flow is least and because some of the sediment eroded from the upper portions of the concave hillslope may deposit as it flattens near the toe. A complex hillslope will generally yield less sediment than a uniform hillslope because of deposition on the flat section at the toe of the hillslope.

Some geomorphologists regard the complex, convexo-concave, hillslope profile form as the "equilibrium" form under many environmental conditions. Others suggest that convex, uniform, complex profiles tend to evolve toward concave forms. All considered, the best available evidence suggests that a concave profile form is the best grading and shaping objective, with the complex, uniform, and convex profiles as progressively less desirable.

To summarize, a spur-end hillslope plan with gentle, short, concave profiles should yield the lowest erosion rates. However, it is obvious that a reclaimed landscape cannot be constructed of a single hillslope shape. Nevertheless, the foregoing principles indicate where erosion problems are least likely to occur and where erosion control measures are likely to be especially important.

### 6.1.4.6 Surface Manipulations

After grading and shaping the reclaimed surface, various techniques may be employed in modifying the microtopography in order to enhance erosion control. These practices are referred to as surface manipulations. Their general effects are to increase infiltration rates, conserve soil moisture, and direct runoff. The geomorphic effect is to reduce the force impinging upon the surface by reducing runoff while increasing surface resistance by increasing roughness. Further, the numerous depressions created serve as small sediment traps within the landscape.

Some surface manipulations, such as terracing and the scouring of dozer basins, markedly alter the surface; while others, such as the common agricultural practices of plowing and disking, result in more subtle modifications. Research demonstrates that these techniques significantly reduce runoff and erosion in many environmental settings, at least for a few months or years, often long enough for revegetation to take place.

There are some who advocate surface manipulation subsequent to topsoiling. With this sequence, the techniques will reduce any compaction caused by heavy equipment traffic associated with topsoil spreading. Further, the practices that penetrate deeply, such as ripping, tend to bind the topsoil and spoil materials by mixing across the interface; this may encourage deeper root development.

### 6.1.4.7 Modeling of Erosion

Mathematical models have been used for several decades to estimate erosion rates. Early on, these equations were primarily parts of the development and evaluation of conservation programs for agricultural areas. In recent years, these quantitative techniques have been adapted and applied to a wide variety of environmental problems, encompassing not merely agricultural fields but entire watersheds, over diverse parts of the globe and environmental conditions.

All the while, our knowledge concerning erosion processes has grown dramatically as a consequence of the concerted efforts of numerous earth scientists from many disciplines. Frequently, erosion was the common ground among miner, regulatory authority, and earth scientist.

The Universal Soil Loss Equation (USLE) was the most widely used erosion prediction method. This technology reflected the state-of-the-art at the time, was easily understood, taught, and utilized; the latter attributes doubtlessly contributed to its popularity. However, as the USLE was employed in ways extending far beyond the domain of its development and as new knowledge concerning erosion processes was amassed, the deficiencies of this technology became apparent. Further, by virtue of its empirical nature, periodic modifications to incorporate new knowledge was necessary.

In 1985, at a meeting of U.S. Department of Agriculture and university researchers, it was decided that two concurrent efforts were needed to improve erosion prediction capabilities: 1) revision of the USLE to systematically incorporate advances since 1978, and 2) the development of a new generation of water erosion prediction technology based upon the physical processes that cause and contribute to soil erosion by water. It was intended that the physical process model would eventually replace the empirical model. Both were to be computerized to facilitate and accelerate calculations.

The Revised Universal Soil Loss Equation (RUSLE) retains the original structure of its predecessor, namely:

$$A = R\ K\ LS\ C\ P \qquad (6.1.4.7.5)$$

where A = computed soil loss
R = rainfall-runoff erosivity
K = soil erodibility factor
L = slope length factor
S = slope steepness factor
C = cover-management factor
P = supportive practices

(See Section 6.3.2.1.4, Sedimentology Considerations, for additional discussion.)

Although the basic structure is the same, the algorithms used to calculate the individual factors have

been significantly modified (Renard et al., 1991). The R-factor now includes consideration of ponded water and the combined effects of rain and melting snow on partially frozen soil. The values for western United States are much improved, based upon a substantially expanded data base. The program also contains climate data files for hundreds of locations throughout the conterminous 48 United States plus several stations in Hawaii to expedite calculations.

The K-factor now includes consideration of seasonal variability in soil erodibility and the propensity of soils to rill. Generally, the soil erodibility nomograph is retained; however, guidelines are provided indicating conditions under which nomograph values are likely to be inaccurate. Of particular importance to miners, the program now includes consideration of soils containing high percentages of rock fragments.

The topographic factor (LS) now includes more explicit procedures to accommodate hillslopes with complex profile configurations, as well as short hillslopes. To improve user consistency, guidelines are provided to assist in the selection of appropriate slope length. Four separate slope length relationships are used in the calculations; three are a function of slope steepness and the susceptibility of the soils to rill erosion relative to interrill erosion. A fourth relation is intended for the specifics of partially frozen soils in the small-grain farming areas of the Pacific Northwest. Research has demonstrated that soil loss is much more sensitive to changes in the slope steepness than slope length. A new, nearly linear, equation to assess the slope steepness factor replaces the quadratic relationship used in the USLE.

The C-factor is perhaps the most important because it represents an opportunity to control erosion rates through land management. This parameter is now determined on the basis of sub-factors: 1) prior land use, 2) canopy cover, 3) surface or ground cover, and 4) surface roughness. A fifth term, reflecting soil moisture, is used in the Pacific North west. These components account for below-surface biomass as well as above-surface vegetation.

The P-factor has been re-evaluated with special attention to the consequences of contouring. In addition, the effects of rangeland conservation practices, such as pittings, ripping, and land imprinting are considered. These practices are analogous to some of the surface manipulations mentioned previously.

All in all, the RUSLE differs from its predecessor in numerous ways. Research to date indicates better association between measured soil loss and the estimates obtained through RUSLE than the estimates determined by USLE. More detailed information is available from the USDA-ARS, Aridland Watershed Management Research Unit, 2000 East Allen Road, Tucson, AZ 85719, as well as from local Soil Conservation Service offices.

Advances in hydrology, soil science, erosion mechanics and microcomputer technology have provided the foundation for the development of process-based erosion prediction models (Laflen et al., 1991). In 1985, the U.S.Department of Agriculture organized a team of scientists and initiated the Water Erosion Prediction Project (WEPP) to develop a new generation prediction technology, ultimately intended to replace the USLE and RUSLE for use in conservation and environmental planning and assessment. Other applications include special modeling studies and erosion predictions for design storm investigations.

The WEPP will contain three versions: 1) the hillslope profile version, for variations along the landscape profile, comparable in scale of application to the USLE, 2) the watershed version, to accommodate greater, but limited, spatial variation including concentrated flow channels, such as natural and constructed waterways, and 3) the grid version, to address larger, more complex watersheds with greater spatial variability. The application of WEPP is intended for situations where overland flow and surface runoff prevail. WEPP is intended for applications where "Hortonian overland flow" dominates. WEPP is not intended for undisturbed forests or other areas where partial area runoff or subsurface flow dominate. The technology is designed to be operational on personal computers and operate quickly so that several management/land use alternatives can be quickly evaluated.

In structure, the model includes three fundamental components: climate, hydrology, and erosion. The climate component consists of a weather simulation program and a storm disaggregation procedure. The weather generator provides inputs of daily precipitation, maximum and minimum temperature, solar radiation, wind run, and relative humidity. Rainfall events are described by storm depth, duration, relative time to peak intensity, and the peak rainfall intensity.

The hydrologic component partitions rainfall into runoff and infiltration. Runoff is, in turn, partitioned into interrill and rill components, and routed with surface resistance reflecting roughness and management practices. Water balances provide estimates of soil moisture in the profile to drive infiltration, plant growth, and residue decomposition calculations.

The erosional component considers interrill sediment detachment and transport as well as rill detachment, transport, and deposition. Erosion in the interrill areas is a function of a surface cover parameter, rainfall intensity, and a soil erodibility parameter. Erosion in rills is a function of the difference between the flow's ability to transport detached sediment, transport capacity, and the existing sediment load in the flow.

In operation, the model uses a steady-state sediment continuity equation for predicting interrill and rill

processes. Further information, including the governing equations can be found by writing the National Soil Erosion Research Laboratory, Purdue University, Soil Building, West Lafayette, IN, 47907.

#### 6.1.4.8 Soils and Overburden

Following grading and manipulation of the spoils, topsoiling is the next step in the reclamation process. Topsoil is the key to revegetation, which in the short term is aimed at rapid establishment of a protective cover to prevent accelerated erosion and in the long term at establishing postmining land productivity. Topsoil quantity and type are initially determined by a sampling program and the horizon(s) are excavated and directly distributed or stockpiled for later redistribution onto the prepared reclamation surface. In some cases, overburden material may be substituted for topsoil if the material is more suitable as a plant medium. During the initial prestripping or box cut phases of a mining operation, topsoil will be stockpiled until adequately prepared reclamation surfaces are available. Once the topsoiling operation nears equilibrium, stockpiles are utilized to balance the material flow with material added or removed from the stockpile based on topsoil stripped ahead of mining and demanded on the regraded surfaces.

Reclamation practice often calls for distribution of topsoil in uniform thickness. However, erosional rates tend to be greatest in straight slope segments and least in convex segments while deposition frequently takes place in the basal concave element. Less topsoil could be distributed on the concave and convex slopes and more on the straight slopes. Some of the topsoil on the convex and straight elements will naturally migrate to the concave element (Toy and Hadley, 1987.)

Scrapers are commonly used for topsoil removal and redistribution because of their capability to excavate and distribute material in thin lifts. Where quantities are small, self-loading scrapers, that load independent of other equipment, are employed. Push-pull or push-loaded scrapers are used where quantities warrant. However, because of their relatively high unit costs, other larger equipment, often the primary stripping equipment, are finding increased use. In contour operations and others where distances are short, large dozers are utilized to push topsoil directly uphill into stockpiles beyond the economic limit of mining. Once the pit has progressed beyond a stockpile and the pit is backfilled, the dozer redistributes the topsoil downslope. Where excavator and truck systems are in use, graders or dozers windrow the topsoil for the excavator with the trucks used for topsoil transportation. The truck dumped material is then spread by dozers to the required depths. Careful planning is required to ensure proper topsoil balance and minimum compaction, regardless of equipment selected.

### 6.1.5 CONCLUSION

Under natural conditions, landscapes generally exist in a dynamic equilibrium or steady-state. Here, there is a semblance of balance between the forces produced by geomorphic processes and the resistances provided by souls and geologic materials. Geomorphic work proceeds at low to moderate rates and the landforms are considered stable.

Mining operations create disequilibrium between forces and resistances, processes and forms. Geomorphic work is accelerated toward the goal of re-establishing the equilibrium or steady-state. The rate of work may be a measure of the extent of disequilibrium. The products of this work will be transported off-site unless controlled.

In concept, successful reclamation must re-create the equilibrium or steady-state. In reality, it reduces the extent of disequilibrium because certain surface properties, such as vegetation cover and soil profiles, require varying lengths of time to develop. It is impossible to precisely reconstruct an equilibrium or steady-state. However, geomorphic processes will function to "fine-tune" the system.

In addressing any landscape reconstruction project, it is essential to understand that drainage basins are composed of hillslopes and channels that operate together as open, process-response systems. Disequilibria in one component causes an acceleration of geomorphic work, the consequences of which are propagated to other components. Geomorphologists refer to this as "complex response." One adjustment toward re-creation of equilibrium or steady-state begets another and another, until several waves of change, each somewhat smaller in amplitude, pass through the entire system and an approximate balance of forces and resistances once again prevails.

Finally, it is important to consider the role of extreme events on reclamation success. Extreme events are high energy phenomena with low recurrence intervals, such as the 200-year storm or flood, capable of devastating reclaimed surfaces overnight. Viewed from the perspective of the geologic time scale, these occurrences are not especially unusual and certainly no cause for any allocation of blame for the reclamation failure. However unfortunate, the impacted system will likely require retreatment to achieve the reclamation goals.

## 6.2 BIOLOGIC EFFECTS

### 6.2.1 SEEDING AND PLANTING
**by F. F. Munshower**

Plant growth constitutes the final and most visible phase of land rehabilitation. Vegetation development is brought

about by the introduction of plant propagules onto a disturbed site and the germination, establishment, growth, and reproduction of these seeds or other plant reproductive parts. If any of these phases of plant development is not suc cessful revegetation cannot be said to have taken place.

On any disturbance from a coal surface mine in Montana, to an eroding hillslope in Nepal, to a natural gas pipeline in Eastern Europe a certain sequence of events must take place before plant propagules can be successfully placed in the disturbed soil. The first event is the definition of the post disturbance land use. Adequate revegetation cannot be initiated until this is clarified. Commercial forest, livestock grazing, and parking lots are examples of land uses. In the Great Plains in western North America disturbed sites are almost always returned to livestock grazing and wildlife habitat. In Appalachia with a much greater population density valid land uses cover a wide range of activities including cropland, athletic fields, livestock grazing, commercial forests and many more. Once the question of land use has been answered the other problems facing the reclamation scientist may be addressed.

Before actual seeding or planting can take place on a disturbance the site must be prepared for vegetation. Two activities that must precede revegetation include recontouring and topsoil application. These activities are covered in other parts of this text. If topsoil is not available for application to the site the revegetation activities discussed in this chapter may take place directly in the soil covering the disturbance. However, the probability of rehabilitation success is reduced and plant community succession is slower in the absence of a coversoil.

Revegetation costs are minor compared to the expense of earthmoving, waste reshaping, and topsoiling. Seed, seedbed preparation, and amendments (including fertilizer) generally range from $2,000 to $5,000 per hectare. Specific revegetation projects may cost more but these are disturbances such as tailings ponds or acid generating materials that have high amendment costs. Certain other revegetation practices also introduce greater expense. The cost of erosion control mats, for example, may exceed $20,000 per hectare but these activities are usually practiced on very small scales, e.g., tenths of a hectare.

### 6.2.1.1 Seedbed Preparation/Surface Manipulation

After a disturbance has been recontoured and topsoiled, but prior to actual placement of seed or plants into the soil, plant root zone materials must be manipulated to improve the probability of seed germination and successful plant establishment. On most disturbances the surface soil will need some type of activity to level the seedbed and break up large clods. If the soil is not seeded immediately, it may be necessary to break up a soil crust and/or destroy competitive plants when the site is seeded.

Tillage is the operation of plows, chisels, harrows, discs, or other implements on the seedbed to prepare a soil that is loose enough to permit the rapid penetration of the seed root and infiltration of water yet firm enough to insure close soil-seed contact and support seeding equipment. Ripping and gouging, including the digging of dozer basins, may also be part of the surface manipulative program but they are not normally considered standard agricultural techniques.

Before tilling, soil samples are usually collected from the seedbed for nutrient analyses and determination of amendment needs. If the surface soil is of good quality such tests are unnecessary when native species are seeded. These species evolved in nutrient-poor environments and they will germinate, establish, grow, and reproduce without the addition of fertilizers or amendments if the coversoil was stripped and placed directly on recontoured, nontoxic materials or stored for only a short period of time (less than one growing season). Addition of unnecessary amendments to such sites only contributes to increasing costs of reclamation without a concurrent increase in the quality of the new vegetation. Most revegetation projects and degraded sites without coversoils will require fertilization and organic enrichment to reach satisfactory production levels.

#### *6.2.1.1.1 Standard Farming Techniques*

Plowing breaks up compacted surface soils, mixes amendments with the soil, and kills unwanted vegetation. It is followed by discing to break up large clods. Discing may also be substituted for plowing. The chisel may be substituted for a plow or disk. A chisel can break up a soil crust, incorporate fertilizer and kill shallow rooted weeds. Discing or chiselling are usually followed by harrowing to break up small clods and prepare a final seedbed for drill seeding. If broadcast seeding is to be employed, a rougher seedbed is desirable. Either chiselling or discing may be the final seedbed preparatory activity when broadcast seeding is employed.

#### *6.2.1.1.2 Nontypical Seedbed Preparation*

Ripping or pulling a steel tooth or group of teeth through the soil, subsoil, or overburden is practiced on recontoured sites to break up compacted layers. However, it may also be used on a slope to roughen the surface and destroy any slip page plains that might develop between overburden, subsoil, or surficial soil layers. Ripper teeth may be of almost any length with 40 to 50 cm an adequate length for most uses. Ripping like plowing, chiselling, discing or harrowing should always be practiced on the contour.

Both gouged depressions and dozer basins are widely used in arid or semiarid regions. Gouging is the digging of a series of small depressions across the landscape. Dozer basins are simply large gouged depressions. The purpose of these techniques is to retain moisture on the disturbance and concentrate infiltration in the depressions. Seedling surviv al is enhanced by the augmented water supply in these depressions.

In the coal fields of semiarid western North America gouged depressions are usually 10 to 20 cm deep, less than 90 cm long, and 25 to 40 cm across. This technique or a modification of this technique is used in semiarid to arid regions throughout the world. Dozer basins are made with an attachment to a bulldozer and are much larger than gouged depressions. They may be 1.2 m deep, 2.5 m wide, and up to 6 m long (Dollhopf et al. 1985).

Gouging and dozer basin construction are carried out after topsoiling. The resultant soil surface is very rough and drill seeding is not possible. These sites must be broadcast seeded. Often the sites are so rough they require aerial seeding or hydroseeding. Gouged depressions weather to a smoother topography within 10 years but dozer basins remain quite irregular even after more then 10 years.

First year plant growth is concentrated in the depressions. During subsequent years rhizomatous species or seeds produced by the originally seeded vegetation will develop into plants that fill the intervening spaces. Research has shown that these two techniques increase water availability and decrease erosion on disturbed lands (Dollhopf et al. 1985).

### 6.2.1.2 Seed Mixes

Species lists prepared for seeding should be tailored to the soils, environmental setting, and proposed land use for the degraded site. Simple revegetation with one or two species can be accomplished but resulting plant groups are poor substitutes for complete plant communities. For example, cool-season grasses are the dominant species seeded in the Northern Great Plains of North America but a seed mix composed only of these species will not provide year-round livestock forage nor adequate wildlife browse. Complex, multiple-species seed mixes develop into plant communities that more closely resemble undisturbed plant communities than the simple plant aggregations produced by two or three species seed mixes.

When designing a seed mix the revegetation specialist must decide whether to plant native or introduced species. Native plants are those that have evolved in the area. Introduced plants are those known to have been brought into an area by man. They may be naturalized or exotic. Naturalized plants are those that are well adapted to the area of introduction. Smooth brome and crested wheatgrass are well adapted to the Great Plains but were brought to this area from Eurasia. Both plants survive and reproduce on these plains but are not native to the region. They are considered naturalized. The performance of several saltbush species from Australia on these plains is not known. Their short term performance may be encouraging but long term success is of much greater importance to land revegetation. Until the performance of a species from seed germination to seed dispersal is known it must be considered exotic. That is, of unknown value and/or persistence in the seeded area.

Scientists develop seed mixes to control erosion, provide livestock and/or wildlife forage, and to restore plant communities on degraded soils. To maintain the integrity of the new plant community, post disturbance grass, forb, and shrub species should be matched with similar life forms and species present in the predisturbance plant community. When the predisturbance plant community has been destroyed the revegetation specialist must utilize predisturbance vegetation inventories, adjacent plant communities, or educated judgement to determine what plant species to seed. When seeds for these species are not available substitutions must be made.

Multiple species plant communities meet multiple land uses better than small groups of plant species. Unfortunately, when multiple species seed mixes are utilized a few aggressive species may dominate the landscape. This dominance is exacerbated by lack of variation in micro- and macrohabitat on the degraded site. The diversity inherent in site characteristics on the natural landscape is not found on rehabilitated lands. Without this diversity it is impossible to develop plant communities on degraded soils that support as many species as were found on the site prior to disturbance. Nevertheless, the rehabilitation specialists must produce as diverse a community as possible by manipulating species selection, seed rates, seeding methods, and other techniques available to the revegetation program.

#### *6.2.1.2.1 Plant Species Selection*

The vegetation found on mine areas before disturbance is almost always composed of perennial grass, forb, shrub, or tree species. The vast majority of mined areas will be restored to their previous use after disturbance and rehabilitation, therefore, the seed mix should reflect predisturbance vegetation. The permanent vegetation selected for seeding on a degraded site must be based on at least four factors: 1) life forms expressed in the predisturbance plant community; 2) seed availability; 3) species usefulness for the designated post disturbance land use; and 4) habitat.

Plant species are grouped in life forms such as grasses and "grass likes," forbs, shrubs, and trees. These categories may be further subdivided. Grasses and forbs may be perennial or annual and cool- or warm-season

species. Trees and shrubs may be deciduous or evergreen. Terms such as warm-season perennial grasses, annual forbs, and deciduous trees are used in descriptions of disturbed land vegetation.

The plant community on a reclaimed soil should mimic the species within each life form identified in the predisturbance vegetation inventory. However, it is the rare site at which seed is available for all species identified in this inventory. Within the past twenty-five years Plant Materials Centers and commercial seed houses have developed numerous varieties or cultivars of perennial native grasses, forbs, and shrub species for seeding or planting on disturbed lands. Many of these varieties are commercially available and represent species found in areas to be disturbed by mining, highway construction, pipeline corridors, or other major disturbance.

When selecting the species, cultivar, or variety for seeding a particular disturbance the reclamation scientist must choose the ecotype that is most appropriate for the environmental, physical, and chemical characteristics of the site. For example, the seeds of several cultivars of western wheatgrass are available for use in the Great Plains (Mandan, Rodan, Rosana, etc.). Each of these varieties has slightly different growth requirements. The revegetation specialist must weigh the advantages and disadvantages of each before selecting one for a project. In many cases, however, no cultivar of a desirable species is available. When commercial cultivars of a plant are not available, seed of wild plants is often collected and utilized.

The characteristics of any wild plant population or ecotype are genetically determined and have been carefully selected by the environment in which the population is found. If wild seed is used on a disturbance the seed source should be close to the degraded site for best plant response. Cooper (1956) suggested that an ecotype can perform satisfactorily only if it is seeded at approximately the same elevation, exposure, aspect, and if it is moved no more than 400 to 480 km north or 160 to 240 km south of the point of origin of the plant. East or west movement is comparable to north-south movement depending on changes in elevation, precipitation, soils, and temperature extremes at the origi nal source of the plants and the site to be seeded. Commercial cultivars are genetically selected for specific attributes. They will retain their genetic complement and perform adequately under the limitations originally described for the ecotype regardless of where they are cultivated.

Vegetation seeded on a disturbance should control erosion, promote soil development, and contribute to the attain ment of the land use goal for the disturbance. It should also be adapted to the soils and climatic regime of the region in which it is planted.

Multiple land use goals dominate reclamation programs. Surface coal mines and, to a lesser extent, all mining and large scale surface disturbances face multiple land use goals after rehabilitation. Diverse plant communities meet these goals better than simple mixtures of a few grass and forb species.

Diverse plant communities offer mixed diets and habitat for livestock and wildlife. Forage production tends to be maintained better with a number of species and life forms in the community. The variety of rooting patterns expressed by different plants encourages greater cover and production by utilizing a larger component of the soil water and nutrient supply. More niches are filled by the greater number of adapted species. Diversity is clearly a desirable attribute of new plant communities on degraded lands.

Management is, therefore, confronted with a desire if not a legal requirement to produce a diverse plant community on the post disturbance landscape. All of the species seeded on a disturbance must possess characteristics that enable them to successfully germinate and grow in the texture, pH, salinity, and nutrient levels of the root zone materials. Vegetation must also meet aspect, elevation, precipitation, and temperature limitations of the area.

#### *6.2.1.2.2 Legumes*

These species fix atmospheric nitrogen and help reestablish nutrient cycles. While some other plants and even some Bluegreen algae fix nitrogen, no plants are as universally cultivated and fix nitrogen in the quantities produced by agronomic legumes. These nitrogen fixers are included in almost every seed mix. The nitrogen contribution of legumes is a result of the ability of these plants to form symbiotic relationships with bacteria. These microorganisms live in nodules on the roots of nitrogen fixing plants. Different legumes form these relationships with different species of bacteria. To ensure the presence of the bacteria in the vicinity of the legume root, seed of these species should be inocu lated with the appropriate bacteria prior to seeding.

The best nitrogen fixers are introduced agronomic species. Plants such as alfalfa, the lespedezas, or some of the introduced clovers are found in almost every seeding on large scale disturbances. While these legumes help reestablish nitrogen cycling on degraded landscapes they should not be considered substitutes for native species.

#### *6.2.1.2.3 Temporary Stabilizing Species*

Perennial native plants are slow to develop. During the first growing season they need protection from sun, wind, and high temperatures. In the natural environment, a group of plant species referred to as pioneers provide this protection for the slower growing perennial vegetation. Unfortunately, pioneer species are not

desirable plants for degraded sites. These species are weedy and tend to reproduce themselves to the detriment of the seeded perennial vegetation. A group of plants called nurse crops or companion crops have been seeded to provide the protection for perennial species that was provided by pioneer species in the natural habitat.

Temporary stabilizing species, companion crops, or nurse crops should be short-lived annuals or biennials. They should germinate, establish, and grow rapidly both above and below ground. Dead plant parts that persist through the second growing season continue to provide benefits to the site. They hold snow on site, protect the soil surface from the erosive force of high winds, provide avenues for water movement into the soil, and lower the surface soil tempera ture. Grains and seed-sterile hybrids such as Regreen are commonly used as nurse crops.

Soil disturbances are often the site of germination and development for many noxious weed species. Rapid revegetation is essential to retard the growth of weeds on these sites. Perennial grasses germinate and develop too slowly to control weedy species. Temporary stabilizing species provide protection from weedy species invasion while they also protect perennial vegetation from environmental extremes.

When companion crops are seeded with perennial vegetation they help control water and wind erosion, weed or annual grass development, lower soil surface temperatures, increase infiltration and reduce water loss from the soil surface. While perennial grass germination and establishment are increased because of the protection from the extreme climatic conditions provided by the nurse crop, grass growth is reduced because of competition for moisture. During the second growing season, however, the nurse crop will not regenerate and the perennial vegetation will be released from this competition. Perennial plant growth is enhanced in this second and subsequent growing seasons because of the better establishment made possible by the protection of the nurse crop.

As a general rule nurse crops should not be used where annual precipitation is less than 30 cm. Slower growing perennials are reduced in numbers and vigor in the first growing season due to the moisture deficit created by the companion crop in these regions.

#### *6.2.1.2.4 Seed Rates*

The total seed rate is the sum of all species seed rates. Each species seed rate should be based on the weight of Pure Live Seed (PLS) per unit area. Pure Live Seed may be calculated from information on the certification on the container of seed. Certification describes the seed contents with the following percentages: 1) germination on a specified date; 2) content of other seed; and 3) nonseed waste material (trash).

Certification is the purchasers only guarantee of the quality of the seed. Certified PLS is determined from the equation:

$$\% \text{ PLS} = (\% \text{ Germination})(\%\text{Purity})/100 \qquad (6.2.1.2.4.6)$$

where:

PLS = Pure Live Seed
Germination = percentage of seeds in a unit weight that are viable
Purity = 100 - (% trash + % weed seed)

Variable seed rates are often recommended in texts. These different rates occur because multiple species seed rates are often calculated from seed rates expressed on an as-received basis and not on PLS or by using seeding rates for seed mixes based on suggestions for monoculture seedings. Species-specific seed rates should be based on the number of plants desired in an area (i.e., square meter), expected field emergence, and weight of live seed.

The Soil Conservation Service recommended 20 PLS/0.09m$^2$ (20 PLS/ft$^2$) on drill seeded soils of the Great Plains (Thornburg, 1982). For small seeded grasses and forbs, field emergence is assumed to be around 52% when germination is above 80% and 33% if germination is between 60% and 80% (Seamands and Powell, no date). Twenty pure live seeds/0.09 m$^2$ with an expected field emergence of 50% will produce approximately ten plants in the seeded area. On favorable seed beds this seed rate may be lowered because a greater number of seeds will establish. Harsh sites should receive higher seed rates because more seeds die before they establish.

An important factor influencing seed rates is competition between seeded and weedy species. The number of plants establishing on a site must be sufficient to inhibit the development of weeds. While the number of seeds drilled on favorable sites may be reduced below 20 seeds/0.09 m$^2$, it must not be reduced below the number needed to exclude undesirable plants from the site. The number of seeds necessary to exclude weedy species from a seed bed must be determined experimentally at each disturbance. In the absence of experimental evidence to suggest otherwise the recom mendation of 20 PLS/0.09 m$^2$ should be used as a general guide for drill seeding on prepared seedbeds.

The competitive ability of each species should also be evaluated to determine seed rates. Grasses are more compet itive than forbs, forbs are more competitive than shrubs, and shrubs are more competitive than trees. The naturalized grass species are usually more aggressive than native species. Among native species on the Northern Great Plains, cool- season grasses are more competitive than warm-season grasses. The seed rates for the more competitive and aggressive species should be lowered and the rates for slower responding species increased to meet

final standards of plant community composition.

### 6.2.1.3 Seeding Techniques

The objective of seeding is to place the seed in a soil environment most favorable for its successful establishment. In general, species with smaller seeds establish better when placed at a shallower depth in the soil. Larger seeds may be seeded deeper in the profile. Because of different germination requirements, the best conditions for all plants cannot be met by any single seeding technique. An average set of conditions is usually met by the final seeding process.

#### *6.2.1.3.1 Drill Seeding*

Drill seeders are implements that place seed at a specific depth in the soil. A furrow is opened to a predetermined depth in the seedbed, seeds are metered from a box, fall through a tube into the furrow, and a wheel or another instrument pushes dirt over the seeds. The final step in this process incorporates a soil compacting device (cultipacker) to roll over the soil and firm the seed bed. Drill seeding is the better seed dispersal mechanism when seedbeds are smooth and all seeded species require placement at a uniform depth.

Location of the seed in the soil profile should optimize its potential for contact with water. Planting depth will vary with soil water holding capacity, soil texture, site exposure, aspect, and other characteristics that influence soil moisture. Drills should be set deeper in light sandy soils or on sunny south or southwest aspects. On north or northeast facing slopes, in moist areas, or in finer-textured soils seeds may be placed closer to the soil surface. Seed companies, the Soil Conservation Service, and local county agents should be consulted for seeding depth recommendations in different areas.

Drill seeders have several disadvantages. Seeds of different sizes separate in the seed boxes because of the vibrations produced as the drill moves over the seed bed. Smaller seeds fall from the box faster than larger seeds and cause changes in the proportion of seeded plants across the landscape. Drill seeded plants also resemble a crop rather than a native plant community, because they germinate in rows. Fuzzy or hairy seeds or seeds with long awns also create problems in drill seeders. These seeds tend to stick together, clog the seed tubes, and impede the fall of single seeds from the seed boxes. The segregation and clumping of seeds can be overcome by addition of a carrier to the seed mix or by segregation of seeds into separate boxes on the basis of their size. Since each seed box drops seed into a different row this latter technique creates a plant community consisting of rows of different plant species. The seeding resembles a crop even more than most drill seeded plant communities.

Drill seeding is more expensive and permits seeding at only a limited number of different depths, but it ensures close soil-seed contact, a firm bed over the seed, and maximizes the probability of successful germination and plant establish ment.

#### *6.2.1.3.2 Broadcast Seeding*

Broadcast seeding implements range from aircraft to devices that indiscriminately drop seed to the soil surface. There are also complex broadcast seeders that combine some attributes of drill seeders with the broadcasting of seeds on the soil surface. When seed is dropped to the soil surface and not placed in the soil, some sort of device (e.g., chain or log) must be dragged over the site to push seed into cracks and crevices in the soil. Broadcast seeding should be followed by rollers or cultipackers to press the seed into the soil to provide good soil-seed contact. This technique provides the opportunity for seed to fall into shallow or deep soil cracks or voids. These variable depths are necessary with multiple seed sizes. Broadcast seeding is the preferred seeding method for small seeded species.

Many seeds that have been broadcast, germinate on or near the soil surface. The ensuing embryonic plant often desiccates before the root can absorb sufficient water to maintain the plant. Other seeds never germinate because they are consumed by seed eating rodents or birds. To compensate for these losses a doubling of drill seed rates is normal for broadcast seeding. The recommendation of 20 PLS/0.09 $m^2$ increases to 40 PLS/0.09 $m^2$ on broadcast seeded soils.

Hydroseeding is a form of broadcast seeding in which the seeds are dispersed in a liquid. Seeds should not be included with hydromulch because many of them will be suspended above the soil as the hydromulch dries. However, hydromulch may be applied over hydroseeded sites. Hydroseeding is very effective on steep or rough textured materials that cannot be drill seeded (e.g., waste rock, roadcuts).

Aerial seeding, another form of broadcast seeding, is the dispersal of seed by aircraft. Good ground cover can be attained with this form of seed distribution. Aerial seeding overcomes the problems of site accessibility, permits the operator to cover large areas very rapidly, and does not require the construction of access roads. If seed rates and climatic conditions are carefully evaluated, large amounts of seed (and amendments) may be distributed rapidly and without damage to existing vegetation on the site. Aerial seeding is effective on very rough, inaccessible terrain after fires or other disasters, but seed rates must be heavier than normal broadcast rates.

### 6.2.1.4 Season of Seeding

Seeding should take place immediately prior to the period

of maximum precipitation. In most areas of North America this season is early spring but in many places it may be summer or fall. Early spring or fall seedings are most common.

Dormant fall seedings are the most common form of fall seedings. Seed is placed in the ground as late in the season as possible so that it cannot germinate immediately, but is ready to germinate with the first precipitation and warm temperatures of spring. The two disadvantages of fall seedings are the loss of seed to desiccation and depredation during the long dormant period and the germination of weeds with the seeded vegetation.

Spring seedings avoid the vicissitudes of winter. Cultivation, usually required before spring seedings, destroys any weeds that may have germinated. Spring seedings are generally more productive during the first few growing seasons than fall seedings. This greater production may be the result of a loss of seeds on fall seeded sites and/or the destruction of competitive weeds on spring seeded sites.

Unpredictable spring weather makes seeding during this season difficult. Seedings are often postponed because of inclement weather and equipment and machinery may not be available when needed. If the seed is not in the ground when it rains it may be impossible to plant until after the spring rains in which case the impetus to germination and establishment provided by spring precipitation is lost.

### 6.2.1.5 Planting

Seeds of certain long lived shrubs or trees establish very poorly, or reveal slow growth rates in the natural environment. For these species, transplanting whole plants or plant parts may be the only method to ensure the development of mature plants. However, this practice requires use of relatively expensive nursery stock and is labor intensive.

If transplanting takes place into an established plant community, living plants of more competitive species (i.e., grasses) should be removed from the area directly adjacent to the transplant. This scalping removes direct root competition from the newly placed plant and improves the probability of successful establishment and growth (Sloan and Ryker, 1986). Scalping may consist of physical or chemical (herbicide) control of plant competition.

#### *6.2.1.5.1 Whole Plants*

These transplants may be bareroot plants, container-grown stock, or wildings. Both bareroot stock and containerized stock are grown for a predetermined time in protected environments. When they reach the end of their protected growth period, they are hardened. Hardening is a process by which plant physiological activity is inhibited by exposing the plant to reduced moisture, poor nutrient supply, low temperatures, decreased day length and increased wind. Or simply, hardening is the process of inducing dormancy in protected vegetation by exposing it to ambient conditions the plants are likely to experience at the planting site. After hardening, bareroot plants may be removed from the root medium and stems and roots trimmed. The plants must now be maintained in a cool, dark, moist environment until transplanted. Hardened or dormant plants are more likely to survive handling and transplanting than actively growing plants.

Containerized stock include plants grown in any size root container. These root holders range from individual pots or tubes to multiple-unit packets (from 4 or 6 to over 100 individual plants in separate cells in a single packet). Biode gradable containers (e.g., peat, cardboard, cloth) are placed in the ground when transplanting occurs. Plants are removed from nonbiodegradable containers before being placed in the ground. Plants grown in containers are encouraged to grow rapidly. They are usually thin and stringy, but root hairs and growing tips of roots are protected by the container. These plants have less transplant shock immediately after planting and develop roots in the new rooting media faster than bareroot stock or wildings.

Wildings are trees or shrubs dug from their natural setting and transplanted to degraded landscapes near their site of growth. The mechanized tree space has been widely used to transplant wildings. The use of this instrument has been successful when woody plant of the proper size are moved. The root to shoot (above ground plant part) ratio should be kept greater than one to ensure maximum survival of transplanted wildings. The tree spade is rarely used in large scale revegetation projects, however, because it is slow and costly.

Wildings, bareroot, and containerized stock are expensive and receive attention only for critical or intensive-use areas. To reduce costs several types of tractor powered mechanical tree or shrub planters have been developed. These devices are much faster than transplanting by hand and are common on large disturbances.

Bareroot shrubs and trees are light and delivered in easy to handle bundles. These plants are usually larger and older than container-grown stock. Because of their age and growth in open areas they have tough woody stems and roots, and have the protection afforded by a thick bark. However, the roots of bareroot stock may dry out enough to kill the plant in only a few minutes in a warm breezy environment if the plants are not completely dormant. Container grown plants need not be hardened, they continue growing when they are placed in the soil. Since bareroot plants are usually more mature than containerized stock, they are more likely to survive the vicissitudes of wind, temperature extremes, insect

depredation, and rodent attack after they become established. Shrubs or trees in containers are normally trans planted as smaller plants than bareroot stock and, therefore, per plant and transplanting costs are lower for container grown than for bareroot stock. While many large scale attempts to establish woody plant communities use bareroot stock rather than containerized stock both transplanting methods are used in land rehabilitation programs.

#### *6.2.1.5.2 Plant Parts*

Cuttings, root pads, and sprigging are techniques developed for the rapid establishment of shrubs or some small trees. Cuttings consist of woody stems or pieces of roots. Any shrub or tree that reproduces from rhizomes, root sprouts, or adventitious stems and many other woody plants that reproduce by none of these techniques may be propagated by cuttings. Willows (*Salix* spp.) are a common example of this type of plant. This technique is relatively inexpensive and used for the rapid proliferation of large numbers of plants.

Both root pads and sprigging are used to establish clumps of shrubs rather than individual plants. Shrub stands may be of any shape, and diameters may measure up to several meters. Shrubs to be transplanted are trimmed to a few centimeters height before initiating either transplanting practice. The root pad includes root segments and the accompanying soil. This pad is set into a prepared location on a disturbed landscape. It is anchored with soil or simply compacted in place. Sprigs are root segments removed from the soil. Only roots and sprouts are moved from the undis turbed location to the planting site. Sprigs must be covered with sand or topsoil and lightly compacted. Thicket forming shrubs such as snowberry, some wild roses, and raspberry lend themselves to sprigging or root pad construction.

#### *6.2.1.5.3 Special Planting Techniques*

Planting should be carried out during the fall immediately prior to freeze up or very early in the spring before the period of maximum precipitation. If transplants are not placed in the ground during these periods a major proportion of the new plants may be lost. To avoid this loss, condensation traps and gel-forming, water absorbing polymers have been used.

Condensation traps consist of a plastic shield or cone surrounding the base of a transplanted shrub or tree. The shield should be at least 1.2 m in diameter, airtight, sloped at a minimum of 25°, and form an airspace between the soil and the surface of the plastic (Jensen and Hodder, 1979). Afternoon sun heats the soil under the shield and vaporizes soil moisture. Water that vaporizes under the shield condenses on the cooler plastic and runs down the sheet to the base of the plant irrigating the transplant. This technique improves the survival of dryland plantings of shrubs or trees, but is labor intensive and expensive.

Gels are organic polymers that are capable of absorbing and retaining large quantities of water. Small amounts of the polymer are inserted into the hole dug to receive the transplant or the plant roots may be dipped in the material. The plant is placed in the hole and dirt is placed over the roots as if the polymer were not present. During precipitation events or irrigation the polymer absorbs and retains water. This water is available to plant roots at some later time. Plant survival is often enhanced by this practice, but it increases the cost of the transplants.

### 6.2.2 AMENDMENTS

Any additions to soils or overburden before or shortly after seeding are included in the category of "amendments." In general, amendments are added to correct soil or site inadequacies. They change the soil or the near-soil surface environment by modifying macro- or micronutrient concentrations, organic matter contents, pH, plant inhibitory salt levels, hydrologic properties, erosion, and temperatures at the soil surface.

#### 6.2.2.1 Fertilizers

Deficiencies of nitrogen, phosphorus and potassium are a common attribute of degraded soils. But, when endemic species are seeded on degraded sites that have been topsoiled fertilizers are rarely needed. When topsoil is not available, in mesic regions, and when agronomic species (pasture grasses and legumes) are seeded fertilization is necessary to insure adequate growth.

#### *6.2.2.1.1 Nitrogen Fertilization*

Application rates for this element should be based on soil analyses, but nitrogen analyses of disturbed soils are very unreliable and hard to interpret. Nitrogen additions should be adjusted to meet the demands of the particular soil and species being seeded, but will depend upon organic matter content of the soil (Table 3). Most plant nitrogen needs are met by releases of this element by the decomposition of organic matter in the soil.

**Table 3** Generalized Organic Matter Content of Soils

| Rank | Percent |
|---|---|
| Low | <1.5 |
| Medium | 1.5-3.5 |
| High | > 3.5 |

Since nitrogen fertilizer requirements of native species are so much lower than the nitrogen needs of various agronomic species, crop nitrogen recommendations should not be referenced for nitrogen application rates for native vegetation seedings. Native perennial grasses evolved in nutrient deficient environments and can usually meet their nitrogen requirements from the decomposition of soil-organic matter alone. Most researchers do not recommend the addition of nitrogen to native grasslands when the soil-organic-matter content exceeds 2% (Soltanpour et al., 1985). Research in Montana and Colorado supports the hypothesis that fertilizer amendment of minesoils in the semiarid west produces little or no beneficial effect on plant performance (DePuit and Coenenberg, 1979, Rennick et al., 1984).

When topsoil is not available for application to a disturbed site and in mineral soils nitrogen fertilization is necessary. However, the addition of organic matter in the form of green manure, compost, livestock manure, or other nitrogen rich organic material should be the first step in the reestablishment of a nitrogen cycle in the revegetation program. Nitrogen need only be added in small quantities (around 25 kg/ha or less) when these types of organic amendments are added to the disturbed site.

#### *6.2.2.1.2 Phosphorus Fertilization*

Amendment with this element should be based upon soil phosphorus analyses, but like nitrogen, the major soil phosphate reserve is in the organic fraction of the soil and plant-available soil phosphorus is hard to measure. Soil phosphorus is adequate for most native plant species if soil organic matter is above 2%; however, phosphorus deficiency symptoms are frequently encountered in vegetation growing on disturbed soils from mesic regions, on hard rock wastes, and on acid soils.

Legumes, so essential to the nitrogen cycle, require relatively large amounts of soil phosphorus and may be inhibited by deficiencies of this element. If the post disturbance land use is legume hay, phosphorus fertilization will be necessary for the production of an adequate crop.

Perennial grasses showed little response to minesoil phosphorus fertilization in the Great Plains of North America (Rennick et al., 1984). Amendment of direct hauled topsoil with this nutrient produced little growth enhancement and adverse impacts on diversity (Hertzog, 1983). Only the less desirable species such as annual grasses and weedy forbs revealed positive responses to phosphorus. The use of this fertilizer on degraded soils must be carefully evaluated and amendment undertaken only when nutrient concentrations and soil organic contents are low.

#### *6.2.2.1.3 Potassium Fertilization*

Young soils usually reveal concentrations of this element in the medium to high range. Potassium amendment of disturbed or intact western North American soils has produced little or no measurable effect in numerous experiments (Hertzog, 1983, Rennick et al., 1984). Topsoiled minesoils of the Great Plains are not usually amended with this element. On disturbances in the eastern part of the continent, in the western mountains, and in the rehabilitation of mill or smelter wastes potassium amendment is often necessary.

### 6.2.2.2 Mulches and Organic Amendments

Mulches are organic materials applied to the surface of a disturbance. They include substances such as paper, wood resi dues, straw, native hay, manure, compost, and sewage sludge. When these materials are incorporated into the soil, they are technically not mulches but organic amendments. Organic amendments increase the organic matter content, infil tration rate, and cation exchange capacity of the soil. They improve soil structure and contribute nutrients to the soil system. Mulches, on the other hand, decrease soil erosion by reducing wind velocities at the soil surface. They shield the soil from raindrop impact, reduce evaporation of water from the soil, trap small soil particles on the site, reduce surface soil temperatures, and help prevent soil crusting. They have only a limited impact on soil structure and the reestablishment of soil-plant nutrient cycles.

The most common mulches are straw or native hay. Their effectiveness is strongly influenced by the length of the stems. The longer stemmed mulches are most beneficial and their benefits last longer (Kill and Foote, 1971, Kay, 1978).

Mulches are applied after seeding by a number of methods. These include hand scattering, manure spreaders, mechanical dry blowers, and hydromulchers. Modified manure spreaders are used on many small flat disturbances, hydromulchers on larger disturbances or slopes, and dry blowers on only the largest disturbed areas. Dry blowers are expensive but can distribute very large quantities of mulch very rapidly. Hydromulchers are the most widespread economical method of dispensing mulch over slopes or flat areas.

Surface mulch applications are lost to wind or overland water flows. To stop or inhibit their removal mulches are held on the site by crimping, tackifiers, or netting. Crimping uses some sort of mechanical disc or wheel to push part of the mulch 5.0 to 7.5 cm into the seedbed. However, this implies that the mulch is rather long and composed of material such as straw. Straw and crimpers may be used on slopes to the limits imposed by

safe operation of wheeled vehicles on the contour, approximately 3H:1V to 2.5H:1V.

Hydromulchers mix fibers with a fluid and permit the operator to spray the mixture onto the site. The liquid is typically a combination of water and some type of organic glue-like substance called a tackifier. This material binds the mulch particles together and to the surface of the soil. It is the ability of the hydromulch machines to disperse mulch and a binding agent (tackifier) simultaneously that contributes to the economy of operation of these machines in large scale operations. Fibers used in hydromulches must be very small (1 to 2 cm) to pass through the equipment and application nozzle. This reduces the effectiveness and longevity of these materials. Nevertheless, when erosion is a potential problem hydromulches and tackifiers are applied on the vast majority of slopes. They have been successfully used on slopes as steep as 2H:1V.

Netting is also used to hold mulch on a site, but it is labor intensive and is only placed on the most erosion prone areas. Nets have been used in alpine areas where wind erosion potential is high (Theisen, 1988) and on very steep slopes (steeper than 3H:1V) (Proteau, 1988). Netting is the most effective method of holding mulches on a slope, but it is expensive.

The organic amendments sewage sludge, compost, and manure provide a ready source of carbon and nitrogen for microorganisms and nitrogen for higher plants. Other organic amendments such as wood products, paper, and straw contain small quantities of nitrogen. Carbon-nitrogen ratios for typical mulches include sawdust 350:1, wheat straw 150:1, mixed grasses 19:1, cow manure 18:1, and raw sewage sludge 11:1 (Golueke, 1977). When low nitrogen organic amendments are added to a degraded soil, the increased biological activity consumes a major portion of the available nitrogen in the zone of mulch incorporation. Under these conditions, nitrogen becomes limiting to further growth of microorganisms as well as higher plants and must be added to the soil. As a general rule, amendments sufficient to maintain a C:N ratio between 12:1 and 20:1 are satisfactory. Amendments with ratios from 20:1 to 30:1 indicate that nitrogen will become limiting to plant growth as microorganisms reproduce and consume all of the nitrogen in the soil. At C:N ratios above 30:1, nitrogen is limiting to higher plant growth and to microorganisms.

If topsoil is stripped from a disturbed site and not placed in storage but directly deposited on another site, supplemental organic material is rarely needed. The decomposition of organic matter while topsoil is in storage has been documented (Ross and Cairns, 1981, Elliott and Veness, 1985). The addition of some form of organic material and nitrogen fertilizer to such topsoil is necessary to ensure adequate plant development. Subsoil and spoil used as topsoil substitutes must also receive some form of organic amendment and nitrogen.

#### *6.2.2.2.1 Paper*

Paper is one of the cheapest of the mulches. It is usually composed of recycled material and fibers are very short (< 2 cm). It is commonly applied at rates of 1700 Kg/h or more. Paper is light, decomposes very rapidly, and even when applied with a tackifier particles tend to detach and blow or float away. Newer emulsions hold paper fibers on site better than older tackifiers and these newer materials receive widespread application on mild slopes (e.g., approximately 3H:1V). Paper is not as effective reducing surface temperature or soil moisture loss as straw or wood residues.

#### *6.2.2.2.2 Wood Residues*

Woodchips and fibers are commonly used as both mulch and organic matter but sawdust should not be used because of its rapid breakdown and extremely high C:N ratio. Wood products are applied at rates of 1700 Kg/h or more with a tackifier or they are incorporated as an organic amendment. Slopes mulched with wood residues have increased seedling establishment and reduced soil erosion. As an organic amendment, the benefits of wood residues are somewhat reduced by their rapid digestion by microbes. Carbon-nitrogen ratios in wood products are very high and nitrogen fertil ization is usually required with this type of amendment. Chips are the most commonly used form of wood residue and are vastly superior to sawdust or paper. They may be applied with any of the mechanical mulching devices or dry mulchers. If applied as hydromulch, the particles must be ground to an appropriate size thereby decreasing their effec tiveness, but this mulch may be stabilized with a tackifier. When woodchips are applied as an organic amendment, they must be mixed into the soil or soil substitute.

#### *6.2.2.2.3 Straw*

Straw is primarily composed of the stems of cereal grains such as wheat, barley, or oats. Application rates for loose straw are 1.0 to 4.5 mt/h (Meyer et al., 1975, Thornburg, 1982) depending upon slope, soil, and other site specific characteristics. Straw contains almost no nitrogen, so fertilization is necessary with this amendment. It is held on site by either crimping or a tackifier and provides an excellent means of reducing surface water velocity and soil erosion, increasing infiltration rates, and decreasing surface runoff and soil temperature.

Although straw has numerous benefits, when used as a surface mulch, it decomposes even more rapidly than wood products. The stems used in a straw mulch must be as long as possible to prolong the life of the mulch and

provide maximum benefits from its application. The stems of cereal grains are one of the better all around surface mulches available today. They are inexpensive, readily available, easily affixed to the soil, and perform satisfactorily on slopes up to 3H:1V.

After it has been crimped or attached to the soil surface with a tackifier, straw acts like stubble; it shades the ground, breaks the force of wind or rain, and funnels precipitation into the soil. Crimping is the cheapest and easiest method to hold a mulch in place on small areas on slopes of 3H:1V or less. But straw may be hydromulched with a tackifier much more rapidly and will perform adequately on areas of equal or slightly steeper gradient.

The main disadvantages of straw mulches are the short life of the stems and the seed of the parent crop contained in the straw. When straw is crimped into a site, a nurse crop of the mulch species is inadvertently seeded. However, cereal grain crops rarely persist from one year to the next and the nurse crop seeded when the straw was applied is short lived.

#### *6.2.2.2.4 Native Hay*

The main advantages of native hay mulches compared to cereal grain straw are longer and stronger stems in the native hay and seeds of native plants rather than cereal grains. If properly cut, native hay contains seeds that are beneficial to the development of a diverse plant community on a disturbance. Viable seeds not commonly available commercially may be collected and distributed as native hay mulches (Darling, 1983), but the seeds of undesirable plants may also be distributed in this material. Care must be exercised in the cutting and collection of native hay mulches to exclude undesirable plant species.

This mulch also requires less amendment with fertilizer than most other similar mulches. Native hay should be distributed with a modified manure spreader or specialized hay spreader. It should not be ground to pass through the dry blower or hydromulcher. In general, native hay mulches reveal the same advantages as straw and are applied at similar rates.

#### *6.2.2.2.5 Erosion Control Blankets*

Any type of organic material (e.g., straw, wood fibers (excelsior), coconut fiber, burlap, hemp) woven together or held in place by some woven material is called a mat, or erosion control blanket. They are designed to prevent erosion and stabilize soil on steep slopes. The most common form consists of a woven core of straw surrounded by two layers of plastic netting. Variable amounts of straw or different types of materials may be used for different slopes, flow rates, soil materials, erosion potential, or post disturbance land use.

Seeds are placed in or on the ground under the mat or impregnated into the mat. In either case, seeds germinate and plant stems elongate and penetrate through and above the mat. Mats require close soil contact to guarantee plant growth through the material. They are, therefore, securely attached to the seed bed with large staples and all edges buried. If wind gets under the fabric, it destroys soil-mat contact and any seeds or seedlings under the mat die. The effectiveness of the erosion control blanket is dependent on vegetation germinating under the mat and growing through it. A mat gradually loses its ability to control sediment loss as it decomposes, but it is replaced by living plants which continue the soil stabilization initiated by the erosion control blanket.

The cost of erosion control blankets prohibits their use on most disturbed sites. Their costs range up to many thousands of dollars per hectare, but erosion reduction will range up to 90% of soil loss on unprotected soils (Kay, 1984). Mats have been successfully used on steep slopes (steeper than 2.5H:1V) and erosion prone soils throughout the world.

#### *6.2.2.2.6 Manure*

Livestock waste material is one of the more complete organic additives that may be applied to a disturbed soil. When available in adequate quantities, manure provides a valuable source of soil organic matter and nutrients. Typically, it is distributed with a manure spreader and incorporated into the soil with a moldboard plow. Manure may be composted or fresh. In either example, it decomposes and provides both carbon and nitrogen to the soil. The desirable C:N ratio (between 20:1 and 12:1) increases its benefit to soil microorganisms and higher plants.

#### *6.2.2.2.7 Green Manure*

This technique is used on disturbed lands to improve soil structure while providing immediate vegetation cover to the surface soils and inhibiting the development of weedy species. It consists of the growth of plants and their subsequent plowing into the soil. Legumes are favored for this purpose when soils are nutrient deficient because they are nitrogen fixers and contribute nitrogen-rich-organic matter to the soil. However, any plant that produces an abundant root system and a large amount of above ground biomass in one or two growing seasons would be an adequate candidate for such a crop. Green manure crops have been successfully used on agricultural lands and the technique has been successfully applied to minesoils and other disturbances in North America.

#### *6.2.2.2.8 Compost*

Any residue remaining after biological decomposition of

organic materials is called compost. It has been found to be an excellent soil conditioner, to enhance macronutrient fertility and the cation exchange capacity, increase infiltration and moisture holding capacity, decrease bulk density, impart a better crumb structure to the soil, and reduce the erosion potential of the receiving soil, subsoil, or overburden. The organic source for compost may be anything from grass clip pings to municipal solid waste. Since it has undergone at least partial decomposition, carbon:nitrogen ratios are usually less than 20:1. For example, composted newspapers have high C:N ratios (100:1 or higher), whereas grass clippings or manure have lower C:N ratios (10:1 to 20:1). If the C:N ratio is low enough compost may be used as a fertilizer as well as a soil conditioner.

The decomposition period for a compost may have been brief or it may have lasted several months but the compost should be relatively stable. The slow breakdown of compost after incorporation into a degraded soil ensures a gradual release of plant nutrients and the beginnings of nutrient cycles. Compost is a relatively new addition to the rehabilitation of disturbed lands in this country, but it has been used in Asia and Europe for centuries. Compost is especially useful as a soil component to enhance soil structure when topsoil is not available or in poor quality surface soils. Recent research in the state of Washington illustrated the benefits of compost in the revegetation of arid rangelands without adequate topsoil (Brandt and Hendrickson, 1991). These authors found that additions of 25 to 33% by volume were most effective enhancing soil properties.

Most municipalities in this country have established composting centers as alternatives to landfilling organic wastes. The quality and quantity of compost are rapidly increasing. The use of this material, like the use of other organic amendments, however, is limited by transportation costs. The material is light and bulky and may not be available in adequate quantities near the disturbed site.

#### *6.2.2.2.9 Sewage Sludge*

This material may be raw or composted. It begins as material from a sewage treatment plant composed primarily of water but its solids content can be increased by several successive steps. The sludge contains a number of inorganic macro and micronutrients in addition to organic residues. The combination of nutrients and organic matter make sewage sludge a valuable addition to the amendments that may be added to degraded sites. When incorporated as an organic amendment, its effect upon soils is similar to that of compost; it improves soil structure, increases the water holding and cation exchange capacities of the soil, reduces the bulk density and surface temperatures, ameliorates pH extremes, and contributes nutrients to the receiving soil.

Sewage sludges are becoming increasingly available near large urban areas. They are often composted, mixed with other organic material (e.g., composted yard waste or woodchips), and marketed as a soil additive. In other areas, these wastes may be applied as a liquid or as a solid directly on or into disturbed soils or agricultural lands. When applied as a solid, sewage sludges are mixed into the soil with a plow, disk, or chisel. Studies in Pennsylvania have shown good results using a mixture of sewage sludge and fly ash as a topsoil or rooting media on severely denuded and eroded slopes (Oyler, 1988, Sopper, 1988). In Montana, a composted sewage sludge mixture enhanced the performance of seeded vegetation on high elevation minesoils when the waste was incorporated into the minesoil (Vodehnal, 1993).

The inorganic contents of aerobically digested sewage sludges varies widely. A nitrogen:phosphorus:potassium ratio of 5.0:2.5:0.4 has been suggested as typical of many sludges (Halderson and Zenz, 1978). Several micronutrients (e.g., copper, zinc, iron) are found in these sludges. The phytotoxic metals (e.g., lead, cadmium, nickel) are also usually present in elevated concentrations (Williams et al., 1980). Application of large amounts of sewage sludge to a site may produce elevated levels of one or more of these phytotoxic metals in the soil.

Potentially phytotoxic metals occurring in sewage sludge present a limiting factor to the use of this material as a soil amendment. Published maximum amounts of metals that should be deposited in or on agricultural soils are shown in Table 4. These application rates are based upon the possible accumulation of elevated metal levels in plants and animals in human food chains.

**Table 4** Federal Recommendations for Maximum Trace Element Loadings for Agricultural Lands (Anon., 1977)

| | Cation exchange capacity (meq/100 g) | | |
|---|---|---|---|
| **Metal** | **<5** | **5 to 15** | **>15** |
| Cd | 5[a] | 10 | 20 |
| Cu | 125 | 250 | 500 |
| Ni | 50 | 100 | 200 |
| Pb | 500 | 1000 | 2000 |
| Zn | 250 | 500 | 1000 |

a = kg/ha
kg/ha x 0.9 - lb/a

Sludge loading rates may be calculated from the formula:

Sludge Loading Rate = RMMLR/MCS (6.2.2.2.9.7)

where: RMMLR = Recommended Maximum Metal Loading Rate in mg/ha, MCS = Metal Concentration in the Sludge in mg/kg

### 6.2.2.3 Irrigation

Vegetation seeded in a degraded soil should germinate, establish, grow, and reproduce with the average precipitation of the disturbed site. Supplemental water should only be applied when precipitation is not adequate for seed germination and plant establishment (see Fig. 6). When additional water is applied to a disturbed site in a semiarid or arid region only a few centimeters should be applied. Prolonged irrigation stimulates the development of an irrigation dependent plant community. Termination of irrigation after such a community develops results in drastic changes in plant production and composition.

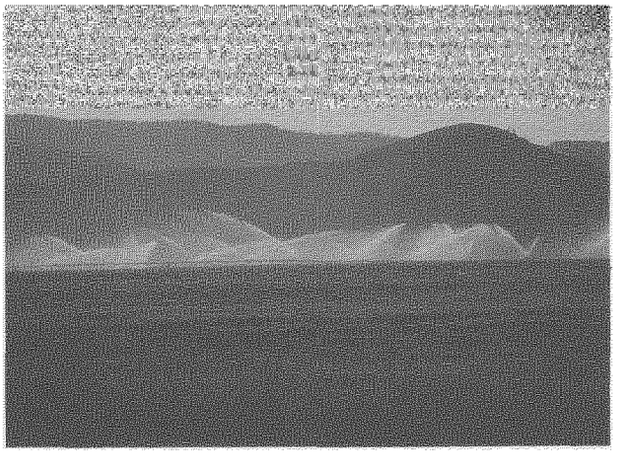


**Figure 6** Irrigation to establish new plants.

Extra water has been found to stimulate seed germination and plant establishment. Irrigation also extends the planting or seeding season. The benefits of irrigation can be measured during the first few growing seasons. However, as the number of years between irrigation and response measurement increase the detection of any plant response becomes less clear.

The short-term value of irrigation water has been documented but the long-term value is questionable. Since it is usually less expensive to seed a site a second time than to activate an irrigation program to compensate for the lack of spring or early summer precipitation, the expense of irrigation of disturbed sites requires careful evaluation.

## 6.2.3 WILDLIFE
**by W. F. Schwarzkoph and R. T. Moore**

### 6.2.3.1 Mitigation of Common Impacts

Mining activities can affect wildlife populations in a variety of ways. The most common areas of impact are: 1) physical injury/mortality; 2) habitat loss/fragmentation; 3) loss of wetland; 4) loss of critical habitat types; 5) toxicities; 6) increased human activity; 7) induced harvest changes; and 8) migration barriers.

This section summarizes technologies available to offset or mitigate negative effects of mining on wildlife populations. For additional and more detailed information, the reader is referred to three books listed in the references (Payne, 1992, Buckley, 1989, and Berger, 1990).

#### *6.2.3.1.1 Physical Injury and Mortality*

The loss of wildlife through actual physical injury and/or mortality caused by mining and its associated activities is probably quite minor overall but can be locally significant. Fairly simple measures can be taken to keep these losses small. Wildlife mortalities can occur due to impact with mine related traffic. Roadkills occur on extensions of public roads, construction of new public roads to the mine and on the mine haulroads. Although this type of loss probably cannot be stopped, it can be minimized. Proper seeding of roadsides is one method to reduce this loss. The seed mix used to stabilize roads, road sides and ditches should not contain "candy" plant species (such as legumes) for deer. Some seed mixes for roadside seeding have inappropriately included alfalfa (*Medicago sativa*) and yellow sweet clover (*Melilotus officinalis*), which attract deer to roadsides. Roadside seed mixes should contain no plants that will attract deer or other species.

Enforcement of speed limits also reduces wildlife loss. Speed limits must be reduced on roads through high deer concentrations. Defensive driving techniques and careful observance of wildlife crossing signs must be encouraged at mine safety meetings. Dawn, dusk and nighttime are very active periods for wildlife and they will be moving across roads as they travel from resting to feeding areas. Motorists should be aware of this and drive accordingly. Shift changes may be timed to minimize traffic during these periods of peak activity. Fencing at specific locations may also alleviate road kills in problem areas.

Deer whistles may or may not help, but mine vehicles can easily be fitted with whistles at a very low cost. At the Rosebud Mine in southeastern Montana, all mine vehicles that are scheduled for extensive highway travel are fitted with deer whistles.

Small mammal populations can appear to be totally

eliminated, but due to their high natural reproduction capabilities, they will quickly reinvade and inhabit reclaimed habitat. Repopulation is hastened by keeping reclamation current and minimizing the active disturbance area. Contemporaneous reclamation requirements keep regrading current with mining activities and also allows for the direct haulage of soil, which can reduce soil salvage costs since soil stockpiling can be avoided.

Other causes of physical injury and/or mortality and available mitigation techniques are:

*Falls from highwalls* - Fatalities of wildlife due to falling from highwalls appears to be rare, but knowing it can happen should allow for proper planning of mitigation. A radio-collared deer that was darted and drugged later was killed when it fell from a highwall at a Montana mine. Researchers should be aware of highwall locations when working with mobile big game. Highwalls remaining after open-pit operations can be fenced or reduced to ensure stability and prevent access. Typical four-strand, barbed-wire fencing would cost approximately $4.10 to $4.92 per meter ($1.25 to $1.50 per foot). Woven-wire security fencing is typically more expensive.

*Power lines* - Information is available on proper construction for cross arms on power poles to eliminate electrocution of large birds of prey (Olendorff, 1981). Proper construction design is effective mitigation at minimal additional cost.

*Contaminated water* - Pond liners can be used to keep mine water from polluting local aquifers and streams that may harm fisheries and other aquatic life (Richardson and Koerner, 1990). Synthetic liners are an expensive option but are commonly required to meet water quality regulations.

*Silting of streams* - Sediment control usually requires construction of ponds designed to hold a 100-year, 24-hour storm run off. Other options include sediment fences (Mallard and Bell, 1981) to allow the water to pass but retain much of the sediment.

Some species may require relocation to be protected. If the animal numbers are few, trapping and moving them to other suitable habitat may be the best solution. Many times, however, local mitigation measures are sufficient to keep populations intact in the mine vicinity. In general, the mitigation measures to minimize direct wildlife mortality are within the realm of what is considered good engineering practice or can be implemented within reasonable additional cost. On the other hand, if trapping and relocation should be necessary to protect a threatened or endangered species, such efforts tend to be labor intensive and can be extremely expensive. For example, costs of providing trained biologists to search for, protect, and relocate desert tortoises in the path of corridor (roadway, transmission line, pipeline, or buried cable) construction activities may run $1,243 to $3,108 per kilometer ($2,000 to $5,000 per mile).

#### *6.2.3.1.2 Habitat Loss and Fragmentation*

Probably a greater threat to wildlife populations in aggregate, rather than as individuals, is the direct loss or fragmentation of habitat. A thorough knowledge of all the components of habitat, learned through pre-mine baseline surveys, allows the mining company to reclaim the proper type of habitat or design the mine plan so as to replace that which is lost. These surveys should be conducted by professionals in the wildlife field. Just as professional engineers are recognized as PE's, qualified wildlife biologists are recognized by The Wildlife Society as "Certified Wildlife Biologists." Every aspect of the habitat must be considered including, foraging areas, wintering areas, and security cover to name a few. Perhaps only a specific segment of the habitat will be lost and, therefore, only that portion must be addressed in the reclamation plan. If foraging areas are a key element, a proper reclamation plan that includes a seed mix designed to replace valuable forage is all that is necessary. If wintering areas are lost, the reclamation plan should address the important elements such as a dense planting of specific browse species. If security cover is lost then planting should include trees, or a topography must be designed that will allow for wildlife species to be able to obtain security through topographic cover. At some western U.S. mines, spoil ridges maintained at specific locations can be a simple and cost effective method of providing for topographic security. In some situations involving wildlife issues, a mining company may actually be able to reduce costs in the reclamation plan. Spoil ridges constructed for topographic cover can reduce the cost of regrading and topsoiling, which typically ranges from $15,000 to $20,000 per hectare.

#### *6.2.3.1.3 Wetlands*

Wetland conservation has become a major issue in the United States and many other countries today. Most species that depend on wetlands have declined in number due to the large scale drainage programs of the past, mostly due to agriculture. Mine operations are unlike agriculture in that they commonly result in a net gain of wetlands. Mine regulations require construction of sediment ponds and other systems for surface and groundwater, which are beneficial to waterfowl species.

Many papers have been prepared on how to construct

wetlands to eliminate toxic drainages from a mining operation (Payne, 1992). These wetland construction projects can enhance the ability to mine where acid mine drainage exists. Chemical methods are available, but passive systems offer a low cost, more natural approach (Skousen et al., 1992). Technology is available to diminish acid discharge through proper construction of wetlands.

In nontoxic areas, groundwater pumped from the mine can be used to construct marshes, ponds, and lakes in areas once devoid of any water or wetland species. Gold mines in Nevada and coal mines in western states of the United States have actually increased waterfowl numbers in a fashion that Ducks Unlimited has been trying to perform for decades. Construction costs for most ponds need not be excessive; a typical sediment pond currently costs $11,000 for a 3/4-hectare pond.

Hardpans can be created by flooding low-lying sites with clay tailings to build nearly impervious layers. When the clay dries, it can be covered with topsoil and planted with marsh-loving plant species. The hard clay pan functions to hold water near the surface (Lotspeich, 1992).

#### *6.2.3.1.4 Loss of Critical Habitat Types*

Special attention must be given to recognize the locations of critical habitat. Mitigation measures must be undertaken where habitat critical to a species' existence is involved. For example, the loss of a critical winter range will require extensive shrub plantings in the reclamation plan. Rather than plant by direct seeding, technology exists to grow indigenous shrubs in nurseries and then plant them as either bare-root or as containerized stock. Costs range from $0.20 (bare-root) to $0.80 (containerized) each. Dense plantings of 1,000 plants per hectare may be required. Shrubs can be planted by hand or with a tractor-mounted 3-point tree planter. About 1,000 to 2,000 shrubs per day can be planted in this manner (Schwarzkoph, 1989).

Further study of critical habitat can generate more data and eliminate the necessity for special mitigation or change of mine plans to exclude the critical habitat. In southeastern Montana, 10,000 tons of coal were eliminated from a mining area because of a sharp-tailed grouse dancing ground located over federal coal. An area encompassing 0.8 km around the dancing ground was thought to be necessary for nesting habitat. The mining company had an extensive study done on sharp-tailed grouse and found that the grouse were actually nesting 1.6 to 19 kilometers from the dancing ground. Also at the same time mitigating studies revealed the ability to reconstruct the sharp-tailed grouse habitat necessary for sharp-tailed grouse dancing grounds (Anon., 1982.) After the study, the area was readmitted for mining purposes. It is important to plan ahead to allow for the time necessary for proper studies, in this case several years.

#### *6.2.3.1.5 Toxicities*

As mentioned previously, some mines have chemical solution ponds or acid-drainage problems that can be especially hazardous to aquatic species and waterfowl. Specific methods are available to re-create a natural wetland to mitigate the acid drainage (Skousen et al., 1992) Factors important to acid mine drainage treatment by wetlands are initial flow, water chemistry, wetland substrate and vegetation and microbial composition.

Most heap-leach mine methods involve ponds with toxic leachate (Hallock, 1990). Wildlife mortalities can be prevented by protective fencing for ground-dwelling species and by placing netting over the ponds to prevent waterfowl and other birds from flying onto the ponds. Netting of solution ponds may range from $3.23 to $5.38 per square meter ($0.30 to $.50 per square foot), depending on the expected life of the operations and requisite durability of materials involved (Hough, 1994). While netting of solution ponds is an economically feasible approach for protecting birds from these small impoundments, detoxification of the waste solutions is normally a more economical approach for the typical large tailings ponds. Netting of solution ponds is a very effective method of minimizing bird losses at these facilities, but care must be taken to maintain the netting and repair any tears or holes that develop. In windy areas, improperly installed netting may wear out quickly from abrasion against the support cables.

Potential copper-molybdenum problems could occur by grazing wildlife that consume plants with high concentrations of copper and molybdenum (Munshower, 1977). In areas where a copper-molybdenum problem is possible, pre-mine and post-mine sampling must be done on overburden and plant material. Separation and special handling of spoil material could be required, which, if extensive, could be impractical to mine operations. Therefore, the mining company would be prudent to sample both pre- and post-mine overburden and vegetation in order to gather enough data to properly mitigate potential toxicity problems.

#### *6.2.3.1.6 Increased Human Activity*

Most mines are located in fairly remote areas, and therefore the mining activity is accompanied by increased human activity. Increased traffic has been discussed earlier on roads from population centers to the mine, but at many mines, small towns are built or at least increased in size to accommodate mine employees and their families. The expansion of towns and the increased hunting activities all have an effect on wildlife populations. Proper planning of town sites or expansions may save important wildlife habitat.

Increased hirings of state wardens should help to protect wildlife and assure that seasons and harvest limits are not abused. Many times a mining company may be required to fund the cost of an additional game warden through mitigation efforts with state agencies. Costs can run from $20,000 to a $50,000 per year for a warden's salary, benefits and vehicle. In Montana and North Dakota, special coal funds are earmarked for use in coal impacted areas.

Significantly, many mine and reclamation areas have become wildlife havens. Increased wildlife numbers on the mine can positively offset the negative effects that occur off the mine, until such a time when the increased population of wildlife in itself becomes a problem. At the Rosebud Mine at Colstrip, Montana, mule deer became a nuisance in town among residential flower and vegetable gardens (Fritzen, 1993). A special deer reduction hunt (highly supervised) can be used to alleviate high deer population problems.

#### *6.2.3.1.7 Induced Harvest Changes*

Due to the mine's need for manpower, an increase in population occurs in nearby towns, or new small towns are actually built (Colstrip, Montana and Wright, Wyoming are examples). When this occurs, both legal and illegal harvests of game animals increase dramatically. Harvest quotas may need to be updated to insure that wildlife populations are not being overexploited. In some cases, increased harvests can be beneficial to the wildlife populations (Fritzen, 1993). Hunting used as a management tool can benefit wildlife populations by keeping animal numbers balanced properly with available habitat.

#### *6.2.3.1.8 Migration Barriers*

A good example of a potential migration barrier is the Alaska oil pipeline. Special techniques were employed to raise the pipeline higher at specific locations to allow for Barren Ground Caribou (*Rangifer articus*) migrations. Some raised areas are used, but in general the caribou simply pass under the pipeline. Coal mine conveyors pose no barrier to deer. Many mule deer have been observed crossing under the conveyors even while in operation. Many wildlife species are so adaptable that they soon become accustomed to the so-called barriers.

However, some barriers do exist. Fences can pose real problems. For example, woven wire fences can disrupt antelope travel routes. Familiarity with the species in an area allows for proper fencing that will not disrupt travel routes. Just as fish ladders can be built on streams, thought must be given to the mobile wildlife species in the mine area. Large underpasses at roads and railroads allow mobile species to continue their traditional routes.

### 6.2.3.2 Special Wildlife Impact Issues

#### *6.2.3.2.1 Threatened and Endangered Species*

The presence of species on the Threatened and Endangered (T&E) list can be enough to prevent mining in an area, if these species are seriously threatened by the proposed mining activity. However, several opportunities exist to maintain or even enhance habitat for T&E species through proper reclamation (Schwarzkoph, 1993). For example, highwalls left as replacement features for original cliffs can provide replacement or even enhanced nesting habitat for peregrine (*Falcon perrinius*) and prairie falcons (*Falcon prairieensis*). This type of mitigation can be achieved at minimal additional cost and often at a cost savings compared to other reclamation alternatives.

In some cases, species can be trapped and relocated to another location where suitable habitat exists. Although mining was not involved, a good example of trap and relocation is the work done in Wyoming with blackfooted ferrets (*Mustela nigripes*). The extremely rare ferrets were trapped and taken to state facilities where they were protected and propagated for later release to other areas. Plans are to relocate the ferrets to sites on federal land in Montana, Wyoming and South Dakota.

In some instances, wildlife protection can be achieved by avoiding certain mining activities during specific important seasons. For example, mining activities may need to be restricted during the nesting season when near active eagle and falcon nests. Through proper planning, dragline and shovel activities could be done during the time when normal migrations have moved the birds south. These activities should not be performed during the nesting period. Proper timing of mine operations is important.

#### *6.2.3.2.2 Raptors*

Many mining activities can be altered so as not to negatively affect raptors. Mining can be selective, to avoid activities during periods of nesting and brooding. Highwalls replacing original cliffs can be left and enhanced for future nesting areas. Ponds can be designed and built that may attract prey species such as ducks for peregrine falcons, or fish for osprey. Nesting platforms can be constructed where no nesting structures (trees or cliffs) existed previously.

Standard grassland reclamation can create excellent hunting areas for raptors. Small mammals and song birds abound in reclaimed grasslands. At Colstrip, Montana, prairie falcons were noted to hunt reclaimed land. The falcons' nests were found by radio-tracking sharp-tailed grouse that had been killed by the falcons. The radios were found in or below the cliff nests. The sharp-tailed grouse were previously recorded utilizing the reclaimed

area every day, which was proof the falcons were hunting the grassland reclamation. Brush piles and rock piles can enhance small mammal habitat, which would also increase raptor food sources. This type of specialized small mammal habitat can be created at minimal additional cost using equipment that may be temporarily idle from other operations.

#### *6.2.3.2.3 Migratory Waterfowl*

Waterfowl can be positively affected by the creation of new wetlands resulting from mining activities. Negative impacts can be eliminated by constructing buffering wetlands in acid mine drainages. Leach ponds can be covered, and new water sources can be easily created. Sediment ponds can be left for temporary ponds or year-round ponds depending on surface runoff. Old pits filled with groundwater offer year-round habitat if pit water quality is suitable for wildlife use.

## 6.3 HYDROLOGIC EFFECTS

### 6.3.1 SURFACE WATER QUANTITY
**by J. O'Hearn**

Mining operations, like other activities of man, have significant potential to affect natural resources including surface water quantity. Effects to surface water resources typical to mining operations can be significant. Knowledge and technology have evolved for preventing, minimizing or mitigating many such effects. Such knowledge, often based upon lessons learned from the mistakes of the past, is particularly useful during the planning phase for new operations. Various technologies can be applied to existing mining operations in a remedial fashion to eliminate or reduce existing adverse effects to the quantity of surface water resources. These same technologies can also be applied to new areas associated with both expansion of existing operations and totally new projects.

Proper planing is crucial to the minimization of surface water resource impacts that otherwise could have detrimental effects upon the mining operation itself as well as upon the surrounding environment. The need for a multi-discipline approach and use of a systems approach is necessary to assure proper consideration of and an optimal solution to a mining operation's affects upon local and regional hydrologic systems.

#### 6.3.1.1 Runoff

The amount and distribution of surface water runoff is directly related to the characteristics of the precipitation event and the drainage basin (including vegetative cover, type and depth of soil, topography). The effects to runoff are typically greater from surface mining than for underground operations since surface mining of all types alter the pre- mining hydrologic characteristics of the drainage basin(s) within which the operations are conducted.

Stripping of vegetation, topsoil and overburden during mining reduces the affected watershed's ability to trap and absorb precipitation for slow release as groundwater recharge and evapotranspiration. Unreclaimed or reclaimed areas that are poorly designed or which have not yet become adequately established can behave similarly. Thus, the percentage of precipitation that is immediately converted into runoff is increased within disturbed portions of a watershed. Runoff entering or originating within areas of active mining and reclamation affects operational efficiency and can damage or destroy reclamation systems depending upon for instance the degree to which revegetation and other erosion protection measures have been established.

Therefore, it is necessary to develop the mine plan with the objective of minimizing unnecessary changes to the drainage basin(s) including excessive lead time for pre-stripping operations and excessive delay in back-filling, re- contouring and reclamation operations. Proper timing, sequencing and sizing of those operations will minimize the area within the basin that is unavailable to retain precipitation from the rainfall-runoff production relation. Despite the best mining and reclamation plans, it will be necessary to utilize structural measures (at least in the short term) to deal with runoff. Such measures include for instance, diversion channels, collection/conveyance channels, detention and retention impoundments and miscellaneous appurtenances.

#### 6.3.1.2 Diversion Channels

Wherever practical, it is advisable to consider diverting overland flow, shallow groundwater flow and watercourses from upland areas adjacent to mining and reclamation around the area(s) of disturbance. Diversions are defined as temporary or permanent channels that collect runoff from undisturbed areas. It is generally possible to discharge runoff from properly designed diversion channels without the need for sedimentation measures such as sediment ponds. It is preferable that the diversions discharge back into the main watercourse within the same drainage basin below the disturbed, or to be disturbed, area. If necessary to divert into an adjacent drainage basin, due consideration must be given for prevention of consequential damage to the receiving watercourse. Runoff from the added tributary area associated with the trans-basin diversion will generally increase the peak (and possibly the base) flow rate. The degree of severity of the effects of the trans-basin diversion upon the receiving watercourse are related for instance to: the relative proportion of the added area to

the natural tributary area at the discharge point of the diversion; the erodibility of the receiving watercourse's channel, the differences between the sediment types and loads and the duration of the trans-basin diversion. Blench (1978) presents useful information for predicting the effects of trans-basin diversions.

In general, diversions can result in less operational costs and environmental degradation by reducing the expenditures required for adequate water control, erosion protection and sediment control measures within the operational and reclamation areas than would otherwise be required. However, proper planning and economic analysis should be applied whenever practical to verify that the total marginal cost of those elements without the diversion is less than the cost for the diversion and associated elements. Clearly, a trans-basin diversion requiring substantial protective measures within the downstream reaches of the receiving basin's watercourse may not always be cost-effective.

Unfortunately, it is frequently the case that impacts to mining and reclamation operations from surface runoff are difficult to quantify. Unless actual experience provides data regarding loss of resource or increased operational costs caused by runoff and flooding, speculation and numerous assumptions will be required to develop a reasonable range for such costs. This difficulty is further compounded by the unpredictability of the frequency and magnitude of significant precipitation events.

#### 6.3.1.3 Collection/Conveyance Channels

Collection/conveyance channels are temporary channels existing within disturbed areas prior to reclamation and post mining hydrologic restoration. The purpose of a collection channel is to collect overland flow from disturbed areas and route it as channelized flow to a main or conveyance channel. The purpose of a conveyance channel is to route flow through and around disturbed operational areas to sedimentation measures such as a sediment pond. Sedimentation at the point of discharge, distinguishes conveyance channels from diversions.

Both collection and conveyance channels are intended to provide minimization of uncontrolled runoff that otherwise would cause needless erosion/sedimentation and which would also impact mining efficiency by for instance, flooding of operating and reclamation areas. Collection channels generally have a fairly short life as they are constructed in disturbed areas that become mined through, backfilled, re-contoured and reclaimed. A different collection channel for instance could exist in one or more of these phases of mining and could be relatively different in location and design for each phase. Generally speaking, conveyance channels are longer lived, often located adjacent to semi-permanent mining facilities such as access slots, haul roads, etc. Additionally, restored post-mining watercourses often traverse the same route as a conveyance channel. They often are connected to the upper or lower reach of a conveyance channel, depending upon the direction of mining in relation to post-mining topography and drainage pattern.

#### 6.3.1.4 Design of Channels

The same principles apply for proper design of diversion, collection and conveyance channels. The first part of design for a system of runoff control channels is development of an overview of the mining operation itself or the mine plan in the case of a proposed project. This overview will provide the basic information required for a first-cut determination of the needs for diversion and conveyance channels and sedimentation facilities. This initial effort is probably the most important step in the design process for surface water control systems. In keeping with its importance, it is often the most difficult part of design. The designer must thoroughly comprehend all significant aspects of the specific mining operation in order to most effectively locate and size the individual components of the water control system. The ability to visualize the progression of pre-stripping, stripping, spoiling, benching, resource extraction, spoiling/haul-back, back- filling, re-contouring and reclamation operations (all of which may be occurring simultaneously) in three dimensions is an asset to the designer. This visualization is developed by careful study of the mine plan. Close interaction with the mining engineers who have developed the mine plan and/or actual observation of the specific mining method over a duration adequate to allow familiarization, can greatly facilitate this conceptualization.

The time expended in familiarization/ conceptualization will pay dividends by maximizing the effective location and subsequent sizing of water control system elements while minimizing recommendation of infeasible or ineffective elements. For example, since watershed area is a principal variable in estimating peak flow rates and volumes of runoff, all other things being equal, it is important that the longer lived elements (typically conveyance channels and sedimentation ponds) be designed for the maximum drainage area tributary to them over their lifetime. For instance, maximum tributary area could occur during mining or during reclamation depending upon the particular mine/reclamation plan.

Once the overall water control system and its elements have been laid out in a preliminary fashion and design criteria established, accepted hydrologic, hydraulic and civil engineering principles can be employed to refine and finalize the design.

Establishment of proper design criteria for elements of the water control system includes consideration of the

frequency and magnitude of the precipitation event (including snow-melt runoff where appropriate). The return period and duration of the design precipitation event are key criteria. Proper selection of these values includes consideration of issues including, for instance: the duration or "life" of the project and individual system elements; the economic, environmental and safety impacts associated with failure of the element; governmental regulations; professional standards; and the availability of useful climatic and hydrologic records.

The following general guidelines are provided as examples of typical design criteria for selection of design precipitation events for minor, temporary water control system elements located in rural areas of the western United States. It is cautioned that individual circumstances for each project, location/climate, and system element including downstream development could easily dictate selection of more or less rigorous design criteria.

| Element | Return Period (years) | Duration (hours) |
|---|---|---|
| Collection channel | 2 | 24 |
| Conveyance channel | 10 | 24 |
| Diversion channel | 10 | 24 |
| Sedimentation impoundments | 10 | 24 |
| Impoundment outlet works | 25 | 6 |

Determination of the design peak runoff flow rates is necessary for design of channels and pond outlet works. Total runoff volume and distribution (runoff hydrograph) is necessary for impoundments and outlet works (principal outlet and emergency spillway). It is usually necessary to estimate design flow rates and volumes for mining projects by means of rainfall-runoff simulation techniques owing to the general lack of historic stream flow records and the dramatic changes to the drainage basin's natural characteristics during mining and reclamation.

Information required for runoff simulation includes for instance: precipitation depth, duration and distribution (snow- pack depth and melting scenario where appropriate); tributary area; soil and vegetation characteristics (sometimes called Curve Number); time required for overland and channel flow to reach the design location (time of concentration).

The reader is directed to publications of the U.S. Department of Commerce, National Oceanic and Atmospheric Administration (NOAA) and earlier Weather Bureau publications for specific design precipitation data for the United States. The reader is also directed to the Soil Conservation Service's (SCS) National Engineering Handbook (Anon., 1972) for further information on characterizing watersheds and estimating runoff rates and volumes. The SCS has developed several excellent methods for simulating or estimating the rainfall-runoff phenomena. The SCS has developed IBM personal-computer-compatible software that can be employed to simulate rainfall-runoff and model many aspects of a surface water control system and published it (Anon., 1984a.)

The SCS methods can be employed throughout the world if reasonable effort is made to estimate or collect the requisite input data. The NOAA/Weather Bureau information is generally related to the fifty states of the U.S. Climatic information for areas outside of the U.S. must be obtained from equivalent agencies in the country of interest or must be estimated from scant data.

Certain other criteria also apply to the design of channels. One very significant criteria pertains to flow velocity, which is partly a function of channel slope. That criteria is the maximum velocity of water flow that will not result in significant channel erosion (non-erosive velocity). If non-erosive velocity can be maintained, it will not be necessary to line the channel with rock or other erosion resistant material to prevent channel degradation. Therefore, at this point in the design effort, it is necessary to have established the vertical profile for each channel in accordance with the alignment selected for tributary area determination and calculation of associated peak flow rate.

The Manning formula is a very well accepted means for defining the essential hydraulic relationships of open channel flow. The reader is referred to "Open-Channel Hydraulics" (Chow, 1959) for further information on application of the Manning formula, selection of appropriate design parameters, and channel design. The basic parameters for channel design include the channel's cross sectional dimensions, roughness of its banks/bed and slope. Given this information, the velocity and depth of flow can be calculated for any flow rate.

If the design flow rate results in exceedance of the non-erosive velocity, the designer has several main options. Where practical, the channel's grade can be decreased by realignment to a flatter but longer route. The non-erosive velocity may be increased by lining the channel's bed and banks with erosion resistant material such as rock, geotextile or concrete. The channel could be widened to decrease depth of flow and increase the cross-sectional area and friction drag. These options are often constrained by practical or economic factors such as limited ability to re-align the channel; cost of channel armoring material and installation labor; the tendency for narrow channels to develop within broad, unlined channels, defeating the benefit of increased cross section.

Modern cost-effective materials such as geotextiles and gabions provide the designer with more flexibility than previously available to increase non-erosive flow velocity. The designer must also consider the effects of too slow a velocity with resultant deposition of sediment, plugging the channel, potentially resulting in uncontrolled, undesirable realignment and flooding.

Closed channels such a culverts and pipes are important means of conveying flow in certain difficult conditions, such as down extremely steep slopes, across or beneath highly disturbed areas and through embankments. The reader is directed to Anon., 1965, for further information regarding proper hydraulic design and sizing of culverts.

#### 6.3.1.5 Post-mining Hydrologic Restoration

Successful post-mining reclamation of disturbed areas must consider adequate planning for restoration of the disturbed hydrologic system. Overall reclamation planning must include the consideration and balancing of numerous important parameters including: volumes of spoil, waste rock, cuts/pits, resource removed and material swell; abutting undisturbed topograpy; geotechnical stability of highwalls (if any), interfaces between undisturbed and replaced materials, regraded spoil/topsoil; and, abutting hydrologic systems.

Mining, reclamation and hydrologic engineers must work in concert to assure that selection of an optimum combination of these parameters is possible. If the selected combination cannot be achieved cost-effectively, then, development of the mining operation should not be allowed to proceed in order to prevent substantial environmental damage. Federal and state mining regulatory agencies in the United States are empowered to deny a permit for mining if unacceptable impacts will result from the operation after its cessation.

Generally speaking, it is easier to prevent or mitigate adverse environmental impacts during the life of a mine's operation. However, after reclamation, prevention of environmental degradation becomes more difficult for at least two reasons. First, the operator is often not present and certainly is less interested in enduring a continual negative cash flow to maintain the reclaimed landscape and drainage basin(s). Secondly, the time factor is greatly expanded from the relatively short time span of active mining to the continuum of geologic time post-mining reclamation.

Therefore, it is critical that post-mining reclamation be founded on proper consideration of the aforementioned, crucial parameters. Proper consideration will help assure that the post-mining topography, vegetation and drainage systems are in basic harmony with the natural processes affecting the surrounding region. In order to include the possible remedies for protecting the valley environment in a mining and reclamation plan, however, the processes that have shaped the environment must be accommodated (Hadley and King, 1980). Ideally, the reclaimed mining area should be no more or less stable than the abutting areas if an equilibrium, albeit dynamic, is to be achieved and maintained.

Significant environmental problems are likely to be avoidable, if the reclamation plan's principal objective is to re- establish equilibrium. Then, the consideration of and balancing of the critical parameters will provide the proper point of beginning for design and implementation of the site-specific means to assure post-mining landform stability at minimum long-term cost to the operator, the public and the environment.

Post-mining restoration design of the hydrologic system, specifically those components related directly to surface water runoff, can commence effectively once the critical parameters have been optimally balanced. Replication of pre- mining drainage system characteristics including, for instance, stream order, drainage network density and longitudinal profile, is the next proper step in restoration design. Thereafter, peak flow rates can be estimated as described above for each post-mining channel and reach. Due consideration must be given to changes in runoff affecting conditions such as soil and vegetation characteristics (Curve Number) which may be different than those selected for design of water control systems during the mine's operational period. The key criteria of design precipitation-event-return period and duration also may differ. Generally speaking, return period should be greater for restoration design to account for the indefinite life span of the post-mining channel system and the practical need to demonstrate a very small likelihood of failure and subsequent maintenance/repair. The inclusion of additional hydraulic features such as provision of a floodplain as part of the channel's designed overall water conveyance capacity will be beneficial. The floodplain will serve to increase capacity in a natural way without requiring the channel itself to be massive in either its relative size or its ability to resist degradation during extreme runoff events.

The specification of natural materials such as rock and gravel for use as restored channel linings is strongly recommended over "structural measures" such as concrete and pipe. The longitudinal profile of the channel should also replicate that which was characteristic of the pre-mining basin. "Nick points" or steepened reaches should be avoided wherever possible. If a nick point cannot be avoided, for instance at locations where the strata of extracted mineral resource is significantly thicker than the overburden strata, a drop structure or energy dissipation should be employed to prevent or forestall head cutting of the channel. For this eventuality, again, the use of native material designed and installed to function in a forgiving and flexible manner is preferred

over rigid structures. These approaches are consistent with the concept of establishment of fluvial geomorphic equilibrium whereby the net sediment leaving a reach of channel is equal to that which enters it.

#### 6.3.1.6 Impoundments

Impoundments are natural or artificial means for storing water. Man-made impoundments are formed by providing a barrier to flow such as an earthen, waste material or concrete embankment located in a ravine for instance or by providing a depression in the ground such as a pit or an excavation. Impoundments have various mining related applications such as storing water for beneficial application such as supply of potable, industrial or dust control water. They are also used for flood control, sedimentation, waste treatment and storage such as tailing ponds. Tailing ponds are generally retention facilities. That is zero or essentially zero discharge to downstream systems. Impoundments that eventually discharge all or most of their stored water but do affect that natural temporal distribution of runoff are called detention facilities. In the context of runoff, most mining impoundments are detention facilities used for sediment removal and flood control.

The principal environmental (and safety) issues associated with impoundments pertain to catastrophic failure of the water holding embankment. Failure modes typically include rapid collapse caused by direct or indirect structural failure.

Direct structural failure occurs for instance when the foundation or embankment itself becomes unstable and moves or cracks allowing the stored water to rapidly escape around or over the displaced material or through a crack. The stability of earthen or waste material embankments is greatly affected by poor geotechnical design and construction of the embankment or foundation. Unanticipated saturation, often caused by poor embankment material selection, placement or drainage can cause those types of embankments to become unstable and fail by slipping or sliding. Once the slide area is overtopped, the erosive power of the impounded water could rapidly cut through the entire embankment.

Indirect structural failure of a water holding embankment is defined as uncontrolled overtopping by water resulting in destruction of the embankment by erosion or under-mining caused by erosion of the toe of the embankment. Proper estimation of and consideration for reasonably expected peak inflow rates is necessary to provide reasonable assurance against indirect embankment failure. Additionally, consideration must be given to the possibility that over-topping could occur if the principal means of discharging water from the impoundment should be rendered ineffective by clogging, mechanical failure, etc.

Selection of appropriate criteria, particularly the design precipitation event as mentioned above and determination of the design runoff hydrograph and total volume of water is particularly critical for impoundments. Once these parameters have been properly established in conjunction with the standard operational mode for the impoundment (i.e., anticipated pool stage elevation at the beginning of the design storm event, artificial sources of discharge to the impoundment, etc.), hydraulic design can come into play.

Most significant impoundments make use of several measures designed to prevent overtopping. One measure is the provision of adequate freeboard (vertical distance between the anticipated pool elevation and the embankment crest elevation - including consideration for wave height) to detain the peak inflow flow rate without over-topping resulting from filling all possible storage volume behind the embankment. Another measure is the provision of an emergency spillway. (This presumes the presence of a principal outlet works, such as a gated discharge pipe and/or decant structure, capable of adequately handling peak inflow rates, somewhat less than those resulting from the design storm, without over-topping.)

An emergency spillway is intended to safely pass the design peak-flow rate that cannot be handled by storage behind the embankment (freeboard) and by discharge through the principal outlet. Emergency spillway design considerations include allowance for ample freeboard while the spillway is discharging the peak design flow rate and adequate erosion protection for the discharge exiting the spillway. That discharge would be at a relatively high elevation and potentially have to traverse the entire downstream face of the embankment prior to discharge into the watercourse below the embankment. If practical, good design practice would locate the emergency spillway discharge at a point away from the embankment in a more erosion resistance material.

#### 6.3.1.7 Summary

Consideration of the measures mentioned above during the planing for, design and construction of a surface water control system and each of its elements will greatly reduce the environmental impacts of mining associated with surface water quantity.

### 6.3.2 SURFACE WATER QUALITY

#### 6.3.2.1 Sediment Control Systems by R. C. Warner

##### *6.3.2.1.1 Introduction*

The design, cost and effectiveness of stormwater, erosion and sediment controls for mining are enumerated.

Erosion controls encompass items that primarily influence the generation of sediment and include areal coverage by vegetation, mulches and mulch anchoring methods. Mechanically prepared surface modifications such as contour furrows, pitting, and ripping are addressed separately. Terrace systems provide a reduction of the slope length, thus reducing erosion, increasing deposition of sediment, and convey stormwater. The primary function of diversions is to convey stormwater in a channel that remains stable and has an adequate discharge capacity. Sediment separation and flow detention devices include vegetative filter strips (VFS), silt fences, sediment basins, and swirl concentrators.

The effectiveness of various control methods is difficult to quantify since soils, climate, and site conditions differ greatly from region to region. Also, research data often only addresses sediment trap efficiency and not the retention of individual particle sizes. Thus prediction of effluent concentration is not always available. For instance, an eroded silty loam soil, on steep topography, in the humid east will be more difficult to deposit within a sediment basin than a predominantly sandy soil on relatively flat terrain in the arid west. Thus a single sediment trap efficiency for the same basin is not available, hence basin effectiveness is estimated based on specific hydrologic watershed response to a design storm for the soil and site conditions. Furthermore the effectiveness of a basin will be highly influenced by the specific design decisions regarding type, size, and location of principal spillways, hydraulic characteristics of the basin, etc.

The effectiveness of erosion control measures is based on the Revised Universal Soil Loss Equation (Renard, 1991) and numerous studies of mulches, tackifiers, and commercially available products. The effectiveness of surface water reduction methods is based on large scale studies conducted in the western United States. Very limited data exists on the sediment trap efficiency of terrace systems along the terrace itself. Thus effectiveness estimates are based on the P-factor of the RUSLE, reduction of slope length, and limited analysis of terrace design methodologies. Diversions may retain sediment but are usually designed to convey runoff. Data on vegetative filter strips is excellent as long as shallow, uniform, overland flow can be established and maintained. If concentrated flow exists then published predictive techniques are lacking. The predicted effectiveness of sediment basins is good for overall sediment trap efficiency and is adequate for predicting effluent concentration. Field data for predicting the sediment effluent concentration from the newest basin passive dewatering systems does not exist except for limited grab samples and estimates are based on extensions to standard sediment basin designs. Filter fabric fences have been researched in the laboratory but little field data exist. The predicted effectiveness of filter fences is usually based on a "standard" particle size distribution, which may not accurately reflect regional soil conditions and which could cause clogging of the fabric and subsequent failure of the control. The swirl concentrator research is promising but, as with other controls, is based on large scale laboratory investigations.

Most of the data available on the effectiveness of controls simply addresses the overall sediment trap efficiency for a particular set of test conditions. Very limited data is available on the overall effectiveness of controls that entail effluent sediment concentration and stormwater infiltration, reduction, and stormwater discharge. Effectiveness of controls is primarily based on the incoming eroded sediment particle size distribution, flow rate, and the design attributes of the control.

#### *6.3.2.1.2 Cost Effectivenes*

The cost effectiveness of a stormwater, erosion and sediment control system is based on the sediment control efficiency of individual controls, a combination of controls, and the regulatory requirements. Effectiveness of an individual control can be measured in various ways: 1) comparison to an alternative baseline condition, such as a mulched area compared to a bare unprotected soil surface condition; 2) the sediment trap efficiency of a control such as a sediment basin, filter fabric silt fence, or vegetative filter strip; and 3) the peak flow reduction afforded by contour furrows, pitting, etc. When viewed with respect to alternative baseline conditions control effectiveness is highly dependent upon the mine plan and reclamation plans. The effectiveness of individual measures cannot be simply multiplied together to obtain a measure of the effectiveness of a combination of controls or a comprehensive control system. For instance, a terrace that is designed to retain a portion of the eroded material generated from the upslope area will capture a portion of the sand size particles. If the terrace is followed by a sediment basin the basin trap efficiency will be reduced since the incoming sediment particle distribution will have been previously treated by the terrace and the more easily retained particles have already been trapped. Several previous studies have simply determined the effectiveness of individual controls, assigned a value such as 70%, and then determined the combined effectiveness of a system of controls by multiplying individual control values. This simple type of effectiveness assessment ignores the true linked conditions of a system of controls.

To accurately determine the effectiveness of control measures, effectiveness must be related to the ability to meet regulatory constraints. The predominant sediment standard in mining in the U.S. is based on a settleable solids determination by using the Imhoff cone. Thus the clay size fraction, which does not readily settle in an

Imhoff cone are essentially disregarded and control measures are directed toward retention of the sand and silt size fraction. It should be noted that such a control strategy does not address the complete potential impact on the fluvial system, fish, or aquatic invertebrates. It is well known that fish and invertebrates are influenced by the concentration-duration-frequency of transported sediment and not only an assessment of a single discharge value.

The approach taken in this section is to provide information on the design technology that will help enable an assessment of the control effectiveness of both individual controls as well as a system of controls, cost of such control measures, and the ability to meet regulatory constraints. A simplified approach was taken to provide an estimate of the effectiveness of individual controls. To determine the efficiency of a combination of controls a comprehensive model such as Sediment, Erosion, Discharge by Computer Aided Design (SEDCAD+) (Warner and Schwab, 1990) can be used. Additionally applied research on sediment controls is needed to provide a stronger basis for models and estimates of effectiveness.

#### *6.3.2.1.3 Stormwater Design Consideration*

Prior to assessing the effectiveness of stormwater, erosion, and sediment controls it is necessary to address rainfall- runoff conditions. Sediment control measures are usually based on a specified design storm (e.g., 10 yr.-24 hr.) precipitation amount, temporal distribution of precipitation, and the infiltration characteristics of the land surface. Storm depth-duration-frequency values are provided in HYDRO-35 (Frederick et al., 1977) and Weather Bureau TP40 (Hershfield, 1961) for the eastern U.S. and in a series of National Oceanic and Atmospheric Administration (NOAA) Atlases for 11 Western states. To develop a storm hydrograph, it is necessary to know the design storm-duration- frequency (e.g., 4.2 in. or 107 mm, 10 yr.-24 hr.) and the temporal pattern of rainfall throughout the duration of the storm. The rainfall pattern is usually associated with a synthetic rainfall distribution such as the Soil Conservation Service (SCS) Type Curves.

Soil Conservation Service type curves are applicable to specific regions throughout the U.S. (Anon., 1986a). Such design storm information can be used to estimate the erosive power of the storm (Renard, 1991).

When only stormwater conveyance is of interest, such as in the design of culverts and nonerodible channels, only the peak flow needs to be estimated. The rational method is useful for peak flow estimates. To determine the effectiveness of sediment controls, which requires storm routing, development of a complete hydrograph is required. Development of a hydrograph is more complex but has been simplified through computer programs such as Sediment, Erosion, Discharge by Computer Aided Design, SEDCAD+(Warner and Schwab, 1990, and Anon., 1986a).

#### *6.3.2.1.4 Sedimentology Consideration*

To predict the effectiveness of surface treatments, terraces, and sediment basins it is first necessary to determine the quantity and particle size distribution of sediment eroded from a slope. The amount of erosion generated from a slope depends on the erosive power of rainfall and runoff, soil characteristics, slope length and gradient, and the type of soil treatment and conservation practices utilized. These parameters have been combined into the Universal Soil Loss Equation (Wischmeier and Smith, 1978) and recently extended by the Revised USLE (RUSLE) (Renard, 1991):

$$A = R\,K\,LS\,C\,P \qquad (6.3.2.1.4.8)$$

where A is soil loss per unit area generated from the slope in tons/ac (Mg/ha); R is a rainfall-runoff factor; K is a soil erodibility factor; K is soil erodibility factor; LS is a dimensionless length-slope factor that accounts for the actual length and slope gradient compared to a standard 9% and 72.6 ft (22.1m) in length; C is a factor that accounts for the effect of vegetal cover, mulches etc.; and P is a factor that accounts for the effectiveness of conservation practices such as terraces. (See Section 6.1.4.7, Modelling of Erosion, for additional discussion.)

Values for these factors can be found in (Renard, 1991). Average annual R factors can readily be found from a series of maps provided in the RUSLE manual (Renard, 1991). This information is useful for estimating the annual effectiveness of controls. Similarly, R values for 15-day intervals throughout the year are listed in the RUSLE manual, which are useful in evaluating seasonal effects and in the temporal placement of control measures. To determine the effectiveness of a control measure it is necessary to calculate a design storm R value (Hotes et al., 1973):

$$R_{st} = 19.25\,P^{2.2}/D^{0.47} \qquad (6.3.2.1.4.9a)$$

$$R_{st} = 2.48\,P^{2.2}/D^{0.47} \qquad (6.3.2.1.4.9b)$$

where P is the precipitation in inches (mm) and D is the storm duration in hours. These equations are based on the SCS Type II storm distribution.

The quantity of erosion is also dependent on the soil characteristics. Table 5 lists estimated soil erodibility K values as a function of soil texture, i.e., the distribution of primary sand, silt, and clay particles. The representative slope length and gradient of a subwatershed is compared to the standard erosion plot to determine the LS factor. Usually the slope length and gradient factors are evaluated together. The average erosion due to slope

length varies as:

$$L = (l/72.6)^m \quad (6.3.2.1.4.10a)$$
$$L = (l/22.1)^m \quad (6.3.2.1.4.10b)$$

where L is the slope length factor, l is the horizontal projection of the slope length in feet, and m is a slope length exponent that is related to the ratio B of rill erosion (caused by surface runoff) to interrill erosion (primarily caused by raindrop impact). The predictive equations are (Foster et al., 1977 and McCool et al., 1989):

$$m = B/(1+B) \quad (6.3.2.1.4.11)$$
$$B = (\sin \Theta/0.0896)/(3.0(\sin \Theta)^{0.8} + 0.56) \quad (6.3.2.1.4.12)$$

where B represents low, moderate and high rill/interrill values and $\Theta$ is the slope angle. The slope factor, S, equals 10.8 sin $\Theta$ + 0.03, and 16.8 sin $\Theta$ - 0.50 for slopes less than or greater than 9%, respectively. The RUSLE manual list LS values as a function of slope length, slope gradient, and low, moderate, and high rill/interrill ratios. Additionally, LS values for thawing soils where most of the erosion is caused by surface flow are listed in the RUSLE manual. LS values for nonuniform slopes can also be calculated.

**Table 5** Typical Topsoil K Factors for the RUSLE

| | Estimated K value | |
|---|---|---|
| **Texture** | (ton/ac/R unit) | (Mg/ha/R unit) |
| Clay, clay loam, loam, silty clay | 0.32 | 0.72 |
| Fine sandy loam, loamy very fine sand, sandy loam | 0.24 | 0.54 |
| Loamy fine sand, loamy sand | 0.17 | 0.38 |
| Sand | 0.15 | 0.34 |
| Silt loam, silty clay loam, very fine sandy loam | 0.37 | 0.83 |
| Shale/sandstone spoil | 0.12 | 0.26 |

Table 6 lists C factors reported in the literature. These factors can be used directly to estimate the effectiveness of area coverage control practices such as mulching rates, grass cover, soils or spoil with rock fragments, etc. A more sophisticated estimation method for the C factor is described in the RUSLE manual. The P factor provides a method to account for terraces, runoff reduction methods,

**Table 6** Selected C Factors for the RUSLE

| Surface conditions | C Factor |
|---|---|
| Bare soil, seed bed prepared, racked smooth | 0.9 |
| Bare soil, seed bed prepared, rough graded | 0.8 |
| Bare soil, compacted by a bulldozer | 0.9-1.2 |
| Undisturbed forest with >90% ground litter and >75% effective canopy | 0.0001-0.001 |
| Undisturbed forest with 75 to 85% ground litter and 40 to 70% effective canopy | 0.002-0.004 |
| Undisturbed forest with 40-70% ground litter and 20-25% effective canopy | 0.003-0.009 |
| Rangeland/Idle Land, no appreciable canopy, 0% groundcover | 0.45 |
| Rangeland/Idle Land, no appreciable canopy, 40% ground cover | 0.10-0.15 |
| Rangeland/Idle land, no appreciable canopy, 80% ground cover | 0.01 |
| Rangeland/Idle land, 50% tall weed or short brush canopy, 0% ground cover | 0.26 |
| Rangeland/Idle land, 50% tall weed or short brush canopy, 40% ground cover | 0.07-0.11 |
| Rangeland/Idle land, 50% tall weed or short brush canopy, 80% ground cover | 0.01-0.04 |
| Clear Cut Woodland, 20% residue on soil surface | 0.06-0.44 |
| Clear Cut Woodland, 60% residue on soil surface | 0.05-0.20 |
| Straw mulch at 1 ton/ac (2.26 Mg/ha) | 0.1-0.2 |
| Straw mulch at 2 tons/ac (4.52 Mg/ha) | 0.02-0.08 |
| Woodchip mulch at 2 tons/ac (4.52 Mg/ha) | 0.65 |
| Woodchip mulch at 4 tons/ac (9.04 Mg/ha) | 0.4 |
| Woodchip mulch at 8 tons/ac (18.08 Mg/ha) | 0.1 |
| Rock mulch, 20% on soil surface | 0.55 |
| Rock mulch, 40% on soil surface | 0.30 |
| Rock mulch, 60% on soil surface | 0.18 |
| Rock mulch, 80% on soil surface | 0.08 |
| Grass cover <60 days after emergence | 0.1-0.4 |
| Grass cover >60 days after emergence | 0.05 |

Source: Adapted from Wischmeier and Smith, 1978.

and surface roughness. Refer to Tables 7 through 9 for P factors.

Through the use of C and P factors the effectiveness of controls can be estimated. The C factor information can be used directly for mulch and vegetation. This factor will show a reduction in the quantity of eroded material. The P factor can account for furrows on the contour, terraces with closed or open outlets, and mechanically prepared roughness on rangelands as a function of runoff

**Table 7** P Factors for Contour Furrows

| Slope gradient | P Factor | |
|---|---|---|
| | Furrow gradient | |
| (%) | 1% | 2% |
| <1.0 | 1.00 | 1.00 |
| 2 | 0.85 | 1.00 |
| 3 - 4 | 0.68 | 0.87 |
| 5 - 12 | 0.40 | 0.57 |
| 12-18 | 0.38 | 0.48 |
| 18 - 20 | 0.37 | 0.47 |
| 21 - 22 | 0.45 | 0.51 |
| 23 - 24 | 0.51 | 0.56 |
| 26 | 0.57 | 0.61 |
| 28 | 0.64 | 0.69 |
| 30 | 0.79 | 0.81 |
| >32 | 1.00 | 1.00 |

**Table 8** P Factors for Terracing[1]

| Terrace gradient[4] (%) | P Factor[2] |
|---|---|
| Closed outlets[3] | 0.05 |
| 0 (Level) | 0.10 |
| 0.1 | 0.13 |
| 0.2 | 0.17 |
| 0.4 | 0.29 |
| 0.6 | 0.49 |
| 0.8 | 0.83 |
| 0.9 | 1.00 |

[1]Foster and Highfill, 1983, Foster et al., 1991.
[2]P-Factor for sediment trap efficiency.
[3]Closed outlet allow no discharge at exit.
[4]The terrace grade is measured on the 300 ft section nearest to the outlet or 1/3 of the total terrace length, whichever is less.

reduction and slope. The P factor does not provide information on retention of individual particle sizes. For instance a P factor for a terrace will simply reduce the quantity of sediment that would be exiting a slope and not provide the particle size distribution that reflects sands size particle deposition.

### *6.3.2.1.5 Erosion and Sediment Control Measures*

#### *6.3.2.1.5.1 Vegetation and Mulches*

The use of Table 6 will be illustrated by contrasting a disturbed mine site with various control strategies. It is assumed that the mine is located in the Appalachian coal region, the 10-year, 24-hour design storm is 4.2 inches (10.67 cm), spoil consist of fragments of shale and sandstone, and the topsoil, to be used for reclamation, is a sandy loam. From Equation 6.3.2.1.4.9a and Table 5 the storm R and K values for spoil and topsoil are 102, 0.12, and 0.24, respectively. The spoil is assumed to be regraded to a 14% slope that is 300 ft (91.4 m) long, yielding an LS Factor of 5.11. The C factor for a denuded soil condition from Table 6 is 1. The spoil material is assumed to have a surface rock fraction of 40%. Surface rock functions as a rock mulch and will dissipate the energy of rainfall, thus reducing the erosion rate. This is reflected by using the rock mulch C factor of 0.30 thus reducing the erosion potential by 70%. Once reclamation is initiated the propensity for erosion losses is increased due the more erosive nature of the unstabilized topsoil. The effectiveness of utilizing various control techniques is given in Table 6. For example, straw mulch applied at 2 tons/acre (4.52 Mg/ha) yields a C factor of 0.035, whereas mulch that is combined with a tackifier will be more effective reducing the C factor to 0.025. To predict the quantity of erosion for these various scenarios the LS value is calculated from Equations 6.3.2.1.4.10a through 6.3.2.1.4.12; and multiplied by the R-storm factor, K-factor, and the C-factor. Results of these calculations are 41.9 Mg/ha for the spoil; and 280.4, 98.2, and 70.2 Mg/ha for the bare topsoil, straw mulch, and straw mulch with tackifier, respectively.

Once grass is established the C-factor is further reduced to 0.05 resulting in a generated erosion amount of 14.1 Mg/ha.

*Contour Furrows* - Contour furrows can decrease erosion, reduce runoff, and provide soil moisture needed for the initial establishment and continual development of vegetation. The effectiveness of contour furrows is dependent upon the ridge height, spacing between furrows, slope, severity of the design storm, and grade of the contour. The RUSLE Model provides a mechanism to estimate the effectiveness of some surface modification controls. The P factor is used to determine control effectiveness. To illustrate the methodology developed to determine the effectiveness of surface modifications a western U.S. mine site will be used. The mine is assumed to be located near the Four Corners area. The 10 year, 24-hour precipitation is 6.6 cm. Spoil and topsoil are both silty loam. It is assumed that the spoil is reclaimed to the approximate original contour of 6%. Slope length is 250 feet (76 m). Without any surface modification controls, the predicted sediment yield is 41.5 Mg/ha based on a storm R factor of 35, a K factor of 0.37, and a LS factor of 1.43. The effectiveness of alternative controls will be investigated through the use of the P factor. It is assumed that furrows are constructed 5 in (12.7 cm) high and placed on a 2% grade. Using the data from Table 7 it can be seen that the contouring P factor is 0.57. Table 7 was derived from

**Table 9** P Factor for Mechanically Prepared Land

| | Runoff eduction (%) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Slope | 25 year | | | | 50 year | | | | 75 year | | | |
| (%) | 0 | 2 | 4 | 10 | 0 | 2 | 4 | 10 | 0 | 2 | 4 | 10 |
| 1 | 0.09 | 0.10 | 0.11 | 0.13 | 0.08 | 0.09 | 0.11 | 0.13 | 0.07 | 0.08 | 0.11 | 0.13 |
| 4 | 0.16 | 0.20 | 0.27 | 0.34 | 0.12 | 0.17 | 0.26 | 0.33 | 0.09 | 0.15 | 0.24 | 0.33 |
| 10 | 0.30 | 0.40 | 0.57 | 0.74 | 0.22 | 0.34 | 0.54 | 0.74 | 0.14 | 0.28 | 0.51 | 0.74 |
| 20 | 0.52 | 0.72 | 1.00 | 1.00 | 0.37 | 0.61 | 1.00 | 1.00 | 0.22 | 0.49 | 0.95 | 1.00 |
| 40 | 0.93 | 1.00 | 1.00 | 1.00 | 0.64 | 1.00 | 1.00 | 1.00 | 0.35 | 0.87 | 1.00 | 1.00 |

RUSLE and provides an estimate of the effectiveness of contour furrows as a function of slope gradient and furrow gradient. If the 10 year, 24-hour design storm R exceeds 50 the methodology described in the RUSLE manual should be referenced.

*Terraces* - Terraces reduce erosion by shortening the slope length and reducing the transport velocity along the terrace thereby causing sediment deposition within the terrace. Terraces are designed to convey eroded sediment at nonerosive velocities. Closed or partially closed terrace outlets provide backwater effects that further increase sediment trap efficiency. P factors for terraces are given in Table 8. A closed outlet is either one that does not allow any discharge or slowly releases discharge through an outlet pipe or through a porous rock check dam. To ensure nonerosive transport conditions open outlet terraces are normally constructed at slopes less than 1%. As the slope for open outlet terraces is increased sediment deposition is reduced as reflected by higher P factors in Table 8.

*Mechanical Surface Modifications* - Surface mining in arid areas often utilize mechanical surface modifications such as ripping, pitting, and land imprinting. These controls usually increase infiltration and percolation, increase water holding capacity and surface roughness, increase seed germination and plant growth, and decrease runoff and erosion. The effectiveness of surface modifications is related primarily to runoff reduction. Infiltration is a function of the soil texture. In the arid southwestern U.S. runoff reduction can be quite significant because of the predominantly coarse soils. These controls often increase surface roughness thereby providing areas for sediment deposition. As time passes the effectiveness of mechanical surface modification controls decrease since depressions are filled with sediment and overall surface roughness is decreased. Table 9 lists P factors for surface modifications. Effectiveness is a function of runoff reduction, slope gradient, initial surface roughness, and years since implementation of the control. Most mechanical surface treatment research has been conducted in the western U.S. Pitting has shown a runoff reduction of approximately 20%. Ripping may reduce runoff by 80 to 90%. To use Table 9 it is recommended that the reader consult mechanical-surface-modification applied literature, in the region of interest, to determine runoff reduction and estimate surface roughness associated with a specified control technique.

*Filter Fabric Fences* - Filter fabric fences are designed to detain sediment-laden flow long enough to allow the larger size sediment particles to be deposited in the backwater area and to filter medium-size particles prior to passage of runoff to downstream areas. Fabric water transmission rate and sediment trap efficiency must both be balanced in selecting a filter fabric fence. A thick fabric with a small equivalent opening size (EOS) will initially provide an excellent sediment removal efficiency but exhibit poor water flow through characteristics and have a higher probability of clogging. The sediment trap efficiency of a silt fence depends upon the relationship between the size distribution of the incoming sediment load and the mesh size of the fabric. Specifically the filtering action of a geotextile fabric depends upon the filter composition, EOS, thickness, and the water transmission rate of sediment-laden flow. It is also functionally related to the incoming eroded particle-size distribution, peak flow, and effectiveness changes with time due to clogging.

Fisher and Jarrett (1984) evaluated six synthetic filter fabrics and found tap-water flow rates ranging from 15 to 130 gpm/ft$^2$ (10 to 88 l/s-m$^2$). The slurry flow rate is of

**Table 10** Application of Sediment Basin Design Principles

| | Design consideration | Implementation |
|---|---|---|
| 1. | Location of inflow channels | Locate inlet(s) to provide the hydraulically longest flow path between inlet(s) and outlet(s). This will help reduce short circuiting of flow. |
| 2. | Inlet flow channel gradient | Provide a wide, shallow slope entrance. Stabilize steeper slopes with rock riprap or equivalent protection to avoid severe gully formation. |
| 3. | Size of principal spillway | Size to significantly reduce the incoming peak flow to near pre-mining conditions. |
| 4. | Location of principal spillway | Depending on size, and associated flow rate, locate a minimum of at least 2 to 3 ft above the sediment storage level. Also, locate farthest point away from inlet (s). |
| 5. | Pool length to width ratio (L/W) | The L/W ratio measured at the crest of the principal spillway should be 2:1 or greater. |
| 6. | Basin shape | Provide a L/W ratio of 2:1 or greater and the basin deep enough such that resuspension of settled sediment is avoided. Refer to design considerations 4 and 5. |
| 7. | Sediment storage | Base sediment storage needs depend on (1) estimated sediment loads for at least the life of the project or (2) for the expected sediment load associated with the 10-yr, 24-hr de sign storm. Sediment storage volumes, based on project life, may be reduced dependent upon a sediment removal plan. |
| 8. | Permanent pool storage | Both advantages and disadvantages exists for permanent pools in contrast to a de-watered or partially dewatered pool. The major advantage is dilution of the incoming sediment concentration. Disadvantages are: (1) higher peak flow discharged and greater peak stage, (2) increased fall depth of incoming sediment prior to retention in the sediment storage area, (3) shorter detention time, and (4) discharge of warm, low-oxygen water during summer months. |
| 9. | Pool dewatering (gated risers, perforated risers, stationary and floating siphon tubes, small trickle tubes) | Dewatering provides numerous advantages when compared to the permanent pool option: (1) lower peak discharge, (2) lower storage volume, (3) higher sediment trap efficiency. |
| 10. | Detention storage (time difference between inflow and outflow hydrograph peaks or hydrograph centroids) | Detention storage is an indicator of basin performance. Longer detention times indicate reduced peak flow and potentially more efficient sediment trapping. |
| 11. | Inlet baffles, turbidity curtains, and internal check dams | All of these devices increase the flow path between inlet(s) and outlet(s). In addition, they decrease dead stor age, which improves sediment trap efficiency. |
| 12. | Flocculation additives | Long chain polymers create flocs, a group of soil particles, which settle at rates significantly faster than individual soil particles, thus increasing sediment trap efficiency. |
| 13. | Outlet stabilization | The outlet of principal and emergency spillways should be stabilized by energy dissipators such as impact pools constructed of rock riprap, gabions, or concrete-slurry-filled geotextiles to avoid down stream bed scour. |

more importance and ranged from 4.5 to 99 gpm/ft$^2$ (3 to 66 l/s-m$^2$). In contrast Wyant (1980) found slurry flow rates predominantly in the range of 0.1 to 0.6 gpm/ft$^2$ (0.07 to 0.4 l/s-m$^2$). Both investigators used sandy, silty and clayey soils for their experiments. Based on Fisher and Jarrett (1984) research the sediment trapping efficiency of various filter fabrics ranged from 90 to 100% for sandy soil, 60 to 91% for coarse silt soil and 1 to 22% for the silty clay soil. Wyant (1980) found much higher sediment trap efficiencies: 92 to 100% for the sandy soil, 84 to 100 for the silty soil, and 85 to 99 for the clayey soil. Based on Wyant's work it can be con cluded that the sediment trap efficiency of filter fabric fences is predominantly 90 to 95%. The Virginia Highway and Transportation Research Council (Wyant, 1980) recommends a flow rate of 0.3 gpm/ft$^2$ (0.2 l/s m$^2$) and a sediment trap efficiency of 97% for silt fence when overland flow is treated and the drainage area is less than 1 ac (0.404 ha).

*Porous Rock Check Dams* - The trap efficiency of porous rock check dams is a function of the eroded particle size distribution, peak flow, porosity of the check dam, and characteristic of the inflow channel such as Manning's n, width and side slope. Trap efficiency, based on a first-step-backwater curve analysis and Stokes' Law, for a porous rock check located across a triangular channel, with a channel side slope of 3H:1V and on a 1% slope is 100, 30, 7, 2, and 1% for 0.188, 0.094, 0.046, 0.023, and 0.012 mm particles size, respectively (Warner and Hirschi, 1983). Predictive algorithms have been incorporated into the SEDCAD+ model.

*Vegetative Filters* - Grassed filters have been shown to be quite effective in removing sediment as long as stormwater enters the filter strip as overland flow (Hayes et al., 1981). Concentrated-flow-sediment-trap efficiency is significantly reduced. The function of a grass filter is to decrease the sediment transport capacity, increase the infiltration rate and provide a limited space for sediment storage. Efficiencies are highest for shallow uniform flow that does not submerge vegetation. Important design considerations encompass the relationship between peak flow rate and depth of flow within the grass filter, which is based on selection of filter width and slope. Filter length provides sediment storage capacity and increased opportunity for infiltration and interception by grass blades. Design parameters beyond those mentioned are grass height, spacing, and retardance coefficient; and Manning's roughness coefficient. A graphical sediment trap procedure has been developed but often parameters are out of range of the solution method (Hayes et al., 1981). Through laboratory and field investigations vegetative filters have been shown to achieve efficiencies of 90% (Hayes et al., 1981). The vegetative filter algorithm has been incorporated into the SEDCAD+ version 3.0 model (Warner and Schwab, 1990).

*Sediment Basins* - Sediment basins are used to reduce peak flow and trap sediment. The efficiency of basins to accomplish these two functions is directly related to the basin design with respect to 1) location and gradient of inflow channel(s); 2) selection of type, size, and location of principal and emergency spillways; 3) length-to-width ratio of the pool measured at the crest of the principal spillway; 4) basin shape; 5) percentage of basin capacity allocated to sediment and permanent pool storage; 6) dewatering method(s); 7) detention storage; 8) inlet baffles, turbidity curtains, and internal check dams; 9) use of flocculation additives; etc. As can be seen from this list of engineering considerations, the performance of a sediment basin in reducing the incoming peak storm flow and retaining sediment is directly achieved through design rigor. To enhance sediment trap efficiency consider the function of each of the design factors as explained in Table 10.

A cost-effective sediment basin design that is expected to minimize the hydrologic impact to offsite streams is illustrated in Fig. 7 through 9 (Warner and Schwab, 1989.) The function of the identified features in these figures is described. The length-to-width ratio is approximately 2:1. Due to the higher efficiency of the internal check dam the length-to-width ratio may be reduced. Incoming flow energy is dissipated by the rock-impact pool at the basin entrance. The internal check dam is used to accomplish many functions. It further slows and spreads out the incoming flow by rapidly creating a pool of water in the primary chamber. The larger-sized sediments rapidly settle out in this forward chamber, that, in combination with the access road and/or a check dam wide enough for a backhoe, facilitates sediment cleanout.

Runoff from a small storm is contained in the primary chamber and is slowly dewatered by either a small drop-inlet perforated riser and/or a wide rock riprap French drain (see Fig. 8 and 9). As the primary chamber fills with the larger- sized sediment, it also acts as a slow sand filter that greatly increases the quality of discharged water. For larger storms, short circuiting and dead storage are substantially reduced since the internal check dam evenly distributes flow across the width of pool. The check dam is protected by a geotextile fabric and rock riprap or equivalent.

A drop-inlet perforated riser should be sized to reduce peak flow to near or below pre-mining conditions. The tapered riser perforations slowly dewater the storm pool, thereby providing additional storage for subsequent storms. This also reduces the peak stage, compared to the permanent pool option, thus reducing embankment construction cost. Dewatering reduces peak discharge, increases sediment trap efficiency with respect to total

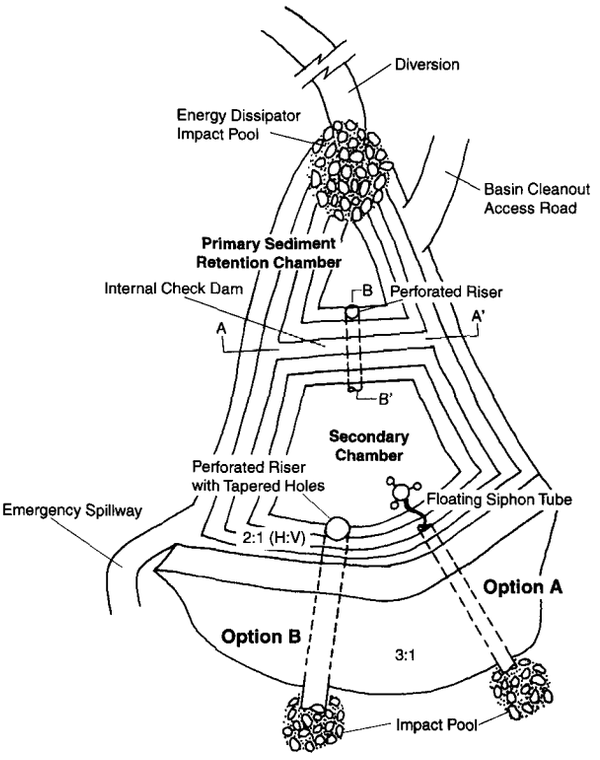



**Figure 7** A cost-effective sediment basin design to minimize the hydrologic impact of offsite streams (Plan view).

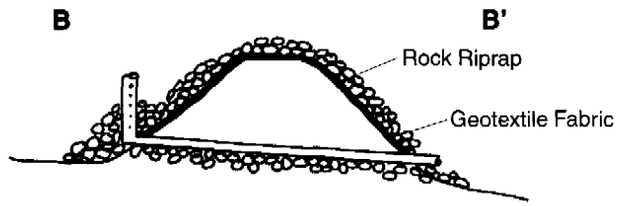



**Figure 8** A cost-effective sediment basin design to minimize the hydrologic impact of offsite streams (Section B-B').

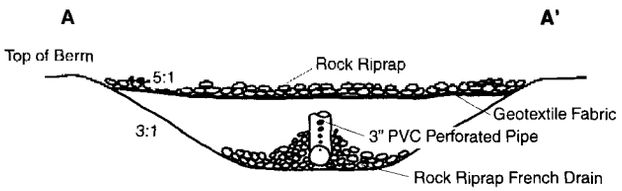



**Figure 9** A cost-effective sediment basin design to minimize the hydrologic impact of offsite streams (Section A-A').

sediment load, and reduces peak and average effluent sediment concentrations (Warner and Schwab, 1989).

Design of stormwater retention basins is facilitated by using computer programs such as DAMS2 that routes water through principal and emergency spillways. Principal and emergency spillway designs, stormwater and sediment routing, inflow and outflow hydrographs and sedimentgraphs, dewatering options, impact pools, sediment trap efficiency, effluent sediment concentration, embankment earthwork volumes, etc., can be calculated through use of the SEDCAD+ version 3.0 model (Warner and Schwab, 1990).

*Infiltration Basins* - An infiltration basin has no direct discharge for surface waters and is used to recharge an aquifer constructed during mountaintop or area mining. A vertical durable rock core is constructed during spoil placement to facilitate the rapid downward movement of stormwater. Infiltration basins have the advantages of recharging groundwater, complete containment of stormwater and sediment, relatively simple construction, avoidance of potential embankment stability problems, and allowance of a large degree of flexibility in a spatial siting.

*Swirl Concentrator* - The swirl concentrator has been designed to intercept sediment-laden inflow. The swirl concentrator separates sediment from the incoming flow through the centrifugal force generated by the inherent inertia of the flow (Warner and Mujiharjo, 1992). Effluent with a high sediment load is transmitted to a small sediment trap while the clearer flow is discharged directly to a stream.

The numerous advantages of this device calls attention to its use as primary sediment control structures on surface- mined lands. The device is relatively simple, containing no moving mechanical parts, and no onsite energy requirements are needed. Since it is relatively small, it can be easily transported on flat-bed trucks and modularized to facilitate rapid installation and relocation once reclamation and bond release have been accomplished. The added advantage of the swirl concentrator is that no sediment maintenance is needed since it is self-cleaning; that is, the concentrated sediment- laden flow, which represents 5 to 15% of the incoming flow, is automatically discharged to a small sediment basin. Sediment trap efficiency for a 3.5 cfs (0.0991 $m^3/s$) inflow rate and a 10% effluent setting is 100, 93, 82, 70, 67, 58, 54, 50, 45, and 43 for particle sizes 0.35, 0.30, 0.25, 0.18, 0.16, 0.12, 0.09, 0.053, 0.048, and 0.043 mm, respectively.

*6.3.2.1.5.2 Channel Habitat Enhancement*

Often mining operations require the relocation and reconstruction of streams or stream modifications to increase discharge capacity. An assessment of pre-mining stream parameters and an understanding of flow characteristics necessary for food production, spawning and cover, i.e., habitat, will greatly increase the opportunities for success. Besides stream morphologic

parameters an understanding of stream velocity, depth and substrate will facilitate construction of a balanced, diverse aquatic ecosystem.

*6.3.2.1.5.3 Planning*

The development of a successful reclamation plan that addresses stream considerations is based on the acquisition of pre-mining stream data. A base map normally displays a plan view of the channel, floodplains and generalized vegetation documentation. Such data can be readily obtained through aerial photos or the existing channel can be surveyed. A stream longitudinal profile is extracted that displays distance from a specified downstream location, reach segment number, length and slope of each reach, meander characteristics and cross-section measurements for each reach. The meandering pattern is described by wavelength, sinuosity (ratio of valley slope to stream slope), and radius of curvature. Numerous other meander patterns and characteristics can be helpful in stream reconstruction (Gore, 1985). Meandering has been identified as the primary vehicle of dissipating stream energy and is therefore a principal design tool for stream reconstruction.

A vertical profile of channel substrate should be detailed for each stream environment, i.e., pool and riffle. Each layer of the vertical profile should contain particle size composition. Note should be made of stream geometric factors such as cross-section shape, stream pattern (meandering patterns and braided), and pool-riffle patterns. Also location and description of point bars and cross currents should be noted.

*6.3.2.1.5.4 Stream Habitat Components*

To enhance stream relocations it is necessary to gain an understanding of the interplay among aquatic habitat factors and physical factors of stream velocity, depth and substrate. In a pool-riffle environment riffles function as food production and spawning areas. Riffles exhibit relatively shallow depths, higher than average velocity, and coarser substrate than pools. Velocity is the primary parameter describing the distribution of aquatic invertebrates. Velocity in riffles governs the rate of oxygen transfer to properly sized substrate, i.e., rubble, boulders, cobbles, thereby supplying oxygen and removing metabolic waste products from intergravel areas. Water velocity increases the exchange rate thereby enhancing respiration and food acquisition. Optimal velocity is subject to debate but the range for riffle segments for good stream productivity is between 0.5 and 3 fps (0.15 and 0.9 mps) (Delisle and Eliason, 1961). A narrower design range is 1 to 2 fps (0.3 to 0.6 mps) (Giger, 1973). Velocity controls substrate size to a large extent. The larger size rocks are associated with riffle areas since sands and silt are removed by the higher current velocity. Benthic invertebrates decrease in number and diversity as substrate is changed from rubble to coarse gravel to fine gravel and sand. Rubble appears to play a key role in the riffle environment. It provides a broad surface for invertebrates to cling to and functions to protect insects from high velocities (Gore, 1985). Velocity also functions as the vehicle for drift, which is the movement of organisms downstream by current. Drift supplies the mechanism to acquire food, which advances increased population densities and diversity.

Depth controls to a great degree the intensity of light, which controls photosynthetic production of food. Deeper waters are less productive and contain fewer invertebrates than shallower riffle areas. Depth of highest productivity in trout streams range from 0.5 to 3 ft (0.15 to 0.9 m), provided that current and substrate are suitable (Gore, 1985).

The parameters of velocity, depth and substrate combine in the riffle environment to provide an optimal habitat for aquatic invertebrates (Gore, 1985). The repetitive pool-riffle succession creates an excellent habitat for food production, spawning, cover, and resting. Stream cover can take many forms. Bank cover is provide by overhanging vegetation and undercut banks whereas in-stream cover is found by aquatic vegetation and the larger substrate. When reconstructing, stream cover is essential. Elser (1968) found a reduction of 78% less trout in a stream having 80% less cover.

*6.3.2.1.5.5 Structures to Enhance Stream Habitat*

Structures such as current deflectors, low profile dams, and the selective placement of boulders and substrate during channel reconstruction can enhance habitat. Such devices can locally increase velocity, create pools and scour holes, provide gravel trapping areas, remove silt from spawning areas, protect stream banks, enhance pool-riffle sequencing, aerate the water, reduce or increase water temperature, and generally both create enhanced habitat and simultaneously provide bank stabilization.

*Current Deflectors* - Current deflectors are structures extending outward from the streambank into the channel. Common terms for these devices are jetties, spur dikes, groins, etc. As with many controls deflectors have been reported to be both successfully and unsuccessfully employed. Wesche (1985) reviewed numerous applications and reported successes summarized by phrases such as "the number of age 1 and older brook trout had doubled in the modified reach"; "the number of good quality pools had increased from nine to twenty nine, average pool depth had increased by 0.5 ft (0.15m), and additional spawning gravel had been exposed"; and "...improved the carrying and reproductive capacity of the reach for trout, was cost effective when compared with stocking, and had their greatest effect on the substrate,

increasing the exposed gravel in each reach from 14 to 24 percent." Wesche (1985) also summarized failures such as "...deposition which occurred immediately downstream from the structure negated any habitat gains", "...deflectors were quite susceptible to damage and needed frequent repairs," and "flood flows reduced the ability of certain structures to concentrate the flow, while the pools provided little trout cover."

To be effective deflectors require application of design methodology and rigorous construction methods. Unfortunately few design aids exist for the proper sizing, location and spacing of deflectors. Consideration should be given to location along the reach, i.e., locate along a straight or concave (the bank at the outside of the bend) stream section, spacing among a sequence of deflectors, location of riffles, stability of the substrate, ability to anchor the deflector in the bank, bank height and stability, point-bar deposition location, bed transport, and specific deflector design parameters. Important deflector design parameters include the deflectors length, width, height, shape and orientation angle. Selection of these parameters will depend upon the channel width, water depth, and velocity besides those factors previously mentioned.

For habitat enhancement the development of scour holes at the tip and along the face of the deflector are also design considerations. It should also be noted that design for stability of the stream banks and the deflector itself may be based on a design discharge associated with a specified storm recurrence interval but the predicted size of a scour hole will remain a highly time dependent aspect due to the time-variability of stream discharge and sediment transport. Scour holes will progressively enlarge and be partially refilled during the rising and falling stages of the hydrograph. Thus available habitat scour hole size will vary throughout the flow regimes experienced by a stream.

Current deflectors influence the creation of primary and secondary scour holes, gravel and sediment deposition patterns, and the stability of stream banks across and downstream of the deflector. Localized increased-flow velocity occurs near the tip of the deflector resulting in the creation of the primary scour hole. Intermediate vortices occur both upstream and downstream along the deflector face. The size of the primary scour hole is functionally related to water density and viscosity; flow depth and velocity; deflector length, orientation angle with the downstream bank, and side slope; size, density and gradation of bed sediment; and sediment concentration of transported material (Klingeman et al., 1984). Klingeman et al. (1984) list nine predictive equations for primary scour hole size near current deflectors. Sediment deposition patterns vary depending upon the orientation angle of the deflector. Generally deposition occurs slowly in the lee of permeable dikes (Lindner, 1969) but due to decreases in flow velocity upstream deposition can also occur. To enhance habitat in the lee of the current deflector it may be designed to prevent overtopping during flood events thereby facilitating scouring by secondary eddy currents during normal flows.

Orientation angle recommendations are normally perpendicular, 90 degrees, to the flow; or downstream. However, Klingeman et al. (1984) notes that the upstream-oriented current deflector "is more effective in deflecting the current away from the bank than the downstream-oriented dike." That is, a greater distance occurs before the current returns to the downstream bank, thus bank stabilization is enhanced. Both orientation angle and deflector length influence scour hole development. Effective deflector length is the length perpendicular to the bank. As the effective deflector length and the orientation angle increases the size of the scour hole increases (Klingeman et al., 1984). The limiting feature is the effective length since as the length increases the flow section further contracts thereby creating the potential for an unstable stream bank opposite the deflector. Although no firm design recommendation exists it is generally recommended that the effective deflector length be less than one half of the stream width.

*Low Profile Dams* - Low profile dams are structures that span the entire width of a stream channel and may be constructed to point upstream, horizontal, or point downstream. Low profile dams are also called weirs or check dams and are usually located along relatively small, headwater streams that have steep gradients and lack adequate pool-riffle environment. As with deflectors low profile dams provide a broad spectrum of potential habitat enhancements: 1) creation of a pool by raising the water level thereby inducing upstream deposition of spawning gravel areas, facilitate fish passage, reduce overall channel scour, allows sedimentation of organic debris, and encourages the development of riparian vegetation, which further enhances bank stabilization and bank cover development; 2) creation of localized scour hole(s), which provides fish rearing areas and temperature regime stability; 3) stream aeration; and 4) formation of gravel bars downstream of the structure. These multifaceted benefits can be enhanced by the proper design, placement and construction of low profile dams.

Design elements encompass weir discharge capacity; shape of the downstream face, i.e., vertical, sloped or stepped; structural stability; energy dissipation; seepage control; and creation of the stilling pool by usage of multiple weirs. One relatively overlooked design parameter is the angle of the low profile dam and the influence of the angle on scour hole formation, size, and location. Klingeman et al. (1984) conducted a series of experiments regarding the influence of weir angle on scour hole and depositional area formation. Upstream

pointing low profile dams, i.e., with a weir apex angle of less than 180 degrees, created a single scour hole at the center of the channel due to the convergence of flow. The deepest scour hole existed for the 90 degree angle. The 60 and 120 weir apex angles resulted in the formulation of scour holes approximately 15% lower in maximum depth than the 90 degree angle. Overall scour hole size, i.e., maximum depth times width times length, was greatest for the 90 to 120 degree range of angles. The other advantage of the upstream facing low profile dam is that the scour hole is located at the center of the stream thereby reducing potential bank instability downstream of the weir. Downstream facing low profile dams create smaller symmetrical scour holes near the channel banks. The advantage to the downstream facing weir is the creation of a gravel bar at the center of the channel. Thus depending upon the type of habitat enhancements desired low profile dams can create various sizes of scour holes, placed either adjacent to the banks or centered in the channel, and can facilitate gravel depositional areas, as well as the other potential benefits previously enumerated.

*Boulder Placement* - Only general guidelines exist for the placement of boulders (Wesche, 1985). Either individual boulders or boulder patterns are commonly used. Clusters of boulders are often placed in triangular or diamond patterns. To increase the potential of boulder stability they should be embedded into the stream bed. Boulders ranging from 2 to 5 ft (0.6 to 1.5 m) have been reported to be successfully used (Wesche, 1985). Boulders should consist of durable rock and placement adjacent to stream banks should be avoided.

*Substrate Development* - The use of deflectors, low profile dams and placement of boulders affects the velocity - depth regime and create spawning gravel areas upstream of structures and downstream gravel bars. The key component to substrate establishment is the control of localized velocity. What is the proper size gradation of substrate to enhance macroinvertebrate production? A vertical profile of the bed material taken from existing established stream segments will yield representative information that if somewhat duplicated should provide background goals for substrate. Highest productivity and diversity of aquatic macroinvertebrates are found in riffle environments composed of gravel substrate intermingled with medium size cobbles (Gore, 1985). Also it is important to reestablish the sequence of pools and riffles. Although riffles provide macroinvertebrate habitat, alternating pools provide needed areas for fish habitat and benthic deposition. It may be difficult to establish spawning gravel areas if fine sediments are continuously being generated from watershed areas. Techniques previously detailed for the control of upland sediment should be used in unison with substrate establishment.

The stream bed will normally consist of a series of layers. Ideally these layers include a gravel base, fine sediment - gravel seal, gravel scour protection layer, and an armor layer to facilitate stream bed stabilization. Often in stream reconstruction the bottom three layers are replaced by a single layer consisting of a heterogeneous mixture of silt, sands, and small gravel placed in a series of shallow lifts. The upper armor layer then is required to provide the predominant substrate for habitat and for stream stabilization.

*6.3.2.1.5.6 Cost*

It should be noted that the cost of implementing erosion and sediment control practices is highly variable and depends upon availability and proximity of materials, prevailing labor rates, time of year, magnitude of indirect costs, and maintenance. Cost information is provided in 1994 dollars, on an area or unit basis such as per linear foot (meter) and includes material cost, labor (at $8.00/hour), equipment rental rates, and overhead and profit at 30%.

Vegetation and Mulches:
*Broadcast seed, fertilizer and lime*: temporary $275-350/ac ($700-875/ha); permanent $325-400/ac ($800-1,000/ha)
*Broadcast seed, fertilizer, lime and straw mulch*: $625-825/ac ($1,550-2,050/ha)
*Hydroseeder, seed, fertilizer, lime, mulch and organic binder*: $900-1,200/ac ($2,250-3,000/ha)
*Seed, fertilizer,lime and jute or excelsior mats:* $6,000-8,500/ac ($15,000-21,000/ha)
Silt Fence:
$2-4.50/linear ft ($6.50-15/linear m)
Straw Bale Barrier:
$3-5.50/ linear ft ($10-18/linear m)
Earthen Terrace:
$6-12/linear ft ($20-40/linear m)
Contour Furrows:
$1-2/linear ft ($3-6/linear m)
Porous Rock Check Dam:
2 ft (0.61 m) high and 15 ft (4.6 m) wide) $125-175
Vegetative Filter:
$600-800/ac ($1,500-2,000/ha)
Swirl Concentrator:
$5,000-8,000/unit
Sediment Basin:
$20,000-$50,000/unit (includes stripping, stockpiling, fill and compaction, principal and emergency spillways, and rock riprap energy dissipator)

Cost data was estimated based on discussions with contractors, evaluation of specific operations, and unit cost pricing that considered material cost and equipment and labor production rates. Various scenarios were

evaluated to develop the range of cost estimates. In general, the cost of eastern U.S. operations is less than western U.S. operations.

The determination of cost effectiveness is more difficult to ascertain. The initial cost of some measures may be greater than other controls but such items as the need for maintenance, repair or replacement were not factored into the cost estimates. The effectiveness of some control measures with respect to retention of sediment will decrease over time while others will remain relatively the same or improve. Similarly once a mining area is stabilized some measures will require removal while others can be left in place. The final complicating factor to predicting the cost effectiveness of a series of erosion and sediment controls is that the effectiveness of individual controls will be different depending upon the sequence of controls from sediment source areas to areas adjacent to streams. Optimization techniques such as dynamic programming combined with sophisticated hydrology, erosion and sediment control computer programs are necessary to predict the optimal mix and spatial placement of controls that yield the most cost effective solution.

### 6.3.2.2 Mine Drainage Systems by R. L. P. Kleinmann

#### *6.3.2.2.1 Effluent Limitation*

Effluent limits are discharge water performance standards imposed on the industry by federal legislation and enforced by the U.S. Environmental Protection Agency (EPA), the Office of Surface Mining, and various state agencies. The effluent limits are spelled out in the operator's NPDES permit and typically include, at a minimum, effluent limitations for pH, iron, and manganese. For example, at most coal mines, the pH of the effluent water should be between 6 and 9, and iron should never exceed 6 mg/L, and on average should not exceed 3 mg/L. If the mine water is naturally alkaline, manganese may not be regulated, but if the water is acidic, then manganese is generally limited to a maximum of 4 mg/L and an average of 2 mg/L. In acidic coal mine drainage, the manganese standard serves primarily as a surrogate for eight other more toxic metals that are sometimes present at low concentrations. EPA concluded that manganese toxicity from coal mine drainage was not a serious problem, but that since water treatment to remove manganese also precipitates the more toxic contaminants, the manganese standard was imposed to avoid additional regulatory limits on other metals (Kleinmann and Watzlaf, 1988).

Since metal mines may have higher levels of potentially toxic contaminants, effluent limits are often placed by regulatory agencies on additional parameters, such as arsenic, chromium, copper, cyanide, lead, mercury, selenium, nickel and zinc, and sometimes aluminum and sulfate. The imposed standards vary from site to site and from state to state, and are sometimes set at or below the detection limits by state regulatory agencies eager to protect stream and groundwater quality.

The long-term cost of complying with these effluent limits should be carefully considered before mining commences. Considering such costs in advance of mining also allows one to consider what can economically be done, prior to final reclamation, to minimize water treatment obligations. This may involve selective mining or selective handling during mining or simply choosing a water treatment system that is relatively inexpensive to maintain and operate. At many sites, such water treatment liability will continue for decades after mining is completed. Failing to factor in this obligation can, over the long-term, lead to bankruptcy.

#### *6.3.2.2.2 Mine Water Treatment*

##### *6.3.2.2.2.1 Chemical Treatment*

Mine water is commonly acidic and contaminated with various dissolved metals and high concentrations of sulfate. Generally, to remove the dissolved metal contaminants, the acidity must be neutralized. Most commonly, lime (CaO or $Ca(OH)_2$) is used to treat moderate to high flows of mine water, and more expensive but more convenient reagents, such as anhydrous ammonia ($NH_3$), soda ash ($Na_2CO_3$), and solid or concentrated solutions of caustic soda (NaOH), are used to treat relatively low flows (Skousen et al., 1990, Anon., 1983b). Making the water alkaline causes most dissolved metals to hydrolyze and precipitate, though the pH at which this in practice occurs ranges from 5.5 to 10.2 for various metals. Dissolved metals may also have to be oxidized before precipitation normally occurs; iron and manganese, both of which are common contaminants, follow this pattern. Passive or mechanical aeration is generally relied upon, with chemical oxidants such as $H_2O_2$ being an expensive alternative. If oxygen is not limited, oxidation rates generally increase at higher pH. Iron oxidation, for example, increases 100-fold for each unit increase in pH during neutralization. Therefore, aeration either follows or accompanies neutralization.

After the contaminants precipitate as hydroxides, they must be separated from the water. Most commonly, the water is retained in a series of ponds to allow the precipitates to settle out. Alternatively, the water can be separated from the particles by other means, such as by using a clarifier. In general, the use of a sodium-based alkaline reagent to raise the pH can yield precipitates that are more difficult to settle from solution than those resulting from calcium-based reagents. Thus, at many sites, increasing the Ca:Na ratio will decrease settling

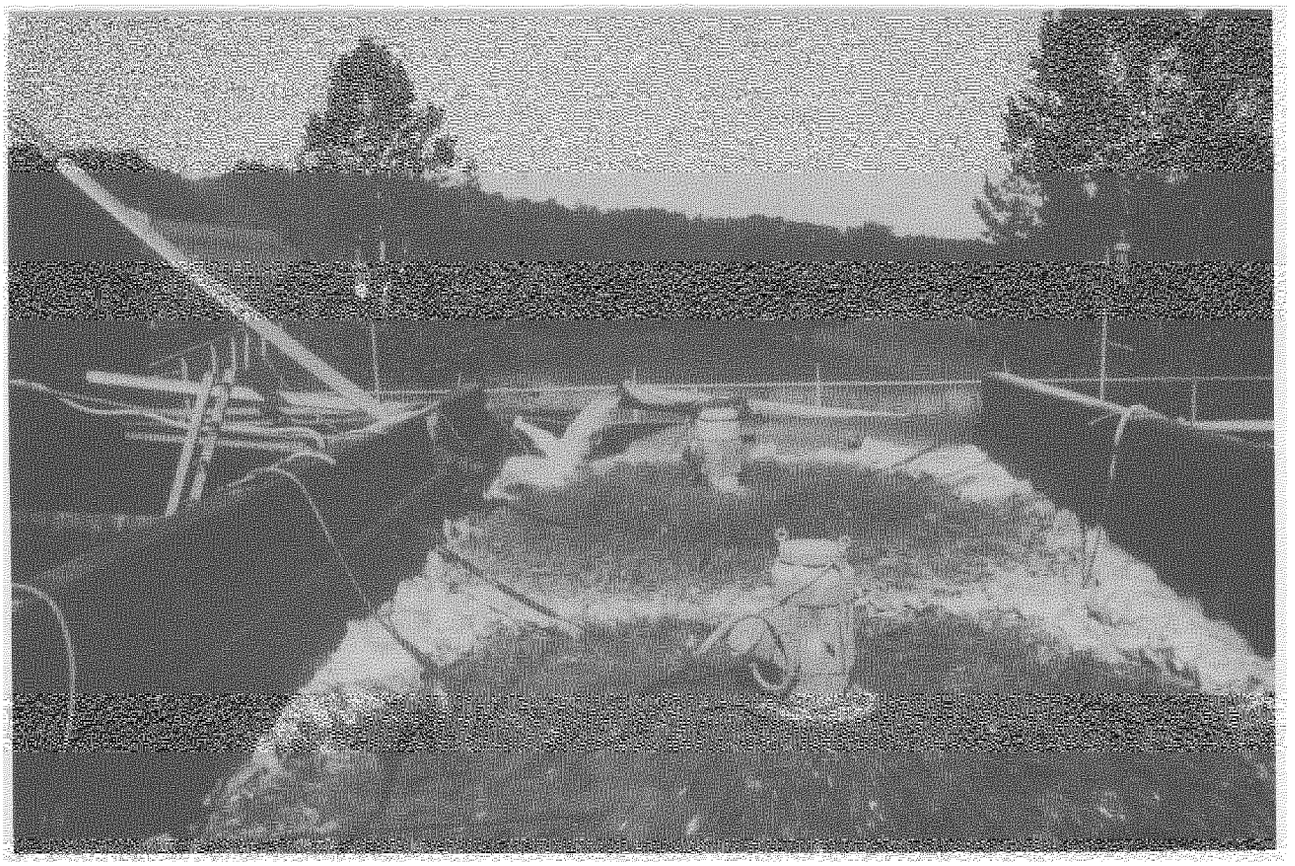


**Figure 10** Conventional aeration and neutralization of acidic mine water.

time (Evangelou and Warner, 1983). Another approach is to use a flocculating or coagulating agent. These must be selected carefully as each reagent's effectiveness is strongly dependent on water chemistry.

Figure 10 shows a conventional water treatment system using a neutralization and aeration tank. A slurried mixture of lime and water is being added to a flow of 1500 gpm of acidic mine water. The mechanical aerators in the foreground are adding oxygen to the water, thereby allowing the dissolved iron and manganese to oxidize and hydrolyze in the now- alkaline water.

An alternative approach is to neutralize and aerate the mine water in transit. This approach is typified by the In-line System, or ILS, developed by the U.S. Bureau of Mines. As illustrated in Fig. 11, the air and alkaline agent is entrained into the water through a venturi orifice (or jet pump). A static mixer is then used to enhance dissolution. There are no moving parts; everything is powered by water pressure in the line. Experience indicates that the ILS is much less expensive to install and maintain than a conventional facility and that its enhanced aeration and mixing action can decrease chemical usage by as much as 30% (Ackman and Kleinmann, 1991). However, the ILS-treated effluent water, like that of a conventional facility, requires a settling pond or solids separation process.

The settled solids are an amorphous mixture of metal hydroxides and oxyhydroxides, and if lime was used as the alkaline agent, gypsum ($CaSO_4$) and, quite commonly, unreacted lime. This mixture, commonly referred to as acid mine drainage (AMD) sludge, accumulates rapidly, occupying as much as 30% of the volume of all the water treated. The sludge must periodically be removed from the ponds or else it will decrease residence time. Depending on its constituents, the sludge may be innocuous or hazardous with respect to solid waste disposal regulations. Redissolution of some metals has been documented. Whether or not redissolution occurs depends on the metals present and the environment to which the sludge is subsequently exposed. For example, iron precipitates are stable above a pH of about 3.5 while some other metals, such as copper, manganese, nickel and zinc can redissolve upon exposure to even mildly acidic (pH 5.0 - 7.5) water.

*6.3.2.2.2.2 Passive Treatment*

Passive treatment of mine water has attracted a great deal

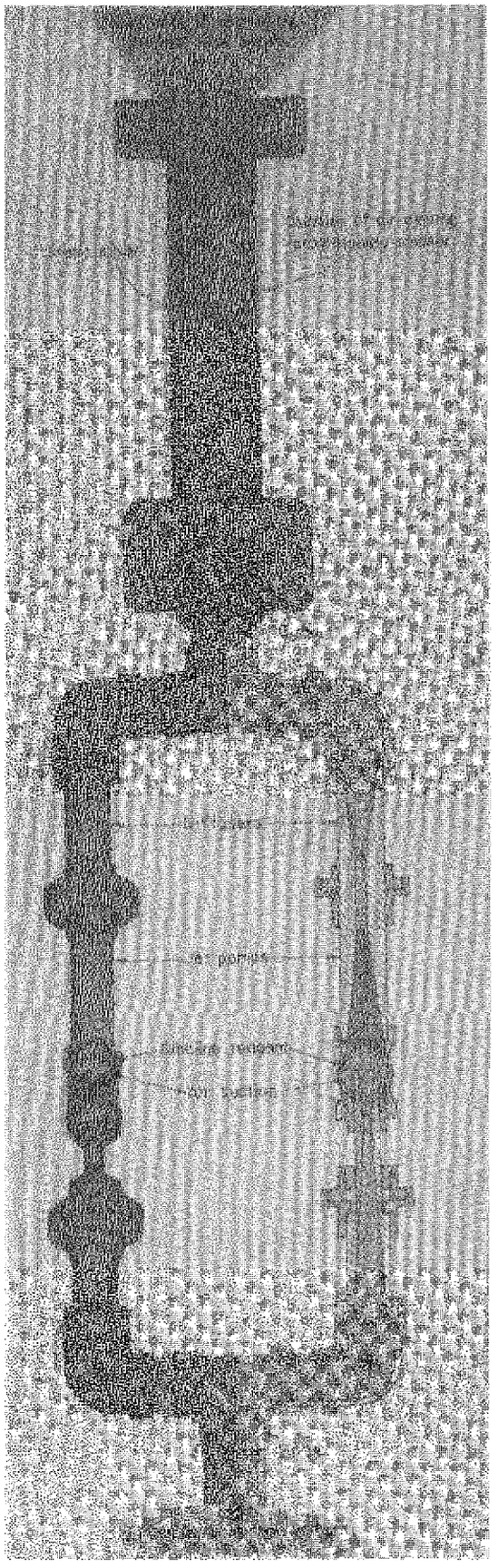


**Figure 11** A schematic of the In-line System (ILS) for aeration and neutralization of mine water.

of interest over the past decade. Initially considered appropriate only for very small flows, passive treatment systems have since been constructed for flows greater than 100 gpm (6.3 l/s). Passive treatment systems have proven to be highly cost-effective in the coal fields of the eastern United States, where over 500 have been constructed. There, they generally consist of simple marsh-type wetlands constructed in shallow ponds designed to enhance retention time and iron oxidation by natural bacteria. Composted organic material, which enhances the activity of sulfate-reducing bacteria, has been used as a substrate in most of these constructed wetlands as a means of reducing acidity and raising the pH. Frequently, limestone is added to the compost to increase alkalinity generation; within the compost, the limestone dissolves without becoming armored with ferric hydroxide, as would occur in an aerobic environment (Hedin and Nairn, 1993).

Dissolution of limestone is the basis of another passive technique, the anoxic limestone drain (ALD). An ALD is a french drain designed to intercept mine water before it is exposed to the atmosphere. Typically, the limestone in the drain is sealed or enclosed with plastic sheeting and clay to minimize oxygenation of the mine water and iron oxidation. With the dissolved iron kept in the reduced ($Fe^{2+}$) form, the limestone dissolves without becoming armored as it would if the iron was in an oxidized state ($Fe^{3+}$). The isolation also confines the carbon dioxide liberated during dissolution of the limestone, which enhances additional limestone dissolution. A well-constructed ALD can generate about 300 mg/L alkalinity (as $CaCO_3$). However, it can only be utilized where there is virtually no oxygen or ferric iron dissolved in the AMD. Aluminum can also cause problems as it precipitates as $Al(OH)_3$ in an ALD; the $Al(OH)_3$ does not actually armor the limestone, but over time the floc can reduce the porosity and nature of the flow paths of the ALD. Use of very coarse (2B - 3B) limestone is recommended to minimize this effect.

Upon exposure of the alkaline ALD-effluent to the atmosphere, ferric hydroxide will rapidly precipitate, so it is necessary to provide a retention pond for the precipitate to settle in. Depending on the initial mine water quality, this may be all that is necessary to meet effluent requirements; otherwise a constructed wetland is often staged down-gradient of the retention pond to provide additional passive treatment.

The appropriateness of these passive treatment technologies is a function of water quality. Fig. 12 is a flow chart of the decision process (Kleinmann and Hedin, 1993).

As already mentioned, these passive techniques have proven to be very useful in treating coal mine drainage but there has been very limited application with respect to metal mine drainage. Researchers are working on ways to utilize the $H_2S$ produced by sulfate-reducing bacteria to

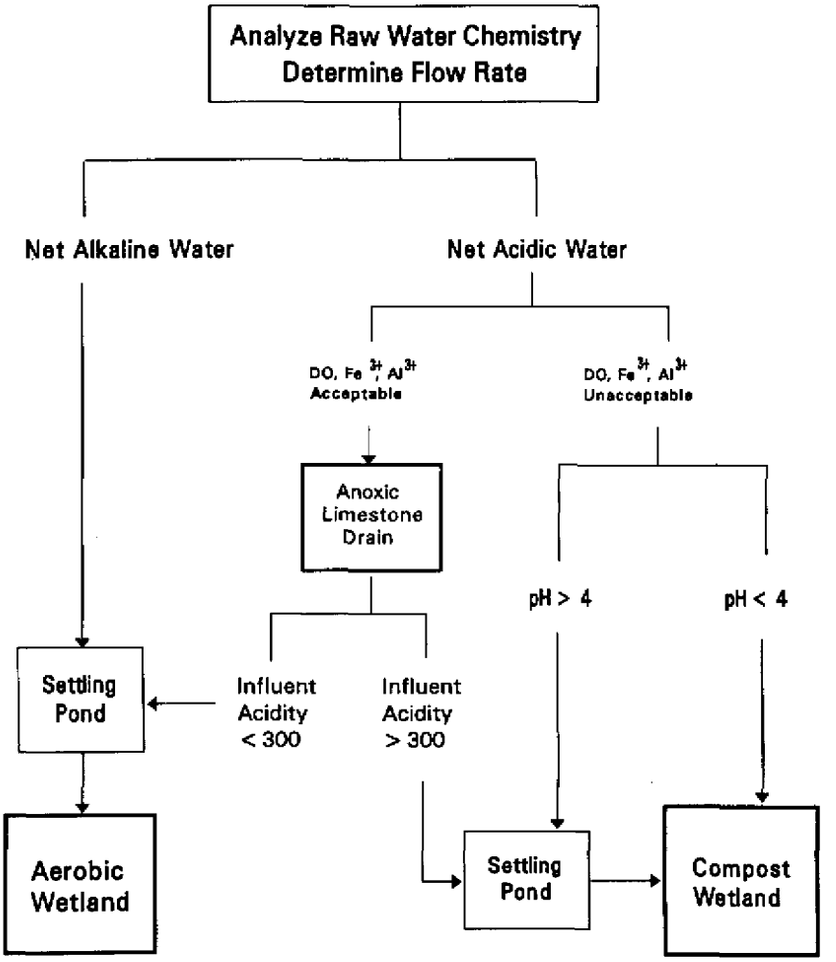



**Figure 12** A flow chart illustrating the decisions that must be made in designing a passive treatment system to treat coal mine drainage.

precipitate some of the metals of concern in closed vessels. Recent work indicates that some of the metals, such as copper, cadmium and zinc, can be sequentially precipitated separately from iron, making recovery of those metals potentially economical (Hammack et al., 1993). Based on on-going research, it appears that truly passive techniques are only applicable to fairly innocuous metal mine drainage, but that in the near future, it may be possible to reduce water treatment costs significantly for metal mine drainage water using less expensive technology developed as variants of passive treatment concepts.

Another approach potentially applicable at metal mines are porous polymeric beads that contain immobilized biological materials. These beads serve as inexpensive ion exchange media, and appear to be especially appropriate as a polishing step, because they can remove contaminants from very dilute solutions. Periodically, the beads have to be regenerated with an acidic solution, which produces a concentrated contaminant solution that must eventually be disposed of (Jeffers et al., 1992).

#### *6.3.2.2.3 Acid Mine Drainage Abatement*

Acid mine drainage results from the oxidation of pyrite ($FeS_2$) and other metal sulfides, by either oxygen or ferric iron ($Fe^{2+}$). Ferric iron becomes increasingly soluble, and therefore an important factor in pyrite oxidation, once the pH drops below 3. However, since the abiotic oxidation of ferrous iron ($Fe^{2+}$) is very slow at low pH, bacteria that obtain energy by oxidizing iron serve as catalysts in generating $Fe^{3+}$ and thereby causing pyrite to oxidize.

Figure 13 illustrates how, as pH decreases below 3, acidity and dissolved iron exponentially increase (Kleinmann et al., 1981). The cyclic oxidation of ferrous iron by bacteria and oxidation of pyrite by ferric iron, which in turn increases overall ferrous iron concentrations, is responsible for this effect. In the field, this cyclical process initially occurs only in the immediate environment of the most reactive pyritic material. At sites where alkalinity is present in sufficient

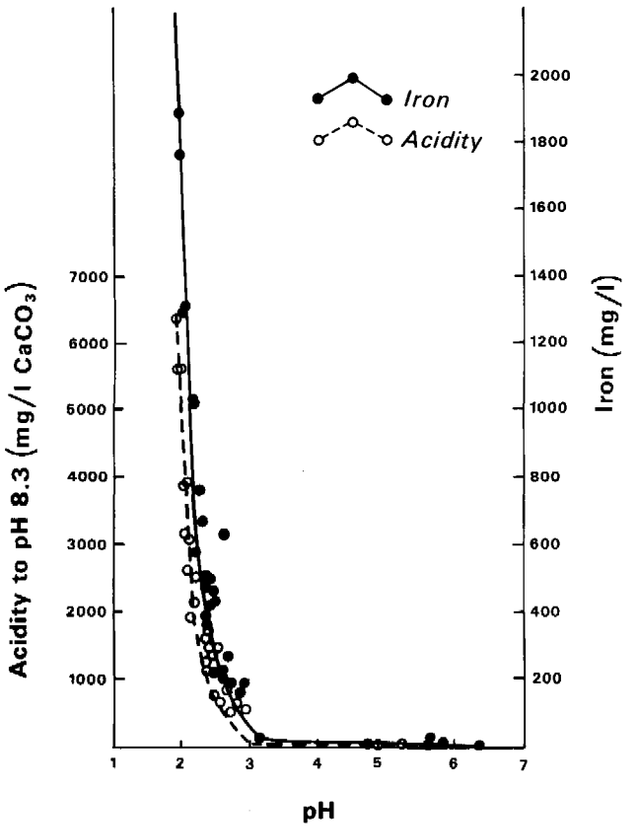



**Figure 13** The exponential increase in acid generation that occurs as the pH drops and the solubility of ferric iron is enhanced.

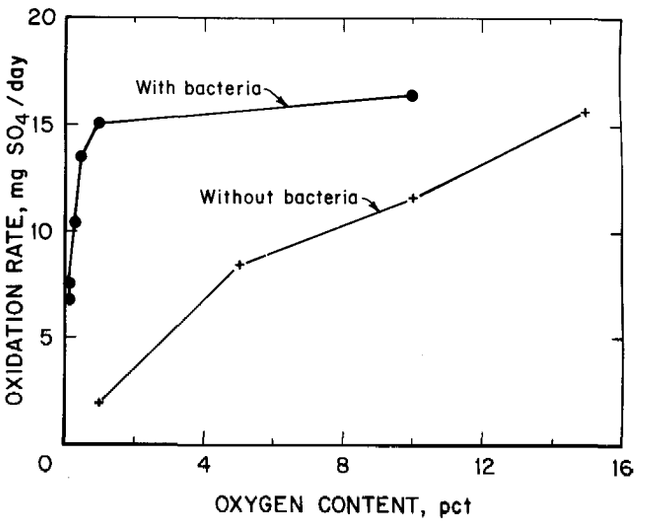



**Figure 14** The catalytic effect of iron-oxidizing bacteria on pyrite oxidation.

quantities to neutralize the reaction products, the ferric iron precipitates as ferric hydroxide and the effect on water quality is minimal: increased sulfate and hardness. However, where alkalinity is insufficient, the amount of pyrite being oxidized by ferric iron increases and the overall water quality rapidly worsens.

However, it should be noted that the catalytic effect of iron-oxidizing bacteria is most significant where oxygen is limited. Fig. 14 illustrates this fact. Without bacterial influence, reducing oxygen concentrations proportionally decreases pyrite oxidation. Oxygen is typically limited in coal refuse, tailings and inactive underground mines. With the bacteria present, this effect is not noted until oxygen concentrations fall to less than 1%. Thus, below about 10% oxygen, the bacteria effectively increase pyrite oxidation rates 50-500%, acidifying drainage water in the process (Hammack and Watzlaf, 1990).

The resultant acidic water is then modified as it moves through the rock strata. Alkalinity present in the rock, most typically as calcite or limestone, may partially or completely neutralize the acidity generated by pyrite oxidation. The acid can also dissolve metals contained in the rock, which adds to the level of contamination. Ion exchange reactions with clay particles can also modify the water chemistry. In addition, dilution may occur.

Methods to control acid mine drainage often target one of three variables: oxygen, water or the bacteria that catalyze pyrite oxidation. Alternatively, reactions that improve water quality can be enhanced, by adding alkaline agents or by manipulating site hydrology.

*6.3.2.2.3.1 Isolation from Oxygen*

The most effective method of excluding oxygen is by inundating the pyritic material. Where this has been done successfully, acid production virtually ceases. However, if the pyritic material is only partially flooded, acid production continues. In such cases, the acid generation has been moved rather than curtailed.

Although the long-term result of complete inundation is improved water quality, the short-term impact may be very different, due to acidity formed before inundation and stored as iron sulfate salts. These salts dissolve as the water table rises. In the case of an underground mine, this can create a mine pool that will be a source of acidic drainage for decades. This problem can be largely avoided by adding sufficient alkalinity to the pool as it forms to neutralize the acidity (Willison and Hause, 1986).

Inundation has also been used successfully to control acid generation from metal mine waste rock and tailings by disposing of such material at the bottom of lakes and ponds. Such disposal should be done as soon as possible after processing to minimize acidification time and

thereby avoid adverse effects to water quality. It is also theoretically possible to selectively handle pyritic material so that it is placed stratigraphically low in the backfills of a surface mine and thus inundated after abandonment. However, acidification that occurs before inundation can, once again, be very significant. Also, care must be taken to insure that water table fluctuations do not periodically re-expose the pyritic rock to oxidizing conditions.

*6.3.2.2.3.2 Isolation from Water*

Water serves as a reaction component, a reaction medium and a transport medium, so many attempts have been made to control acid generation by keeping pyritic rock relatively dry. Unfortunately, even water vapor allows the reactions to proceed, and rarely can a site be completely isolated from occasional infiltration fronts, which wash away accumulated acid salts and generate slugs of acid drainage. Nevertheless, although acidic drainage is still produced, the overall annual acid load and associated treatment costs can often be reduced by partial hydrologic isolation.

From underground mines, localized infiltration control can be effective. This first, however, requires that infiltration zones be identified. In addition to obvious surface expressions of subsidence, fractures that intersect surface water streams are considered to be major contributors to the overall volume of underground mine water production. Multiple zones of natural and/or induced infiltration usually exist. These loss zones are usually not apparent from visual surface observations, but can be identified by various techniques such as stream gaging or by using an electromagnetic terrain conductivity survey (Ackman and Jones, 1991). The loss zones can then be sealed by various means. In a Bureau of Mines study, polyurethane grout was injected into the fractured streambed to seal the loss zones. This approach was shown to be relatively inexpensive and to result in streams that retain both their water and their natural appearances (Ackman et al., 1989).

Fracturing can also induce groundwater to flow into the mine. Groundwater inflows can be redirected through well dewatering and grout curtains but these techniques are often relatively expensive and rarely used merely to reduce water treatment costs. However, where groundwater inflow also affects productivity, these techniques should definitely be considered.

Another approach used to minimize the formation of acid water underground include designing sumps and pumping systems to reduce the time water is in contact with pyritic material. Efficient selective water handling used in conjunction with infiltration control can greatly reduce the amount of water flowing through a mine and can produce substantial savings in water treatment costs.

At surface mines, hydrologic isolation usually consists of selective placement of pyritic material high in the backfill so that it remains above the eventual water table. This definitely does not stop acid formation but is generally believed to reduce the overall rate of acid generation. Additional measures have been taken at a few sites, including clay and plastic covers, to isolate the pyritic material from oxygen and water, but these measures have not been shown to be particularly cost-effective in eliminating acid discharges (Caruccio, 1983, Geidel and Caruccio, 1985).

*6.3.2.2.3.3 Inhibition of Iron-oxidizing Bacteria*

The rate of acid formation can also be slowed by inhibiting the catalytic effects of the iron-oxidizing bacteria. Dilute solutions of anionic surfactants, which are commonly used in laundry detergents, shampoos and toothpaste, have been used effectively to forestall acidification and to reduce acid formation 60-95% (Kleinmann and Erickson, 1983). Applications of surfactant solutions must be repeated three times a year to remain effective, which effectively limits their use to active coal refuse piles, but controlled release formulations have been developed that provide sustained treatment for many years (Kleinmann, 1982, Sobek et al, 1990). This allows a one-time application prior to reclamation, which enhances the success of revegetation efforts and, in some cases, reduces the amount of soil that must be utilized. The operating assumption is that after a sustained period of successful reclamation, the natural soil bacterial activity will so limit the amount of oxygen that iron-oxidizing bacteria will not repopulate the buried pyritic material. Long-term studies, now in progress, are needed to confirm this assumption.

Other inhibitory agents have been tested in the laboratory but not in the field. These include nitrapyrine, commercially used to control the activity of nitrifying bacteria, and thiocyanate. Field tests are needed to determine if either compound is more likely to be effective in penetrating the existing soil cover of a revegetated acid-producing site than the anionic surfactants, which bind strongly to the soil and cannot therefore be used on areas that have already been reclaimed. Inhibitory agents have not yet been developed to control iron-oxidizing bacteria in an underground environment; in fact, it is possible that the bacteria may not be very significant in well-ventilated underground mines since oxygen is so unlimited is such an environment. Presumably, however, in inactive, unventilated mines, the iron- oxidizing bacteria are just as important as they are in surface settings where oxygen is typically limited, such as in coal refuse piles.

*6.3.2.2.3.4 Incorporating Alkalinity*

Pyrite oxidation is not as rapid in an alkaline

environment as it is in an acidic environment. This can be seen empirically in Fig. 14, and is apparently related to the extent of ferric oxidation of the pyrite. Where natural alkalinity is insufficient to neutralize acid generation, it is sometimes possible to add sufficient alkalinity to compensate. Possible complications include the fact that limestone solubility is limited, while pyrite oxidation is not constrained and that limestone can become armored with ferric hydroxide. Nonetheless, success stories exist (Larew and Skousen, 1992, Waddel et al., 1986). Generally, alkaline addition is most likely to be successful at sites where the amount of alkalinity naturally present is almost adequate to compensate for anticipated acid generation. Designing hydrologic flow paths that accentuate dissolution of alkalinity can increase the effectiveness of alkaline addition and partially compensate for the relative reaction rates of pyrite and limestone (Caruccio and Geidel, 1984, 1986).

Adding alkalinity underground is routinely done whenever one applies rockdust, yet this does not prevent acid generation. This is, in part, due to pyrite oxidation within fractures and cracks that are exposed to the mine atmosphere but removed from the rock dust. Alternative approaches of adding alkalinity to flooded mine sections, or neutralizing mine water underground and emplacing the alkaline AMD treatment sludges in mined-out sections, are being explored. Calcium phosphate has also been used to control acid generation at surface mines. Because phosphate combines with iron to form a virtually insoluble precipitate, it can interfere with ferric oxidation of pyrite and thereby reduce acid generation. However, field trials in West Virginia indicate that the amount of rock phosphate necessary is too great to be generally cost-effective. Researchers at the University of Kentucky are working on a slightly different approach. They are experimenting with a simultaneous application of an oxidant, phosphate and a pH buffer to cause pyrite to partially oxidize and then armor with iron phosphate. Laboratory studies, though preliminary, are encouraging (Huang and Evangelou, 1992).

#### *6.3.2.2.4 Predicting Postmining Water Quality*

Ideally, the mine operator would like to know, in advance, whether or not mine water from a specific site will meet effluent limits, and if not, how much it will cost to bring the water into compliance. In practice, various levels of predictive efforts are undertaken, usually to comply with permit requirements.

Unfortunately, a high level of uncertainty associated with conventional predictive technology severely limits attempts to quantitatively forecast costs. Instead, at best, it resembles meteorological predictions in that given certain conditions, one can say that there is a higher probability of acidic or alkaline water.

In practice, the first step in prediction is to consider the water quality at nearby operating or abandoned mines, if they represent essentially identical geologic and hydrologic conditions. If nearby sites are acid-producing, one must consider what can be done during mining or reclamation of the new site to avoid or at least reduce the problem. A geological model of the area may also be used to explain variations that do occur, and to estimate the relative quantities of pyritic and calcareous rock.

Customarily, the next step is analysis of rock samples from the site to determine their alkaline-producing potential and their acid potential, based on percent sulfur or pyrite, depending on the analytical procedure (Brady and Cravotta, 1992, Sobek, 1978.) The acidic and basic components are then expressed as tons of limestone and used to produce a net neutralization potential for the mine site, calculated based on the mass- or volume-weighted average composition of all overburden rock units sampled. Alternatively, an evolved gas technique has been developed that simultaneously measures both carbonates and pyritic sulfur, and also indicates the reactivity of the pyrite (Hammack et al., 1988).

As opposed to such "static" tests, kinetic leaching tests have been developed to simulate acid generation in the laboratory (Caruccio and Geidel, 1981, Filipek, 1991). The length of these tests can be problematic, generally requiring a minimum of 10 weeks, but they all involve a sequence of allowing the samples to oxidize followed by periodic leaching. In theory, kinetic tests reflect the difference in sulfide oxidation and calcium carbonate dissolution reaction rates, compared to static tests, which only indicate relative stoichiometry. Whether this makes kinetic tests more realistic is difficult to say, due to a general lack of field verification. An additional problem, shared by both static and kinetic tests, is that their relevance is limited by the degree to which the samples being tested are truly representative of the mine or waste pile compositions. In practice, this means that either technique can be reliably used at the rare sites where there is little variation in rock characteristics in the mine or waste piles, or where the involved rocks are clearly dominated by acid- or alkaline-producing material. However, this reliability breaks down as the geology and mining operations become more complex.

This was clearly demonstrated in field studies conducted by the U.S. Bureau of Mines and West Virginia University at a total of 55 surface coal mines in the eastern United States (diPretoro and Rauch, 1988, Erickson and Hedin, 1988). Both studies demonstrated a correlation between strata thickness-weighted net neutralization potential and eventual water quality but there was little predictive certainty of neutral or alkaline water except when there was a net excess of a least 34 tons of $CaCO_3$/1000 tons. Acidic water was verified at

89% of the sites that had net neutralization potentials of less than seven tons of $CaCO_3$/1000 ton (Brady and Hornberger, 1989). Between these limits, the probability of accurately predicting postmining water quality was equivalent to a coin toss.

In mill tailings, which tend to be more homogenous than surface mine spoils, water quality predictions tend to be more reliable. At sixteen sites studied by Environment Canada, no site with an excess neutralization potential produced acidic drainage (Ferguson and Erickson, 1988). In addition to their homogeneity, tailings are more fine-grained and less permeable than mine spoils; they are also often placed underwater. All of these factors may be significant in water quality predictions.

The results of these studies cannot be generalized to water quality predictions at underground mines or for waste rock from underground mines. Field validation studies at such sites are obviously needed. However, in general, as the extent of heterogeneity increases, the value of overburden analysis decreases simply because the samples are less likely to represent the material that will be disrupted at the site. In such cases, it may be wise to take measures to decrease the likelihood of acid generation. This may require selective handling and special treatment of pyritic material, such as rapid and complete inundation of the pyritic rock or hydrologic isolation. Alternatively, one can add alkalinity, if a readily available source is nearby, or crush and selectively place alkaline rock so as to maximize its neutralization potential. The key is to consider site-specific alternatives to conventional practice that will minimize the likelihood of long-term water treatment.

## 6.3.3 GROUNDWATER QUANTITY
**by A. Brown**

### 6.3.3.1 Remedial Technologies for Groundwater Quantity Problems

Remedial technologies exist for most groundwater problems caused by mining. Many of the solutions are generally applicable, but in almost all cases the application must be modified to suit the particular circumstances of each mine. The more common remedial technologies for groundwater quantity problems are described below.

### 6.3.3.2 Aquifer Depletion

Aquifer depletion or reduction of capacity commonly accompanies mining and can result in a loss of resource to users. The effects of aquifer depletion can be mitigated by prevention, remediation, or restitution for unavoidable impacts.

#### *6.3.3.2.1 Prevention*

Prevention actions generally include avoidance of those activities that will create a permanent impact on water quantity. Such activities include the following:

- Avoidance of mine design features that will be difficult or impossible to decommission: unsealable french drains; wells that connect different aquifers; open exploration holes or other drill holes; drifts and workings that cannot be sealed during mine abandonment.

- Minimization of removal of water from aquifers during operation. This is achieved by minimization of dewatering, sealing of workings, and other actions. This may require expensive and difficult choices during operation, and safety considerations may determine dewatering or depressurization activities.

- Eliminate removal of water from aquifers at reclamation. This involves decommissioning of dewatering wells and groundwater removal systems used during operation.

- Minimization of evaporative losses during mining and after reclamation; this involves minimization of surface water area, and minimization of saturated or evapotranspirative surfaces.

#### *6.3.3.2.2 Mitigation*

Remediation or mitigation of groundwater quantity problems created by mining is required when depletion of water in the system is sufficient to create unacceptable impacts. The remedial actions that have been used, and are contemplated are discussed below:

- Increasing infiltration by the creation or expansion of wetlands, by creation of swamped areas and provision of appropriate soil, vegetation, and drainage conditions to create a permanent wetland area (Hammer, 1992) - This approach provides a method to increase natural infiltration to the ground surface, as well as having a range of environmentally attractive amelioration effects in its own right.

- Injecting water directly to the aquifer, using infiltration galleries, well injection, or directly flooding mine pits or underground workings - Experience with these systems indicates that plugging of the point of injection of the water can be a problem, requiring either pretreatment of the water by filtration and chemical modification, or

continual upgrading or replacement of the injection wells or drains.

- Reduction of surface water loss, by modification of infiltration patterns - This approach includes reduction of evaporative losses by recontouring, or land use changes that minimize interception of infiltrating water (Jensen et al., 1990).

Mitigation of the effects in production of water from an aquifer system due to mining may, however, be limited by the availability of water, availability of legal access to the water due to water rights issues, and availability of water of an appropriate quality for mitigation.

#### 6.3.3.3 Aquifer Flooding

Some activities associated with mining may add water to the groundwater system, or modify the flow of water so as to create a flooding problem in adjacent properties or facilities.

##### *6.3.3.3.1 Prevention*

The principal mitigation for the prevention of aquifer flooding problems resulting from mining are to plan the mine to drain during operation and after reclamation. Ideally, the aquifer system should be maintained at, or returned to, the hydraulic equivalent of the conditions that existed prior to mining. This approach has the additional benefit that the capacity of wells in the area will be maintained, and the groundwater table will remain in the approximate location it occupied prior to mining. This latter effect is particularly important in the case of areas of sulfide mineralization, as it essentially prevents further generation of acid mine drainage from these materials (Brown and Logsdon, 1990).

In the event that changes that cause flooding cannot be avoided, the effects of aquifer flooding can be prevented or addressed after mining using the following strategies:

*Modification of topography* - Topography can be engineered so that flows from the mine emerge at locations where there is no damage. However, this approach is not effective where the water quality is not adequate to allow direct discharge to surface waters.

*Slope drainage* - Flooding of low lying areas can sometimes be prevented by slope drainage. In this approach, permanent horizontal drains or other drainage features are installed on the slopes of mine workings (Brawner, 1982). Water is intercepted by these drains, and conducted to the surface water system for discharge. This approach may, however, create a point source discharge, with attendant permitting problems and permanent monitoring obligations and may also engender acid rock drainage problems.

*Egress of water from pits/workings* - After reclamation it is possible to connect the actual mine workings to the surface drainage system, by (for example) allowing the pit to flood, and allowing excess water to flow from the mine portal to the surface water system. This strategy may be assisted by the construction of specific drainage systems, including drainage adits and canals. Again, water quality issues may prevent this approach, and in potentially acid generating situations this approach may be contrary to good reclamation practice (Brown and Logsdon, 1990).

The costs of prevention of aquifer flooding due to mine developments range widely. The backfilling of mine workings can be achieved at a cost of about $1 to $4 per $m^3$ of mine void filled (Brown et al., 1988), depending on when and how it is done. The costs of construction of water interception trenches are in the order of $300 per lineal meter, depending on the depth and nature of the trench. The cost of construction of a drainage adit are in the order of $2,000 per lineal meter, and depend on the degree to which the rockmass is perforated to draw water to the adit.

##### *6.3.3.3.2 Mitigation*

Mitigation of the problems associated with mine flooding generally require the removal of water, either at source or prior to the flooding impact being felt. Methods used include the following:

*Water removal* - The removal of the water supply at source is a method of reducing or eliminating aquifer flooding problems. Methods that are used for this purpose include elimination of ponding, decreasing infiltration by enhancing surface runoff, artificial sealing of ground surfaces, sealing of river and lakebeds, and modification of plant cover in recharge areas.

*Dewatering* - Dewatering of the flooded area is (generally) an active response to the problem. Dewatering is generally achieved in the same way as it is achieved in an active mine: wells, drains, evaporation, and drainage from mine workings. By far the most common dewatering technique is the use of pumped wells to extract the water and deliver it to an appropriate disposal location. For permanent flooding control this is expensive and troublesome, as it requires permanent operation.

It should be noted that any activity undertaken to reduce aquifer flooding effects may have negative side-effects. In particular, reduction of aquifer water levels may be contrary to the objective of providing wetland and other habitat enhancements requiring plant growth,

and may be counterproductive with respect to the flooding of potentially acid- generating materials associated with AMD control strategies.

Costs of flooding mitigation strategies can be high. Average costs of installing a dewatering well for this purpose can be expected to be in the range of $1,000 to $10,000, depending on depth, flow, and setting. Power costs for a single dewatering well can be expected to be in the order of $100 to $1,000 per year, depending on flow and lift. If the water needs treatment, the typical cost would be expected to be up to $1 per $m^3$ of water treated. For typical dewatering systems to prevent flooding, a total system might cost $100,000 to install, and $20,000 per year to run; with treatment these costs would likely double.

### 6.3.3.4 Aquifer Characteristic Modification

Mining may have the effect of changing the behavior of a groundwater system, by changing the characteristics of the aquifer. This modification may take place in the aquifer material itself, or in the aquitards that separate them. Both may have critical impacts on the behavior of the groundwater system. Techniques for environmental protection are described below.

#### *6.3.3.4.1 Prevention*

The prevention of aquifer modification during mining is difficult. Mining is by its nature invasive, and has the effect of significantly changing the bulk permeability of the materials in which it takes place. Prevention of this damage generally involves minimizing the invasion of the groundwater system, which is not in general consistent with the extraction of the ore materials.

With respect to the permeable portions of aquifers, prevention of impacts involves:

- Avoidance of disturbance of those areas where the permeability is critical for the performance of the aquifer.
- Avoidance of total removal of materials that give the aquifer permeability, for example by leaving a portion of the lower-grade material in the aquifer.
- Design of mine openings to allow permanent stability, to retain hydraulic conductivity through the mined-out areas of the aquifer.
- Design of flow control systems (particularly grouting) such that only the mining area is affected, leaving the aquifer system capable of delivering water to other users outside the immediate mining area.

For those portions of the groundwater system where low permeability is the key behavioral parameter, prevention of impacts involves:

- Minimization of perforations through low permeability zones.
- Avoidance of development work in low permeability material (although this may conflict with normal mining practice).
- Avoidance of mining techniques that cause disturbance of the low permeability zones (for example, caving or other total extraction techniques that induce ground disturbance).

#### *6.3.3.4.2 Mitigation*

Mitigation of changes in aquifer characteristics that have occurred due to mining are also difficult. With respect to mitigation of aquifer production caused by removal of permeable material, the following are possible responses:

- Replacing removed material with coarse backfill, in order to ensure that flow conduits remain for the passage and storage of water in the system.
- Maintaining layering in backfill material, especially in surface mining, so that the aquifer/aquitard structure is retained.
- Removal of slurry walls, bulkheads, cutoffs and other aquifer plugs when no longer required for control of flow in the mining system.
- Enhancement of hydraulic conductivity in the system after mining, for example by hydrofracturing sealed/grouted areas of the subsurface system (Haimson, 1993).

Reinstatement of low permeability features in groundwater systems is somewhat easier. In general the reduction of permeability has been achieved by:

- Plugging conduits that penetrate low permeability materials.
- Construction of bulkheads, either during mining or after mining (Chekan, 1985).
- Backfilling with low permeability material either during mining or remotely after mining (Brown et al., 1988).
- Slurry wall construction through mined zones to prevent flow (Xanthakos, 1979).

### 6.3.3.5 Recharge Modification

Mining may modify the systems that replenish or recharge groundwater systems, thus modifying the availability of groundwater to later users. These effects may be prevented or mitigated as described below.

#### *6.3.3.5.1 Prevention*

Mining, in particular surface mining, tends to change the surface of the land. This has recharge modification impacts, which can at least in part be avoided by careful mine planning. In general, this requires avoidance of modification of existing recharge patterns during mining or reclamation, which includes the following:

*Avoid surface sealing* - The less mine property area that is placed under permanent liners or sealing, the greater the retention of the original infiltration capacity of the area. Design should contemplate the reduction of area of ponds and sealed areas, both on economic grounds, and to minimize impacts to recharge capacity of the groundwater system (Koerner, 1990).

*Minimize tailings areas* - A principal use of lined areas is for the deposition of tailings. Infiltration can be maximized by the disposal of tailings in ways that maximize the efficiency of disposal, for example by maximizing tailings density and by maximizing pile height. Note that flexibility in this area is limited by safety, process, and cost considerations (Ritcey, 1989).

*Reduce waste volume* - To the extent possible, materials handled during mining should be treated in ways that minimize the need for permanent storage in lined impoundments, for example by neutralization after treatment for cyanide extraction wastes, and separate disposal of non-contaminated materials.

*Avoid surface changes* - Recharge will remain unchanged if the surface is not disturbed, or reclaimed to approximate original land use and vegetative cover.

#### *6.3.3.5.2 Mitigation*

Mitigation of recharge changes can be achieved, but generally is only practical after the cessation of active mining. Techniques that have been used to return recharge patterns to pre-mining conditions are:

*Pond lining puncturing* - It is generally considered normal to puncture the linings of ponds after use (Anon., 1991). However, this may also engender water quality problems, so there is a counterbalancing benefit to allowing the liner to remain intact, particularly where the potential contaminant is biodegradable (e.g., cyanide).

*Surface contouring* - Returning the surface to approximately original contours (if original was desirable) is an approach to minimize surface infiltration changes. Methods include leaving the surface undulating, reducing runoff and increasing infiltration (contour plowing is also used in this connection to increase infiltration). This approach may have negative impacts on surface flow regimes, which should be taken into account when such action is planned.

*Artificial infiltration* - Artificial infiltration can be used to enhance the amount of water that enters a groundwater system, if the mining activity has permanently changed the amount of infiltration. This approach has been used very successfully in recharging aquifers that have been depleted by municipal water extraction (Bouwer, 1988) and where extraction has caused unacceptable subsidence. Artificial infiltration can be effected by the expansion of wetland areas, which has additional benefit in habitat enhancement. However, limited availability of water and the evaporative losses associated with most surface water uses are potential problems that should be considered in the design of such systems.

Costs of infiltration mitigation are generally minor if the mitigation is considered during the operational phase of the mining campaign. The principal costs are associated with earthmoving, and costs of any replacement of water that may be consumptively used.

### 6.3.3.6 Restitution for Unavoidable Impacts

Even after all reasonable mitigation and impact minimization actions have been taken, there are generally some unavoidable impacts to groundwater availability at most mine sites. There is a result of the conflict between the engineering requirements of mining, which in general require dewatering at some level, and protection of the environment in which the mining is taking place. In recent years, it has become more common to provide offsets for those impacts that are essential for the safe and effective operation of the facility.

Direct offsets generally take the form of replacement water provided in kind. Many of the projects where water is withdrawn for stabilization or provision of dry mining conditions have excess water of aquifer quality available for use or distribution; this water can be provided to impacted users during the period of impact, which is a symmetrical conjunction of impact and offset. Alternatively, removal from one area can in some circumstances be directly offset by the reduction of withdrawal of water from the water resource in an adjacent area. A common method of achieving this end is the retirement of farming land in the vicinity of the mine, with a concomitant reduction in groundwater extraction that provides the offset for mining withdrawals.

Indirect offsets provide considerable scope for innovation, and are particularly appropriate where the impacts of the withdrawal are felt in the environment, as distinct from direct effects on water supply. Offsets can be in the form of replacement habitat and wetlands for drained or impacted areas. This provides direct compensation for the injury created, without requiring extraordinary engineering, or safety-threatening modification to groundwater controls at the minesite. As the disturbance at the minesite may in any case reduce the utility of wetland or other generally high-value water-bearing areas, this approach often provides benefits greater than any local remediation can achieve.

## 6.3.4 GROUNDWATER QUALITY
**by A. Brown**

### 6.3.4.1 Remedial Technologies for Groundwater Quality Problems

Remediation of groundwater quality problems can be achieved by the following general methods:

*Source control* - Prevention of the entry of the contaminant(s) into the groundwater system in the first place.

*Pathway control* - Interception, modification, or remediation of contaminated groundwater as it passes away from the mining area and towards receptors.

*Receptor control* - Remediation of contaminated water at the point of use or discharge.

### 6.3.4.2 Source Control

The objective of source control is to reduce or eliminate the presence of contaminants in groundwater by preventing them from leaving the mining facility. The methods and costs of source control include generation control, containment, immobilization, modification of contaminant, and removal. These methods and costs are described below:

#### *6.3.4.2.1 Generation Control*

Minimization of mining contamination of groundwater can be achieved by minimization of the generation of wastes that have the potential to contaminate groundwater. This can be achieved by selection of processing methods that avoid soluble or potentially contaminant generating waste materials. Examples of process modification/selection include:

- Use of nitrate leaching for precious metals rather than cyanide leaching, to reduce the toxicity of the end product.
- Segregation of potentially acid generating materials from inert materials, for separate disposal, to greatly reduce the amount of material that may affect the groundwater.
- Modification of grinding fineness, in order to reduce the ability of metals to be liberated to groundwater from tailings.

All of these approaches have an impact on project economics and feasibility, and most such strategies have secondary environmental consequences that should be considered prior to implementation.

#### *6.3.4.2.2 Containment*

The containment of wastes is the classical approach to environmental protection (Caldwell and Reith, 1993). Containment in mining is usually achieved by the interposition of an impermeable liner or series of liners between the potential contaminant and the groundwater environment. For the containment of liquids, the liner systems are generally in the form of ponds for pure liquids (for example, cyanide process ponds), or impoundments (for example, for tailings). In both cases, the facilities that are constructed for this purpose today are designed to prevent loss of significant quantities of contaminants to the environment, and are also designed to be capable of being monitored, to ensure that they perform their design function (Koerner, 1990). Liners are generally of two types:

*Membranes*, generally made of plastic materials (PVC, HDPE, butyl rubber), and sometimes reinforced, are used where leakage must be prevented.

*Clay liners*, generally protected from erosion, are used where clays are available, the geochemical characteristics of the waste liquid are compatible with the clay, and the clay offers geochemical adsorption.

In addition to constructed containment systems, in situ containment systems can be used in certain circumstances. In situ systems generally take advantage of favorable site conditions, and include the following technologies:

*Slurry walls*, which are vertical walls created in situ, by excavating a slot, mixing the materials excavated from the slot into a bentonite slurry, and returning the material to the slot (Xanthakos, 1979) - Containment depends on the presence of a lower confining unit, generally a clay layer, or low permeability bedrock to which the slurry wall is connected. The combination of

the wall and the underlying confining unit creates a cell that can be capped, entirely enclosing the waste. Slurry wall costs are relatively low: typical walls can be constructed in granular materials under favorable conditions for about $50 to $100 per vertical square meter of trench. At depths in excess of about 15 m, costs increase dramatically, and the maximum feasible depth for these facilities is about 30 m. Costs for a system typical slurry wall around a disposal facility are as follows:

Construction.....$25,000 per hectare
Operation and maintenance.....None
Present value costs.....$25,000 per hectare

*Hydrodynamic containment*, where the groundwater gradient is modified to prevent contaminated groundwater from flowing away from the facility. This can be achieved by a variety of combinations of water injection and withdrawal around the periphery of the disposal system, using wells and/or trenches.

*Withdrawal* - The water is withdrawn from the groundwater system around the discharge area, and is pumped back to the waste facility, or to a treatment plant. The withdrawn water is generally a mixture of contaminated water that is leaving the facility, and uncontaminated water from around the facility, so flow is greater than the flow of contaminated water from the facility.

*Injection* - Injection of clean water around the facility can increase the head in groundwater near the facility, reversing the gradient near the facility, preventing escape of contaminated water. Some of the (clean) injected water flows away from the facility and enters the groundwater flow system; and

*Injection and withdrawal of water* ("push–pull") - Push–pull systems are a combination of both of the above, with water being injected in an outer ring of wells or trenches, and withdrawn from an inner ring. The withdrawn water, which if the system is successful contains all the contaminated water diluted by some of the injected water, must be disposed of or treated.

Hydrodynamic containment can be costly. Costs include the capital cost of installing the system, the cost of supplying water for injection, the cost of withdrawing water, and the cost of disposing of the water withdrawn. The systems are generally high maintenance systems, and are relatively labor intensive. For a typical push–pull system, costs to contain a disposal facility are as follows:

Construction.....$10,000 per hectare
Operation/maintenance.....$5,000 per hectare per year
Present value costs.....$60,000 per hectare

*Immobilization* - If a contaminant cannot be leached from the materials in which it is disposed, it cannot leave the waste disposal facility, and groundwater contamination cannot occur. A range of methods of immobilization of contaminants are available, which generally fall into physical, chemical, or hydraulic controls.

*Physical control* - Physical control entails the modification of the material being disposed so that the contaminant is permanently bound within it. In the mining context, solidification of contaminants can be attractive for dealing with particularly intractable wastes. Solidification is generally achieved by incorporation of the waste into an inert matrix, generally concrete or a rubberized or plasticized material. The resulting solid material is then disposed of in a landfill, either onsite or offsite. Costs for such disposal is high, with typical cost per tonne of contaminated material being as follows:

| Item | Cement (/tonne) | Rubber (/tonne) |
|---|---|---|
| Construction | $5 | $10 |
| Operation and maintenance | $15 | $100 |
| Present value costs | $20 | $110 |

*Chemical control* - Chemical control of contaminants in mining situations generally involves the modification of the chemical characteristics of the material so that the contaminants of concern are not soluble, and therefore not mobile. This can be achieved by a range of methods, including: (a) pH changes - The solubility of many species, in particular metals, is strongly a function of pH (Garrels and Christ, 1964). The control of pH therefore provides attractive opportunities for the immobilization of contaminants. This can be achieved by the addition of materials to wastes to buffer the pH into beneficial ranges: pH's above about 5.5 renders most common metals essentially immobile under most conditions, while pH values above about 8.5 renders zinc and other less pH sensitive metals essentially insoluble; (b) Eh changes - The oxidation state of some metals and other species exerts a sensitive control on their solubility. In particular, metals such as iron, manganese, uranium, and arsenic are very sensitive to the redox conditions in the water (Stumm and Morgan, 1981). Modification of the redox conditions can be achieved by a variety of methods, including treatment with an oxidizer or reducer, aeration, or wetland/bog reduction.

Chemical control may be achieved relatively inexpensively, depending on the precise requirements of the situation. As an example, neutralization, a common chemical control mechanism, can be achieved by lime or limestone addition to a solid waste for approximately: Construction = $2 per tonne and Operation and maintenance = $5 per tonne, a total of $7 per tonne. Costs for other chemical treatment are similar, with variation due to the cost of the chemicals required.

*Hydraulic control* - Hydraulic control is achieved by the reducing or eliminating the flow of groundwater through the contaminated material, thus preventing the transport of significant contaminants into the environment. This is generally achieved by permeability reduction or flow interception.

Applying permeability reduction, waste material permeability can be reduced by admixture with low permeability materials. Materials used include clay, bentonite, cement, pozzolans, and ash. An attractive opportunity that exists at many mines is the use of tailings to reduce the hydraulic conductivity of other waste materials (particularly waste rock); while this has the potential to achieve the reduction of hydraulic conductivity, it may introduce other problems (for example, the release of low quantities of significantly toxic fluids), and is not often practiced.

Interception of flow through the waste materials short circuits the transport system for the movement of contaminants to the environment. A common method of achieving interception of flow is through the use of caps. If these are impermeable, and the waste is located above the water table, then the flow through the waste is essentially eliminated, thus removing the mechanism for groundwater contamination. While this is theoretically attractive, caps alone have not generally been considered an adequate protection against groundwater contamination, and are rarely used alone. Caps are, however, a passive treatment system, and are frequently a component of a total remedial/ protection system.

Hydraulic control is generally of moderate cost. The costs of mixing of materials to reduce permeability depend strongly on the availability of low permeability materials for mixing. In addition, as the mixture creates more waste material than originally existed, there are increased disposal cost issues. An approximate cost for permeability reduction is between $50 and $500 per tonne, depending on the approach taken, and on how amenable the waste is to the treatments available. Capping costs depend on the complexity of the cap and are in the order of $50,000 per hectare, approximately $0.25 per tonne of disposed material.

#### *6.3.4.2.3 Modification of Contaminant*

If a contaminant is modified so that it is no longer a concern for human health and the environment, then it can be released (within nuisance and other limitations) from the mining operation. A range of options exist for removing the hazard from some chemical and other contaminants by changing their nature, including (Tchobanoglous, 1991):

*Neutralization* - Many mining waste streams are potential threats to the environment solely because of their pH, including alkalis, acids, and ash materials. Neutralization can buffer the pH of any liquid that passes through them into the acceptable range, and frequently render any leachate from the material innocuous.

*Oxidation/reduction* - Some contaminant species are deleterious in one valence state, but not in another. An example of this is chromium, which when present in the dissolved hexavalent state is potentially carcinogenic, but in the trivalent state has only chemical toxicity risks, at a much greater concentration. Thus a change in oxidation state provides protection. However, the modification of valence states is difficult to make permanent, so this remedial approach generally restricted to the treatment of relatively small quantities of waste.

*Volatilization* - Volatilization is a remedial strategy that is used widely in mining contamination situations. It is particularly effective in the resolution of solvent, hydrocarbon, and cyanide contamination. The contaminant is allowed to volatilize into the atmosphere at an environmentally acceptable rate, removing it from the possibility of becoming a groundwater contaminant. Volatilization can be enhanced by increasing contact between the air and the contaminated material by a wide range of methods, including land farming, air stripping towers, in situ sparging and soil vapor extraction.

*Biological modification* - Some contaminants associated with groundwater can undergo modification due to biological processes, or biological mediation. These processes include:

*Biodegradation*, for example the oxidation of hydrocarbons to form water and carbon dioxide.

*Bioreduction*, for example the reductive dehalogenation of solvents, and the reduction of sulfates to sulfides.

*Biological removal*, for example the removal of metals from groundwater and surface water by plant uptake.

These processes have been utilized in specialized circumstances to remediate groundwater systems, by modification of the form or location of potentially harmful contaminants. Note that some of the

biologically mediated reactions do, however, create constituents that may themselves be contaminants.

The costs of modification strategies for remediation of mining-related groundwater impacts cannot be readily generalized, as they are very site- and contaminant-specific. However, some of the strategies, especially those that modify the characteristics of chemical species to render them harmless, can in particular situations be extremely cost- effective, with costs substantially less than \$0.25 per $m^3$ treated.

#### *6.3.4.2.4 Removal*

The final remedial strategy that has found use in the control of groundwater contamination from mining sources is the removal of the contaminating species. Two approaches are available:

*Reprocessing to remove contaminants* - The extraction of residual contaminant materials from mining systems provides the opportunity to complete resource recovery, or to totally remove the contaminant from possible future migration. The material is reprocessed, either on site or at a remote location, and the contaminant removed from the mined material. The inert residue is disposed of, while the extracted material can frequently be sold. While this option has been evaluated, and in some cases used, it is generally ineffective in practice. Increased removal of minerals or other mining products usually requires finer division of the host material, and more aggressive treatment than was used in the commercial mineral removal. This in turn results in a more active residue, often combined with more toxic materials due to the processing. In fact studies have indicated in some cases that although there is less mineral material available for contamination of groundwater after such treatment, the finely divided product of the reprocessing is more of a threat to the environment than the original waste material.

Costs for reprocessing strategies are generally high. Processing costs average \$10-\$1,000 per tonne, assuming significant tonnage. Some credit for mineral production can be expected, perhaps halving the cost per tonne.

*Removal of contaminated material from site* - The second class of removal is the removal of contaminated source material from site. This entails excavation, loading, transportation, and disposal. The disposal generally will have to be to a licensed disposal site, such as a landfill or an appropriately permitted tailings or waste facility. Costs for this type of remediation are in the order of \$50 per tonne, much of which is the disposal fee at a landfill or other disposal facility. This strategy is generally only attractive for small quantities of material.

#### *6.3.4.2.5 Control of Ancillary Contaminant Generation*

The objective of control of ancillary contaminant generation is to prevent generation of contaminants that did not exist prior to the mining activity. The most substantial of these problems are the generation of acid mine drainage and the mobilization of leachable materials.

*AMD prevention.* Acid mine drainage is a common concomitant of coal and metal mining in those locations where the materials being mined contain sulfides. Acid generation has been described above. Remedial actions for acid mine generation at source involve the prevention of the formation of the conditions that would lead to the oxidation process (Kim, 1982). These are oxyten denial, water control, biological control, and sulfide removal.

Oxidation is the mechanism of formation of acid in sulfides. This can be prevented or controlled by denying the process an oxidant. The principal method of achieving this is to seal the mine areas where the sulfide exists from ingress of oxygen or oxidants. For underground mines, this involves sealing the mine against air inflow, or alternatively sealing the mine so that groundwater refloods the sulfide areas. An increasing number of abandoned mines are being sealed in this fashion, and optimized mine plug and sealing designs have been developed (Chekan, 1985). These solutions are not without their problems: most mines have many points of egress, sealing is difficult to achieve, and it is possible that the sealing will only succeed in diverting contaminated flow from one location to another, while not achieving the reflooding or oxygen denial objectives.

Water is an essential ingredient for acid mine drainage. The amount of water required for the chemical support of the process is, however, generally freely available in most mine-related situations (Brown and Logsdon, 1990). As a result, it is not generally feasible to limit water ingress to acid generation situations in such a way as to limit or eliminate such generation.

Acid generation in most sulfide situations is biologically mediated. Prevention of this biological mediation can be achieved by suppressing or eliminating the biological mediator (Kleinmann et al., 1981). This has been achieved in field situations with the use of bactericides and retardants (generally detergents). A number of commercial products are available for both these approaches. However, bacteriological systems will generally re-establish after these treatments have been applied.

Removal of sulfide at the source can be achieved as part of the processing system for most sulfide mineral projects (for example, the removal of gold from sulfide ores), and is a common processing option selected for the minimization of waste disposal problems. The sulfide

materials obtained from such approaches can either be stored separately after processing, or can be oxidized to sulfates during the processing system. Based on experience in AMD systems, for this strategy to be effective it is necessary to reduce the average sulfide content to significantly below 1% by weight of the waste material.

*Leaching prevention* - A source control measure that is commonly available in mining groundwater control systems is the prevention of leaching of contaminants from groundwater systems by the passage of mine-related groundwater. The most common of these is the leaching of metals and other constituents from aquifer materials by the passage of acidic or oxidizing liquors from mine facilities. This secondary source of mobilization of contaminants can be minimized or eliminated by preventive groundwater flow through the material, using the methods described earlier in this section.

### 6.3.4.3 Pathway Control

The principal method of pathway control is interception or immobilization of contaminants or contaminated groundwater along the flow pathway from the mining site. The methods and costs of this approach to groundwater contamination remediation are presented below.

#### *6.3.4.3.1 Pump and Treat*

The most commonly used method of intercepting groundwater contamination is known as the "pump and treat" strategy. In this approach, water is extracted from the groundwater system by a series of wells or other extraction devices, and is treated to remove or eliminate the effects of the contaminant(s). The water is then either used, discharged, or reinjected into the groundwater system.

During pumping, the spread of contaminants is contained by the extraction of contaminated water from the "plume," and reinjection of treated or makeup water in the clean portion of the aquifer away from the plume. This process generally arrests the plume movement, and protects the remainder of the affected groundwater system.

During treatment, the contamination in the groundwater is intercepted, and removed from the aquifer. This process occurs as a result of the treatment of the water removed from the contaminated zone of the aquifer. Removal of the contaminants during treatment can be achieved by a wide range of treatment technologies, including (Tchobanoglous, 1991): 1) reverse osmosis; 2) filtration; 3) neutralization; 4) oxidation; 5) reduction; 6) biological treatment systems; 7) flash evaporation; 8) ion exchange; 9) volatilization/stripping; 10) carbon absorption; 11) coprecipitation; and 12) flocculation.

The effectiveness of the pump and treat technologies as a remedial action have been varied in practice, with some successes and some failures. Remediation of particularly organic constituents by this method has been generally disappointing (Doty and Travis, 1991). Costs of pump and treat technologies are often substantial. The following costs are based on a typical substantial flow rate system (0.063 $m^3/s$ or 1,000 gpm), using neutralization technology: Capital - \$100,000 or \$0.05 per $m^3$; Operating and maintenance - \$2.4 million per year or \$1.25 per $m^3$ per year; Total - \$2.5 million per year or \$1.30 per $m^3$.

#### *6.3.4.3.2 In situ Treatment*

Some groundwater remedial activities can be performed within the groundwater system itself. In situ remediation can save the cost and difficulty of removing the water from the groundwater system prior to treatment (Schlitt and Shock, 1979).

*Neutralization* - Acid or basic groundwater problems can be rectified by in situ methods by injecting neutralizing liquid into the aquifer at the location where the remediation is required. The injected liquid reacts with the groundwater, restoring the pH of the aquifer liquids to the appropriate level.

*Oxidation* - Oxidizing liquids (particularly aerated water and hydrogen peroxide) have been used for in situ treatment of groundwater contamination problems, particularly where the contaminant is mobile under oxidizing conditions. This technology was pioneered in the in situ uranium extraction industry, and has been used in the removal of uranium and other oxidation-state sensitive metals from groundwater systems. The oxidizing liquids are injected to the aquifer, and react with the contaminating species in the groundwater system. In the case of uranium and other species that are more mobile when oxidized, the resulting groundwater containing the mobilized species must be pumped from the aquifer and treated. In the case of species for which oxidation creates innocuous products (for example hydrocarbons), no further action is required once the reaction has occurred.

*Enhanced Biodegradation* - Another in situ technology that is available is the doping of aquifers with materials designed to enhance the natural biodegradative or remedial actions of the aquifer. Doping can take the form of adding microorganisms, oxygen or oxidants, or nutrients to the aquifer.

New strains of microorganisms can be injected to enhance the performance of the indigenous microorganisms in eliminating or fixing the

contamination.

Oxidants can be added to the aquifer to enhance the oxidation mediated by the microorganisms. The usual method of adding oxidants is through aerated water or hydrogen peroxide. Oxidation capacity can also be provided by augmenting the concentration of oxidized metals and other species (for example, saturating the injected fluid in ferric ions). The added oxidants increase the size of the aerobic microorganism community, and enhance the biodegradation process.

Nutrients can be added to the injected water to enhance the growth and contaminant consumption of the resident microorganism population. Nutrients generally comprise nitrates and/or phosphates, but may in certain cases include sugars and other hydrocarbons.

Mixing of the aquifer waters by the natural dispersive process assists in the distribution of the injected fluid across the contaminated portion of the aquifer. The advantages of this technology are that all activities occur subsurface, with a corresponding reduction in complexity and cost. The corresponding disadvantage is that the entire process is less certain, due to the open nature of the remedial technology. It has been found that the remediation available using in situ methods is less effective than above-ground treatment systems, but that the cost savings generally more than compensates for the inefficiency of the system.

Typical costs for in situ technologies are generally about half the cost of the comparable above-ground technology. For in situ neutralization, cost of treatment are in the order of \$0.50 per $m^3$ of groundwater treated.

#### *6.3.4.3.3 "Natural" Treatment*

Groundwater flows through a natural aquifer system, which in general has substantial remedial capacity in its own right. This capacity derives from the large surface area of the aquifer materials, the presence in the subsurface of chemically active materials, the presence of biologically active microorganisms in the aquifer, and the variable oxidation conditions in different zones in the aquifer. The processes that occur in the aquifer materials include:

*Neutralization*, due to the presence of carbonate species in almost all natural rock and soil sequences - Many aquifer materials contain in the order of 1% by weight of neutralizing capacity, measured as equivalent calcium carbonate.

*Adsorption*, due to the large available surface area in most groundwater flow systems, and the highly adsorptive behavior of many metallic and other mine-related species - Most aquifer materials have the ability to adsorb up to a percent by weight of metal or other mining contaminants on contact. However, note that this process is generally slow and at least partially reversible, so the contaminant is generally retarded, rather than removed.

*Ion Exchange*, due to the presence of clayey materials in almost all natural settings, resulting from the breakdown of feldspar and other basic components of the soils and rocks that make up the host material - This effect is generally small in the subsurface, but can selectively remove ionic species that are not capable of being attenuated by other mechanisms, and which may control the concentrations of other species.

*Dilution*, due to the large infiltration area involved in most natural flow systems, and the high degree of dispersive mixing within them - Dilution is frequently overlooked as a significant natural remedial factor in groundwater contamination situations.

*Biodegradation*, due to the natural microorganism communities that exist in all natural groundwater flow systems - These microorganisms can oxidize hydrocarbons, fix metals, break down solvents, and modify ionic compositions in groundwater.

These are the factors that make septic disposal systems for domestic and light industrial waste so effective in most geological settings. However, the great size of many mining waste disposal systems can overwhelm the natural remedial capacity available. As a result, natural remedial capacity is not generally relied upon as the primary mitigative factor for protection of groundwater from mining-related environmental threats, but provides a buffer or safety factor for mine contamination that can compensate for incomplete remediation and/or protection in mining waste management systems.

The use of the natural remedial capacity of groundwater systems is free of cost. While some aspects of natural system protection are renewable, use of this capacity generally depletes the available remedial capacity permanently.

### 6.3.4.4 Remediation at Point of Impact

In the event that contamination cannot be controlled at source, economically intercepted, or remediated during flow within the aquifer, it is possible to remediate the effects of the groundwater degradation at the point of impact of the groundwater contamination. The objective of this approach is to recover the resource use of groundwater and/or to protect human health and the environment from the effects of the mining-related contamination.

Remediation at the point of use or point of impact is generally the lowest cost approach to remediation of an existing groundwater problem (prevention is generally

the lowest cost approach to a potential groundwater quality problem). Only that water which actually can impact the environment or that is required for beneficial use is remediated, and the full natural remedial benefit is obtained prior to that remediation. However, the disadvantage of this approach is that contamination is allowed to spread over a much wider area and affects a much greater volume of water than was originally associated with the discharge at the source. In addition, contaminants are left as residuals in the groundwater flow system, and have the potential to continue to contaminate passing groundwater for a very much greater time than it takes for the contaminants to initially pass through the system.

There are two points at which impact can be felt:

*Point of extraction of groundwater* - Groundwater degradation impact can occur whenever a well or other extraction device is placed in a groundwater system and water is extracted.

*Point of egress of groundwater* - If groundwater is contaminated, this contamination can affect human health and the environment when it emerges into the surface water system. The emerging water may contaminate plant life, surface water resources, and/or drinking water supplies that are sourced at the springs based on the emerging groundwater. The remediation of groundwater contamination at the point of impact can be achieved by the following methods.

#### *6.3.4.4.1 Treatment Prior to Use*

The contaminated groundwater can be collected and treated prior to use. Collection is generally achieved through wells, frequently the wells that have traditionally been used for groundwater extraction in the affected area. Treatment of this water depends on the use to which the water is to be placed. For domestic flow systems, the flow rates are small, and domestic-sized treatment units can be employed to treat water prior to use at each wellhead. These units generally rely on removal of contaminants, using ion exchange, activated carbon filtration, reverse osmosis, or volatilization as their operating principle. Costs of these systems range up to \$2.50 per $m^3$ of water treated. For municipal or larger water use, large-scale treatment plants are employed. These are frequently multi-staged treatment systems, with filtration, pH adjustment, precipitation, aeration, volatilization, biodegradation, and active treatment stages being employed prior to final distribution of the remediated water. Typical costs for such municipal water treatment plants are capital costs, \$100,000 to \$1,000,000; operating costs, \$0.25 per $m^3$ treated.

#### *6.3.4.4.2 Natural Treatment*

When mining-impacted water emerges at the surface, it is subject to a series of natural remedial actions that are available as a result of the conditions that exist at ground surface. As a result of the springs that form at these points of egress, wetland conditions generally result. Wetlands have a high capacity for remediation of groundwater quality problems, due to their high adsorptive capacity, their high biological activity, their high volatilization capacity, and the access to oxygen, sunlight, and ultraviolet radiation (Hammer, 1992). Most wetlands have the capacity to remediate between 10 and 100 $m^3$ per day per hectare of wetland, with little cost. The treatment capacity of wetlands can be engineered to increase capacity, with flows up to 1,000 $m^3$ per day per hectare of wetland being available with maintenance and supervision.

It is important to note that there are some limiting aspects of wetland treatment. In the case of non-biodegradable contaminants, such as metals, the wetlands act as a storage system, fixing these materials, and largely preventing them from entering the aquatic environment. However, the metals may be available in soil in the wetland, and in dust that may be generated during dry periods. Ingestion of this soil material, or breathing the dust, may constitute a health hazard. Plants that grow in the wetlands may also selectively uptake these contaminants, and become themselves contaminated, posing an ingestion risk for animals and persons who harvest them. In addition, the effectiveness of wetlands is not total, and varies with the climatic conditions. In particular, cold-weather performance may be very limited, due to the reduction in biological and reductive activity at temperatures close to, or below, freezing.

#### *6.3.4.4.3 Protection/Isolation*

A final "point of use" response to water quality degradation is available when direct remediation is not feasible or is prohibitively expensive. This involves prevention of harm to health and environment by protection from the water, or isolation of the water from human or environmental contact.

Protection can be achieved by removing the ability to legally obtain the water in locations where it is contaminated beyond levels deemed to be potentially harmful. This is generally achieved by deed restrictions on the land beneath which the contaminated groundwater is located. In general this involves reduction in value of the land that is affected, or can require compensation of injured third parties.

Costs of this approach to mitigation of contamination of groundwater generally depend on the quantity of water affected. In general the water supply

capacity that is removed by the contamination is replaced by the provision of alternative water. In the arid west of the US, such replacement water rights are available for between \$1 and \$3 per $m^3$ of water per year. This water still has to be extracted, treated, and delivered prior to general human consumption. Costs for actual supply of this water are in the order of \$0.25 per $m^3$.

## 6.4 EFFECTS ON THE AIR

**by R. A. Arnott and J. T. Dale**

### 6.4.1 INTRODUCTION

This section provides a general overview of air quality emissions and the technologies available for control of air quality for mining and related activities. It covers coal, hard rock and other industrial mining, including mineral surface mining and associated on-site activities of this industry, but does not include effects from coal combustion, smelting, retorting of oil, shale and tar sands, uranium milling and other downstream activities that are not necessarily co-located with mining activities.

This section covers the development, operation and termination of surface and underground mining of coal, hard rock and industrial minerals. It is organized based on activities applicable to many types of mining that may be undertaken. In this section, each activity is described including the pollutants of concern, potential control strategies available for implementation, the general degree of control provided by each control technology and a general qualitative cost of control.

### 6.4.2 OVERVIEW OF CONTROL OPTIONS

Air pollution emissions from mining activities can be difficult to control since they often cover a large surface area, include significant material handling activities, and involve materials capable of producing fugitive emissions and dust. These air quality emissions result from a large number of emission points that collectively may release significant emissions, but which on an individual basis are difficult to effectively control. Many mining activities have historically occurred in areas of the world that are more remote resulting in potentially more limited impacts. Air quality management emphasis has not been as great as for other industrial activities due to the location and type of activity at these facilities. In the future, however, increased emphasis on air quality management of mining and related activities will occur with the result that planning for these activities must include a thorough analysis of the costs and impact associated with air quality. This will lead to increased research into air pollution control technologies for mining activities. This section is designed to provide an overview of presently existing approaches and techniques. The reader is encouraged to consult the references including Anon., 1985, and Buonicore and Davis, 1992.

Control of air pollutants for most industrial facilities falls into two major categories: control of point and area emission units with control equipment and process technologies and implementation of practices to minimize emissions from large area emission units, including those ancillary to the main emission units, or best management practices. In the mining industry the use of best management practices is extremely important as many of the emission units present are not amenable to control by equipment and/or other techniques located at the discharge point. Best management practices are often used to control air pollution emissions from haul roads, material piles and other material handling activities at mining sites.

Other operations associated with mining are amenable to the use of equipment controls at discharge points. Examples of these operations are conveying and dropping of materials and the crushing of ores.

Some activities require both best management practices and control equipment. In general these activities are controlled both by equipment, and best management practices to minimize overall emissions from the activity. Examples of this type of control approach would be the implementation of roofing or hooding over conveyor belts and ancillary material handling activities along with baghouse controls of specific drop points.

In many cases adequate preplanning prior to the implementation of the mining activity can result in the segregation of activities in such a manner that air pollution control is achieved more cost effectively. As an example, such planning could include enclosing tertiary crushing and material handling activities to minimize emissions of the finer materials produced, minimization of quantities of materials stored at the mine site, and implementing a management practice involving time-of-need inventories.

The following discussion is arranged on a process-by-process basis with the description of an activity, major pollutants emitted, and known methods of control discussed. Processes will be divided into two broad categorical areas: fugitive emission units where the emission points are distributed to manage, and point emission units where an identifiable emission point can be determined and managed through the use of air pollution control equipment.

### 6.4.3 AREA AND FUGITIVE EMISSION UNITS

Area and fugitive emission units are most important in mine-related activities. In no other industry group do these emissions play such an important role in terms of

overall emissions. Historically, control of area and fugitive emissions has not been addressed as a highest priority by the majority air pollution control agencies worldwide. With renewed interest in the magnitude of these emissions and emphasis on the development of best management practices for their control, regulatory agencies are now emphasizing the control of area and fugitive sources more than in the past. Any proposed mining activity must during its planning stages develop adequate programs for the control of area and fugitive emission units. This includes the development of protocols for best management practices and, through the development of a strategic mine site plan, minimization of emissions from these activities by minimizing haul roads, material handling piles and other area course and fugitive emission units at the overall mine site to minimize airborne pollutants.

#### 6.4.3.1 Exploration/Drilling/Blasting

Exploration and drilling activities at mine sites, particularly surface sites, provide the potential for significant emissions of particulate matter in the form of fugitive dust. Because of the nature and type of emissions from these activities, controls are primarily based upon good management practices and must be implemented at the point where emissions are generated. These emissions are often caused by action of mechanical force, such as pulverization and/or abrasion of surface materials. Pollutants can be secondarily emitted through exploration, drilling and blasting activities by the entrainment of dust through air currents and/or other impacts associated with drilling and/or blasting.

Factors that affect the amount of emissions produced by these activities include: the characteristics of the material being handled; the amount of the work being done in terms of the size of the exploration, drilling or blasting face; the silt content of the materials being handled; the moisture content of the materials being handled; and the amount and frequency of precipitation at the mining site. All of these factors must be considered during the planning phase of the mine. The area of exposure is addressed as a management practice and proper air pollution control suggests that smaller work units for exploration, drilling and blasting will result in better management of air pollution emissions. The silt content of materials is very important as particulate emissions generally result from the small particles contained within the silty material. Thus, the higher the small particle or silt material the greater the quantity of emissions that will occur. Exploration, drilling and blasting activities can create additional small particles, which will then contribute to the total emissions generated. The moisture content of the material is extremely important as increased moisture will decrease the amount of fugitive emissions emitted from all mine-related activities. Incident precipitation in the form of rainfall or snowfall will greatly reduce the amount of emissions generated, and the frequency and amount of precipitation are very important factors in the control of fugitive emissions.

Control strategies for drilling, blasting and exploration activities do not normally include emission control equipment. Control strategies almost exclusively rely on the implementation of best management practices. These practices would include minimization of the exposed face, careful determination of the size of the shot and powder factor for blasting, and the knowledge of the potential for the production of silt material type. Actual best management practice controls for these types of activities would generally involve the use of watering as the most common and generally least expensive method of controlling fugitive emissions. However, this technique is only temporary and the quality management program is required to obtain optimal results. In some cases for the same activities, the minimization of fugitive dust can be achieved by the use of chemicals, dust suppressants to treat the exposed surfaces. This technique will provide, in general, a longer dust suppression time, but will be significantly more costly and might have adverse impacts on the surrounding plant and animal life. Additionally, drilling, blasting and exploration are relatively short term activities in a specific location and the longer term benefits associated with chemical dust suppressant will not be applicable for any activity that involves frequent or short term disturbance of an area.

#### 6.4.3.2 Construction Activities

Construction activities may include the development of structures and/or tailings impoundments, material storage pile areas, haul roads, and other general construction activity. Again, for this particular activity, the primary pollutant of concern is particulate matter resulting from fugitive dust generated by the construction activities. The same general factors as addressed above for exploration, drilling and blasting effect the amount of emissions produced from these activities. Therefore, it is important to control the amount of work being done at any point and apply the control technologies previously discussed, such as application of water and wetting agents, to minimize the amount of emissions produced.

A second general activity that produces emissions results from the use of internal combustion engines, both mobile and stationary, in construction. The vehicular exhaust from this equipment will produce additional air pollution in the form of particulate matter, oxides of nitrogen, carbon monoxide, and to a lesser extent, oxides of sulfur. Factors that influence the amount of emissions produced includes the type of engine utilized, fuel utilized, and the maintenance

program for the construction equipment. This is a very important management practice area and all internal combustion engines must be kept in proper working order and used with the appropriate fuels. In general, adherence to a regular maintenance schedule and a maintenance program consistent with good air-quality management practices will result in the appropriate control of these emissions.

#### 6.4.3.3 Pit Activities

Pit or actual mining activities at surface mine involve substantial surface material disturbance. Each of these material handling actions can produce fugitive dust and, in turn, particulate matter. This is the main pollutant of concern for these activities. Particulates are created both through activities associated with mining and material handling, and from windborne action on such areas as temporary storage piles, haul roads, etc. Again, the same general factors are applicable to these activities as to the other fugitive areas. These factors are amount of work performed in a unit, silt content of soils, and moisture content or precipitation in the area of the activity. Likewise, the same general control approaches are applicable as described above in section 6.4.3.1, Exploration/Drilling/Blasting. One additional control may be appropriate for these activities. Vegetation coverage and/or the use of wind breaks may provide reasonable control for pit activities. The result of this control approach is to both minimize the surface area available for windborne emissions and disruption of wind current and minimization of wind speeds in areas susceptible to fugitive dust. Again, the implementation of controls for activities associated with pit mining involve the careful consideration during the planning stage of a best management practices plan and the careful implementation and management of control factors to minimize fugitive dust during the operation at these sites.

#### 6.4.3.4 Transportation

The pollutant of concern associated with the transportation of materials at a mine site and traffic on access roads is particulate matter from fugitive dust. Factors that determine the amount of particulate emissions from transportation on roads include the factors already referenced above such as volume of traffic on the road, silt content of materials constituting the roadway, and the moisture or precipitation impacting on the road. In general, haul roads and access roads associated with mining sites are unpaved due to the extensive road system and the cost of paving. In some cases, key roads and access roads may be paved. This discussion will assume that the majority of the roads at any site are not paved. Additional factors that influence the amount of particulates matter emitted from traffic on roads include the volume of traffic on the roads and the speed of the traffic. Control of fugitive emission from transportation sources at mine sites involve the same controls as discussed in section 6.4.3.1, Exploration/Drilling/Blasting, with the additional control of speed. The control of speed is extremely important. Speed controls must be a part of any best management practices planned for the mining activities.

#### 6.4.3.5 Transportation Using Conveyors, Transfer Points and Load-outs

Air pollutants from the conveying, transferring, loading and storage of mine materials of greatest concern on a site is particulate matter from the fugitive dust and from non-point sources and other area sources. Depending on the type of material being mined, heavy metal and other specific chemical species may be important; however, control of particulate matter will control these pollutants as well. Factors that contribute to the emission of these particulates would include the factors described in section 6.4.3.1, Exploration/Drilling/Blasting, above and such additional factors as the specific type of material and particle size, the moisture state of the material, the height of any drop points, and the location of material storage piles and belt transport facilities relative to undisturbed wind patterns.

Control of air pollutants from this type of material transportation can be effective and includes both point source control and fugitive dust control. Fugitive dust controls are generally those described in section 6.4.3.1, Exploration/ Drilling/Blasting, above and would primarily involve the wetting of materials including the wetting of discharge sleeves and other contact points as well as spraying the material transported on the conveyor belt with a water stream. Also, chemical agents can be used for these activities, but water is the material of first choice due to cost and the short term nature of the control requirement while the material is on the conveyor belt or drop point. Chemical agents are appropriate for undisturbed (longer term) or storage piles.

The actual belt transport can be roofed or hooded and in some cases made a part of a venting system to a control device at a related drop point. However, simple factors such as hooding or roofing associated with an adequate spray control system may minimize emissions during transporting of mine materials.

Each drop point on the conveyor system and the load-out points from the material storage pile or silo generally are also able to be enclosed and vented through a baghouse. A baghouse is the most common equipment control-point- source device used in mining operations for the material transfer activities.

### 6.4.3.6 Material Piles, Tailings and Impoundments

Material piles, tailings and impoundments represent one additional area where particulate-emission-fugitive dust can occur at mining sites. The control of this type of storage and/or waste management of mine materials is often made easier by the higher moisture content of the material in tailings or impoundments. On the other hand, the generally small size and large exposed area materials stored are detrimental due to higher wind action contributing to increased emissions from these sources. Factors described above in section 6.4.3.1, Exploration/Drilling/Blasting, are very important for this source type of fugitive emissions as well. Control factors are those described previously for fugitive sources. The use of wind breaks and vegetative cover is more important for this source type. The appropriate planning of the mine site to minimize exposed surfaces prior to revegetation and the best location of tailings and material storage piles relative to potential wind erosion is very important.

### 6.4.3.7 Reclamation Activities

During reclamation of a mine site prior to final closure many of the activities described above that generate fugitive emissions are again present. In particular many reclamation activities involve additional disturbance of the surface and movement of materials at the site as a last closure activity. The primary pollutant of concern during reclamation is particulate matter from fugitive emissions. Of lesser concern will be vehicle emissions as described above in section 6.4.3.2, Construction Activities. In terms of air pollution emissions reclamation activities parallel construction activities to a great degree. Factors that influence the magnitude and extent of fugitive from reclamation activities are described in the above sections. Likewise, control factors are described in section 6.4.3.2, Construction Activities.

## 6.4.4 SPECIFIC POINT AND MOBILE SOURCES

This section addresses sources of air pollutants at mining sites and for mining activities that are individual point or mobile sources. As such the control for these types of emissions will more often involve control equipment and will be similar to the controls for these emissions from non-mining sources.

### 6.4.4.1 Vehicular and Internal Combustion Emissions

Emissions associated with vehicular traffic and other internal combustion engines at mining sites are important because these sources include pollutants other than particulate matter from fugitive dust. Oxides of nitrogen, carbon monoxide and, to a lesser extent, oxides of sulfur, are emitted from internal combustion engines. Two factors control the amount of these pollutants emitted from vehicular and internal combustion engines--the first is the proper maintenance of equipment and vehicles; the second is the requirements for the design and manufacture of internal combustion engines to minimize pollutant emitted.

The development of a well-managed maintenance program for mining related internal combustion equipment is extremely important and should be a part of any mine plan. Additional factors and control elements associated with vehicular emissions have been described in section 6.4.3.2, Construction Activities.

### 6.4.4.2 Fuel Storage/Fueling Operations

The major pollutants of concern from fuel storage and fueling activities are volatile organic compounds. Where regulatory agencies have established and implemented a hazardous air pollutant program, additional components of the volatile organic-compound stream from fueling operations may require control for these additional hazardous air pollutants.

Factors that contribute to the amount and type of emissions from fuel storage and fueling operations include the construction of and type of storage vessels at the sources and the mechanism for dispensing the fuel from the storage containers. Additionally, best management practices designed to minimize spillage, overfilling, and other associated management factors are important components in the minimization of release of emissions through mishandling of fuels.

The most effective fuel storage and dispensing controls include the selection and implementation of proper fuel storage vehicles, vessels and refueling options. Generally, a tank constructed with either an internal or external floating roof would be a minimum installation requirement. Tanks of this construction would minimize the loss of volatile organic compounds both through withdraw and breathing losses. An appropriate maintenance program for tanks includes mandatory provisions for periodic inspections and maintenance of the seals and fittings. Appropriate measures to minimize the loss of volatile organic compounds during the actual refueling of vehicles would include vapor balancing for tank loading from transport vehicles and individual vehicle refueling. The appropriate control for tank loading is commonly referred to as Stage I, vapor control. Stage I, vapor balancing systems can achieve reductions of approximately 90% for underground tank loading. Stage II controls apply to the control of

displaced vapors from the actual filling of vehicle tanks. This control usually is not warranted for mine site activities due to their remote location and the amount of refueling that occurs.

### 6.4.4.3 Compressors/On-Site Power Equipment

Compressors may be fossil fuel fired or electrically driven at a mine site operation. Fossil fuel fired compressors will result in the production of oxides of nitrogen, oxides of sulfur and carbon dioxide and carbon monoxide emissions depending upon the exact fuel used and the operating configuration of the compressor. In general, the type of emission of greatest importance are oxides of nitrogen resulting from the high temperatures associated with stationary gas turbines used to drive the compressor. A significant factor that determines the quantity of emissions generated by a stationary gas turbine is the fuel used (natural gas or number two distillate fuel oil). Residual fuel oil may be used in a few applications.

The most important control factor for emissions of oxides of nitrogen from a gas turbine compressor drive is the operating temperature. A control mechanism to minimize these emissions is water or steam injection. Water or steam may be injected with the air and fuel into the turbine in order to lower the peak operating temperature, which in turn will decrease oxides of nitrogen produced. This lower average temperature may in turn produce higher levels of carbon monoxide and/or hydrocarbons. It is also possible to control the emission of oxides of nitrogen by the use of catalytic reduction as a post combustion control. The exact type of control used and the extent of control required is a function of the individual gas turbine and can best be determined at the time of specification for this equipment.

Electrically driven compressor devices do not result in the emission of these pollutants.

### 6.4.4.4 Mill/Preparation Plant

Emissions associated with milling, preparation, screening, crushing and grinding are major activities that often occur at mine sites. These activities are of primary importance in the preparation of the material for shipment off-site and/or further on-site processing or milling. The extent to which these activities occur at any site is a function of the actual site activities. In a number of cases, particularly in coal mining, the on-site activities include all associated preparation activities necessary to make a final product for commercial usage. For screening, crushing, grinding and other associated process activities at mine sites the primary pollutant of concern is particulate matter resulting from fugitive dust and point source emissions from the actual preparatory activities. These processing activities are necessary to prepare the material in a final physical size for appropriate post processing and/or direct commercial use.

The removal of overburden or gangue material in milling activities and the drying or conditioning of materials to make their physical state appropriate for commercial end use are examples of activities that result in air emissions. These activities can all be characterized as material handling activities with resultant air pollution emissions. Emissions associated with mining activities preparing materials for milling, screening, crushing, grinding or drying have been discussed elsewhere in this section. Specific potential emission points for these activities start with the dumping of a material into a primary crusher and include primary, secondary and tertiary crushing; screening of material to obtain the appropriate particle size; transfer points associated with the conveyor systems for these operations; milling activities as may be required; drying processes where appropriate; and loading to storage piles or storage silos from conveyors. All of these activities may produce significant air pollution contaminates.

Major control approaches that may be used for these materials include wetting of materials or surfaces with water or other surfactants or foaming agents; covering of open operations to prevent dust entrainment by wind; reduction of drop heights for dust producing materials, hooding an/or industrial ventilation systems and dust collectors such as baghouses on processes such as crushing, grinding, screening and load-out points. The majority of the activities associated with the preparation of material from a mine for final commercial products are amenable to the use of point- source control devices, which in most cases will be a baghouse. Crushing activities such as secondary crushing can usually be completed within an enclosure using a ventilation system with a baghouse control device. Screening and material transfer operations are usually amenable to enclosure and venting through a baghouse. Drying operations may produce direct emissions from the actual drying activity. These emissions are point source emissions that may be controlled by baghouses or wet scrubbers.

At the conclusion of processing, materials are either stockpiled or placed in a silo, depending upon the type and size of materials. Dust emissions from stockpiling operations are not generally controlled by enclosures and use baghouses and; therefore, wetting is an appropriate control mechanism commonly used.

Materials in silos do not pose major air pollution problems except during load-out and filling of the silos. Both of these actions are able to be controlled through the use of baghouses at drop points and the use of covered systems.

**Table 11** Mining Fugitive Emission Controls, Effectiveness and Costs

| Mining activity emission control technique | Control effectivness | Cost factors<br>L = low<br>M = moderate<br>H = high |
|---|---|---|
| **Topsoil removal** | | |
| Pre-watering | 50% | L |
| **Topsoil or overburden stockpile** | | |
| Wind breaks | 50% | L |
| Rapid revegetation | 75% | L |
| Mulch | 85% | L |
| Chemical dust suppressant | 85% | M |
| **Blasting** | | |
| Reduce blasting needed | Function of reduction | L |
| Prevent overshooting | Function of reduction | L |
| **Overburden removal** | | |
| Pre-watering | 50% | L-M |
| **Overburden shaping** | | |
| Leave ridges | Function of soil ridge roughness | L |
| Establish wind breaks | Function of the height and wind speed | L |
| Rapid revegetation | 85% | L |
| Minimize spoil pile area | Function of area reduced | L |
| **Product removal, truck/shovel or front-end loader** | | |
| Minimize fall distance | Function of distance reduced | L |
| **Product dumping, end or bottom dump** | | |
| Spray dumped material | 50% - 85% | L |
| **Product storage** | | |
| Keep storage pile wet | 50% - 85% | L-M |
| Enclose with a structure | Up to 100% | H |
| **Haul roads** | | |
| Limit speeds | Function of the speed reduction | L |
| Chemical stabilization | 85% | M |
| Restrict off road use | 100% | L |
| **Road maintenance** | | |
| Remove loose debris (grading) | Function of material removed | L |
| Chemical stabilization | 85% | M |
| **Disturbed areas** | | |
| Rapid revegetation | 75% | L-M |
| Mulch | 85% | L-M |
| Chemical dust suppressant | 85% | M |
| **Crushers and screens** | | |
| Baghouse | 99% control of captured dust | M-H |
| Water sprays | 50% - 75% | L-M |
| **Conveyor belts** | | |
| Full covering | 100% control | H |
| Water sprays | 50% - 75% control | L-M |
| **Transfer points** | | |
| Enclose and vent to a baghouse | 99% control of captured dust | M-H |
| Water sprays | 50% - 75% | L-M |

### 6.4.4.5 Mine Ventilation

Mine ventilation represents a very difficult control area that historically has not been often considered a source of air pollution by regulatory agencies. Pollutants that may be emitted from mine ventilation systems include

particulate matter from general subsurface mining activities and methane and carbon monoxide from coal mining operations. Additionally, both coal mining and hard rock subsurface mining activities could be expected to produce emissions from the operation of vehicles and the exhaust of internal combustion engines used in subsurface transportation and mining activities. In all cases very large air volumes are involved and the potential to control air pollutants through an individual point source approach is very difficult and has not generally been done in the past.

Two factors are important in determining air quality emissions associated with subsurface mining activities. First, health and safety requirements for subsurface mining activities generally will result in the minimization of air pollutants. Air pollutants emitted are measured and controlled for the health and safety of the individual miners. Therefore, emissions will tend to be minimized for personnel protection. Second, air pollutants exhausted from a mine are increased in direct proportion to the background concentration of pollutants in the incoming air. Air drawn into mines for ventilation contains air pollutants from regional activities and long range transport. In any determination of the amount of pollutants emitted from ventilation, both consideration of the subsurface activities and the concentration of contaminates in the background air are important. In the past, control of these pollutant sources has not been considered a high priority due to the tremendous volumes of air and the relatively low concentrations of air pollutants involved.

#### 6.4.4.6 Shops/Maintenance/Repair Activities

Airborne pollutants may result from ancillary activities at mine sites associated with the maintenance and repair of vehicles and mine equipment. Pollutants resulting from these activities are similar to the pollutants produced by repair activities at other industries. A primary pollutant of concern is volatile organic compounds (VOC) from the use of solvents and fuels in the equipment being repaired. Additionally, particulates may be emitted through grinding, machining or other related activities associated with the repair of equipment. Lastly, hazardous air pollutants (HAPS) may result from repair and maintenance activities depending upon the type of solvents used and the type of air pollution control used to minimize the loss of solvents. Factors that impact the amount of air pollution emissions include the size of the maintenance operation and the site management plan employed. These activities are not unique to mining and, therefore, are not discussed in greater detail. Control generally involves good management practices such as: (1) using closed degreasing devices; (2) the use of solvents with lower vapor pressures; and (3) the substitution of water-based cleaning materials for solvent-based cleaning materials.

### 6.4.5 EFFECTIVENESS AND COST

The general level of effectiveness of any air pollution control depends upon the degree to which it is properly utilized. Table 11 indicates a typical level of control that can be achieved from the appropriate implementation of a selected technology.

Costs presented in Table 11 are generic and are provided in the form of ranges, where low (L) indicates less than $25,000, moderate (M) indicates $25,000 to $75,000, and high (H) represents greater than $75,000. These costs are provided only for general guidance to support planning for air quality management at mine and related activities. Detailed costs can only be determined on the basis of a specific implementation plan and activity.

### 6.4.6 SUMMARY

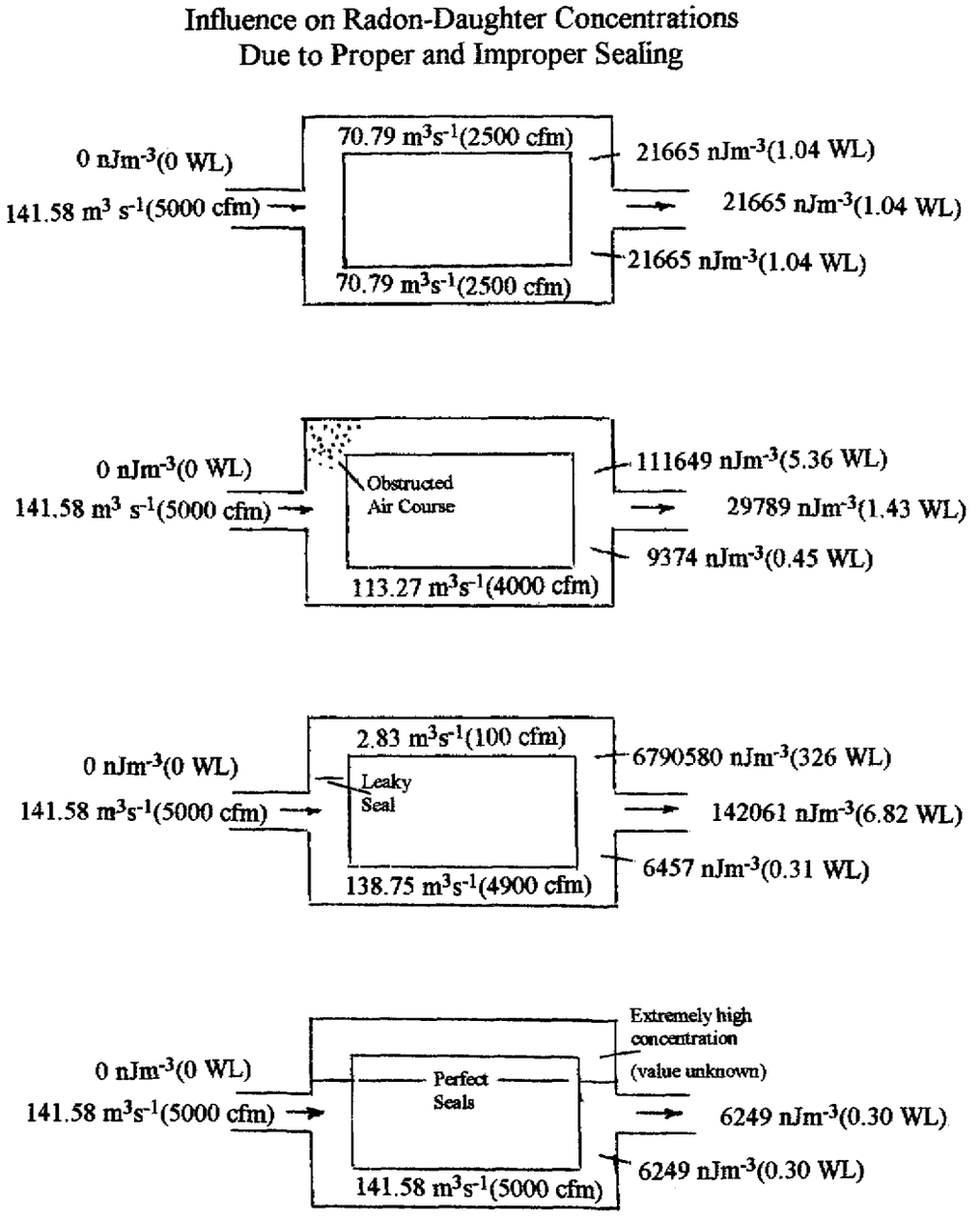
Air pollution control at mining sites is becoming an increasing requirement of regulatory agencies. Historically best management practices have constituted the primary means for control of fugitive emissions at mine sites and baghouses have constituted the major control for point source emission points. Increasing interest in the future will be placed on the control of air pollutants at mining sites with additional requirements for collection of dust and other particulate sources and the conveyance of these materials to appropriately located baghouses. Finally, the employment of additional natural pollution control methods such as wind breaks and vegetative cover, the minimization of speeds on haul roads, and other practices will all contribute to the lessening of air pollution emission.

### 6.4.7 CONTROL OF RADON AND RADON PROGENY IN UNDERGROUND MINES
**by R. T. Beckman**

Radon and radon progeny may be present in any underground opening. In those mines where significant concentrations of radon progeny occur, these concentrations are usually controlled by control of radon influx and/or control of decay time.

Control of radon influx may take several forms. For new mines, all intake airways should be driven in ground with low radium content. This insures that the intake air is not precontaminated with radon.

Retreat mining should be employed to minimize the surface area exposed to intake air. If areas must be mined on the advance, then effective seals must be placed to isolate the mined-out area from the ventilation air. Where possible, a negative pressure should be maintained behind the bulkheaded area to insure that any leakage




Figures illustrate the importance of uniform ventilation and nonleaking seals. If seals are not designed to preclude the entrance of contaminated air into intake air, they are actually detrimental to radon-daughter control.. All calculations assume uniform radon emanation throughout exposed mine surface areas and are based on the equation:

$$V_2 = V_1 (C_1/C_2)^{0.56}$$

where $V_1$ = Initial ventilation rate

$V_2$ = Final ventilation rate

$C_1$ = Initial radon-daughter concentration

$C_2$ = Required radon-daughter concentration

**Figure 15** Results of improper sealing.

through the bulkheads is into the mined-out area rather than into the ventilation air. Ore handling should be minimized and overblasting, which fractures the rock in place, should be avoided.

In mines where significant groundwater is present, the water may contribute significant quantities of radon; if so, the ventilation system should be designed so that the groundwater inflow occurs in the return air or the groundwater should be piped out of the mine to keep the radon from entering the ventilation air.

Efficient ventilation is the primary method used to control decay time. Because radon progeny increase with time, the ventilation system must be designed to keep residence time to a minimum (Beckman and Holub, 1979). A split system of ventilation should be used so that each work area receives uncontaminated air and the return air of the work area is exhausted so that it does not contribute to the contamination problem in other work areas. Recirculation must be completely eliminated because this increases residence time and allows significant growth of radon progeny. Leakage of air from unventilated areas (see Fig. 15) may contaminate ventilation air to a significant degree. For this reason, it is imperative that a negative pressure be maintained behind any bulkheaded area to insure that leakage is into the bulkheaded area.

Secondary ventilation is normally accomplished by a blowing system with ventilation tubing. Care must be taken to assure that the end of the tubing is effectively ventilating the work area and that the face intake is in fresh air.

Air quantity requirements are reasonable if the air has not been contaminated; air quantity requirements increase drastically if the intake air is contaminated. The formula

$$V_2 = V_1(WL_1/WL_2)^{0.56} \qquad (6.4.3.13)$$

– where $V_1$ = measured ventilation, $V_2$ = required ventilation, $WL_1$ = measured radon progeny concentration Working Level, $WL_2$ = derived radon progeny concentration Working Level – tends to underestimate the volume of air required. This is because $WL_1$ and $V_1$ cannot be adequately related (Rock and Beckman, 1980).

Radon progeny (particulates) can be removed from mine air by mechanical or electrostatic filtration, but filtration of mine air is seldom used because of the high maintenance costs. There is no method available to remove radon gas itself from mine air. When workers must enter uncontrolled environments respiratory protection must be used. A number of respirator canisters have been approved for protection from radon progeny or airborne radionuclides.

Occupational exposures to radon daughters in underground mines are regulated by 30 CFR 57.5037 through 57.5047. EPA has developed rules regarding allowable levels of radon in exhaust air discharged to the atmosphere from underground uranium mines. These rules are addressed in 40 CFR 61.23. At the present time, there are no EPA rules regarding radon emissions from surface mines or other underground mines.

## 6.5 SOCIETAL EFFECTS

### 6.5.1 AESTHETICS
**by J. A. Pendleton**

The societal effects of mining, an increasingly important consideration during the 20th century, have become especially important during the past several decades. Visual impact, cultural resources, and land use, which were once regarded as too intangible to be addressed definitively, are now important components of many permitting and land use authorities' decision-making processes. While other more traditional mine design and planning topics, such as slope stability, sediment and dust control, or traffic impacts can be routinely resolved, the consideration of societal effects often linger to be resolved late in the permit approval process. Because they are considered less tangible or more subjective, they are often treated by operators, regulators, and objectors as negotiable items prone to caprice, coercion, and retribution. Improved understanding and aggressive treatment of the societal effects of a mine, in concert with the more traditional mine plan components, can improve the operator's satisfaction and reduce the cost of the permitting process.

The visual impact of mining, once accepted as a necessary and unavoidable consequence of progress and economic vitality in many jurisdictions, is now considered an unacceptable imposition upon citizens' rights. Mining's aesthetic impacts can be addressed along intangible lines, such as degradation to a community's "quality of life," and in tangible terms, such as the quantifiable effect upon property value. A diverse selection of technology exists to manipulate mine plans in order to vary the projected visual impact of a mine. Similarly, an increasingly diverse selection of technology is available with which to accomplish remediation of the visual impacts of a mine's operation.

The increased scrutiny focused upon mining's visual impacts occurs largely through the framework of the statutorily mandated planning and permitting processes. City and county planning commissions, state regulatory agencies, and federal land management authorities each participate in the land use and mine plan approval process. Many mine plans are subject to regulation by agencies at multiple levels of government. Technology is rapidly developing to facilitate the simulation of a projected mine's appearance. In fact, alternative mine plan's various appearances can now be readily simulated at reasonable cost, allowing more informed selectivity to be exercised in the planning process. However, the recent

burgeoning of visual simulation high-technology, cannot eliminate the difficult philosophical dilemmas encountered in the planning process. It is difficult to assign relative weights between aesthetic criteria and the numerous other planning criteria. With the increased versatility available to address the undesirable aesthetic impacts, however, the majority of perceived aesthetic nuisances can be successfully mitigated.

#### 6.5.1.1 Perception of Visual Effects and Landscape Character

In order to discuss visual effects of mining, we must first understand the viewers' perception of visual impact. The U.S. Bureau of Land Management, the U.S. Forest Service, and the National Park Service pioneered and perfected the technology of evaluating visual resources during the 1970s and the 1980s (Anon., 1978a, 1978c, 1978d, 1986b, 1986c). Visual resource analysis was developed in an attempt to quantify the quality of scenic vistas, in order to determine which natural areas warranted protection. Whether or not visual impact practitioners agree with this policy objective, most recognize that the effort facilitated the development of the majority of the contemporary principles of visual impact analysis.

A viewer's perception of a mine's visual impact is affected primarily by the mined area's contrast with the surrounding landscape. Visual contrast is dependent upon form, line, color, and texture discrimination. A bright, unweathered and unvegetated rock cut stands out against an undisturbed, soil covered and vegetated slope. Most viewers also perceive contrasts in texture. A uniform grassed slope will stand out against a mottled shrub or tree- covered slope, even if both are the same color, hue, and chroma. The viewer's attention is focused on a contrasting landscape element, as long as it is large enough to occupy more than a minimum angle of visual arc on the cornea of the viewer's eye.

On a more conceptual level, a viewer's perception of visual impact relates to contrast in overall landscape character and quality. Differences in landform, such as broad gentle slopes versus undulating ridges and valleys, or differences in drainage density, will be perceived as contrast in landscape character. Landforms that are not consistent with the viewer's personal understanding of a region's natural physiographic character will be perceived as unnatural and inappropriate. To further complicate the determination, most individual viewers also value diversity as a desirable component of a landscape. Each viewer personally resolves these competing parameters in arriving at a personal opinion of the quality of a landscape. Because all viewers are not versed in geomorphology or physiography, the approval process may be aided by tactful basic education of the public and the permitting authority.

#### 6.5.1.2 Mine Operations Planning

The visual effects of any mine are directly related to its visibility. If a mine can be rendered virtually invisible in the surrounding landscape, its aesthetic effects will be minimal. If a mine cannot be removed or screened from site, there are techniques available to minimize or mitigate its visual perception. The following design and abatement techniques may be useful in decreasing the visual impact caused by a mine's operation.

##### *6.5.1.2.1 Mining Method*

For completeness the obvious is mentioned that the visual impacts of underground or in situ mining are significantly different from surface mining. Normally the choice of mining method is determined by the proximity of the resource body to the ground surface. In a few unique instances, however, such as hard rock aggregate production in steep terrain, it may be plausible to select a mining method because of visual impact considerations. Commonly, underground extraction will decrease visibility if care is taken concerning placement of surface facilities, resource stock piles and spoil. Candidly, designation of mining method to affect visual impact will not be economically viable for the majority of mines.

##### *6.5.1.2.2 Mine Siting*

The most direct means of controlling a mine's visual impact is to hide it. If the luxury of alternative resource locations exist, the relative visual impacts of the potential mine sites should be considered early in the planning process, along with other primary siting considerations such as proximity to market and population. If one candidate site happens to occupy a restricted, unpopulated box canyon it should be considered favorably versus highly visible, populated sites. All to often, however, such isolated sites are considered desirable residential sites, and few remain undeveloped.

All prospective mine sites have visual exposure. Initial consideration should be given to the various sites' relative degree of visual impact. A visual impact analysis can be performed manually by completing a field reconnaissance mapping of the impacted area to determine locations from which the site can be seen, and by how large an audience. For large operations, it may be warranted to complete a computer analysis using digitized topographic maps and population distribution data. Analyses of visibility represent person-weeks of effort and can be expensive.

A mine plan's visual impact may be manipulated by varying the progression of mining. For example, if a ridge is being mined and 90% of the viewing population

only sees one flank of the ridge, mining might commence on the less viewed side of the ridge and progress toward the populated side of the ridge. The majority of the viewing population would not see the early phase and might only perceive a reconfiguration of the ridge's profile later, rather than a typical progressively enlarging scar. Contemporaneous reclamation of the early phase might further reduce the visual impact if exposed to view during the later phase.

#### *6.5.1.2.3 Visual Screening*

Screening can be affected through a selection of techniques. Mine plan orientation, as alluded to above, is one form of visual screening. More commonly, visual screening techniques include the installation of berming, vegetative curtains, or structural barriers. These techniques construct artificial barriers to screen the mine from site. Manual reconnaissance or computer visibility analyses can determine the effectiveness of a proposed visual screen. Physical and economic constraints normally limit the size and effectiveness of barriers. Barrier effect can be optimized if combined with siting and mine plan progression selection. A barrier constructed early in the mine development on a topographic high may have maximum benefit.

Barriers need not be additional expenses solely for visual impact abatement. Subsoil and topsoil must be stockpiled for later reclamation. Properly located stockpiles can also serve as low cost visual barriers. Surplus overburden can be used to construct permanent barriers, avoiding the expense of redisturbance. Further, barriers created in early mine phases can provide highly visible reclamation demonstration plots. The anxiety of concerned objectors can be significantly reduced by early demonstration of proposed reclamation techniques. If multiple reclamation treatments are proposed, provide multiple demonstration plots.

#### *6.5.1.2.4 Cosmetic Treatment*

In situations in which siting, mine progression adjustment or visual screening aren't feasible or sufficiently effective, cosmetic treatment may help decrease visual impact. The most common cosmetic treatment is revegetation. Most permitting authorities require vegetative stabilization of reclaimed soil and stockpiles to control fugitive dust, sediment generation and storm-water runoff. The establishment of vegetation will also decrease the visual perception of unweathered earthen materials.

Artificial camouflage techniques may also be useful, however, they are only temporarily effective. Netting made of jute and other materials may be draped or spread as simple camouflage. Netting is of short duration and may have other undesirable consequences, such as wildlife mortality. In addition, cost may exceed a dollar per square yard.

Rock and soil staining, which has gained popularity with highway departments during the past decade, represents a longer term cosmetic technique. These staining techniques originated in the arid southwest for treatment of recent cut and fill scars. In the sparsely vegetated Phoenix area, any excavation or grading disrupts the desert varnish, resulting in highly visible scars. Several manufacturers developed oxide stains to reduce the soil and rock contrast. Highway departments have used these stain techniques in Arizona, California and Colorado with satisfactory results. Depending upon the permeability of the rock or soil being stained the stains penetrate to varying depths. Limestone rock faces along I-70 in Glenwood Canyon, Colorado show penetration depths of up to 12.7 mm, which suggests relative longevity. Existing stained rock cuts show little deterioration. Stained soil areas, if redisturbed, require retreatment. The primary drawback of these staining techniques is a cost of up to $1.61 per square meter. While cost prohibitive for large area treatment, staining may be cost effective for visual abatement of small areas with high visual impact, such as unweathered rock faces.

Rock sculpturing, another technique employed by highway departments, provides another cosmetic abatement technique. In confined steep slope situations where mining traditionally produces steep, planar, high contrast and artificial terraced rock walls, rock sculpting can be a particularly effective abatement technique. Rock sculpturing is a blasting and excavation technique designed to produce a diverse final rock face mimicking the character of naturally occurring rock slopes. The technique was used extensively during the 1960's in constructing the portion of I-70 crossing Vail Pass in Colorado (Anon., 1978b). After initial training and experience, blasting technicians report it does not significantly increase excavation cost. However, because it can lower the overall slope gradient, the technique can decrease the recoverable resource quantity in comparison to traditional benched techniques. Further, because the accessible terrace benches are not created, the final facial configuration must be created in one pass, as a portion of mining. Supplemental reclamation techniques, such as topsoiling, revegetation and rock staining can still be completed subsequent to rock sculpturing.

### 6.5.1.3 Remediation of Visual Effects

Unavoidable visual effects of mining should be remediated as completely and rapidly as possible. The earlier approach of mine the resource and then reclaim the site has caused much of the contemporary resentment of the lingering visual impacts of mining. Ideally, remediation should occur contemporaneously with the operation of a mine. However, not all mine sites and

mine plans are amenable to contemporaneous reclamation. Further, the completion of significant landscape restoration and the establishment of mature vegetation requires significant passage of time. Remediation of visual impacts can also include consideration of other mine plan parameters, such as decreasing the duration of the visual impact.

#### *6.5.1.3.1 Restoration of Natural Landscape Character*

Remediation of the objectional visual impacts of a mine can be accomplished through restoration of the natural landscape character. This is not as simple as recreating the pre-mining landscape and reclaiming the disturbed area. For most mines, except large area surface mines, it is not practical to recreate or mimic the original landscape. Rather, the mine plan should create a diverse and natural landscape acceptable to the permitting authority and the impacted population.

#### *6.5.1.3.2 Minimize Duration of Impact*

If possible, operation and reclamation of a mine should be considered synonymous. Reclamation is the final closure phase of a mining operation. The entire mine proceeds continuously from initial topsoil salvage, to extraction of the resource, to regrading, and finally to topsoiling and revegetation. At any given time selected areas of the mine exist in various stages of disturbance. Ideally the resource is extracted using methods that facilitate creation of the approved final topographic configuration. Overburden, subsoil and topsoil are initially stockpiled and later live-hauled to recently disturbed previous areas of the mine. The mine progresses from initiation to closure like a coordinated railway maintenance unit train, consuming the undisturbed mine site in front and creating the restored landscape behind. A contemporaneously reclaimed mine plan should minimize the disturbed area and the associated visual impact.

In the event that visual impacts during mine operation cannot be acceptably minimized, it may be possible to shorten the duration of the impacts as an offsetting accommodation. Many permitting and land use authorities have begun imposing permit life restrictions on mine permits as a means of decreasing impacts. Permits are approved with specific permit life spans, which may require the mine to extract the resource faster than anticipated market consumption rates and stockpile the resource in an approved area, in order to complete reclamation of the mine within the imposed time span. Single project permits with extremely limited life spans are approved for specific public facilities construction. The pro-active mine operator may self-impose such restrictions in the interest of obtaining permit approval, if project economics allow it.

### 6.5.1.4 Evaluation of Visual Effects

The evaluation of the visual effects of mining is difficult for a number of reasons. The evaluation of visual impacts is hindered by the inability of many viewers, whether designers, engineers, regulators, or impacted neighbors, to visualize the mine based upon a two-dimensional plan map. The evaluation is further hindered by the individual nature of each viewer's perception of visual impact. Each viewer personally resolves a concept of natural landscape character in arriving at a personal opinion of the quality of the proposed post-mining landscape. It is difficult enough to conduct an informed discussion of the proposed visual impacts of a mine, without every participant visualizing a different image in their mind's eye. Practitioners of visual impact analysis have confronted these difficulties since the origination of the discipline. As a result of ingenuity and persistence a number of useful visual impact presentation tools have been perfected, which can be beneficially applied to the mine permitting process.

#### *6.5.1.4.1 Visual Simulation*

The architectural profession has employed artists to render site plans pictorially since the time of the Egyptian Pharaohs. An accomplished artist experienced in plan rendering can provide interpretive images to assist the viewers in judging the visual impact of a mine plan. The quality of the renderings are governed by the artist's ability. Realistically, the number of visual vantage points and the mine plan variations that can be rendered are limited. The task can be simplified somewhat by the use of photographic pre-mine panoramas as a beginning image upon which the mine plan renderings can be superimposed. Traditional artistic renderings, depending upon complexity and size, can be expensive, varying from several hundreds to several thousands of dollars per image.

During the past decade, the rapid evolution of computerized visual simulation high-technology has facilitated innovative analysis and design manipulation of visual impacts. Visual simulation software and compatible video processing hardware allow a video taped image of a proposed mine site to be converted to a computer data file. This data file, displayed on the computer's color monitor at essentially photographic quality, can be edited by the visual simulation technician. Computer graphic artists can create the proposed mine's visual image, or file video images of similar equipment, land disturbance and reclaimed land forms can be scaled and edited into the pre-mining panorama. The same image data file can be edited repeatedly to render alternative mine plans, and

progressive aged images, with minimal repetitive effort. Once the initial computer file has been created, many software programs will allow the image to be viewed from different hypothetical vantage points. Visual simulation images may be converted back to video tape or printed on electrostatic color printers.

The quality of the video simulation images are governed by the technician's ability and the capability of the monitor or printer. Unlike the traditional artistic rendering, the number of visual vantage points and the mine plan variations are unlimited. The acquisition and maintenance of the high-technology hardware and software to facilitate video simulation of visual impacts is expensive. As a result, the completion of the initial simulated images can be similar in cost to the traditional artist's renderings. However, the production of subsequent alternative images, which require little additional effort, becomes significantly less costly. Perhaps more importantly, the provision of the additional images facilitates all involved parties understanding and interchange. This heightened comprehension promotes more informed discussion among the mine operator, regulator, and the visually impacted viewer, which facilitates mine plan approval.

Both traditional artistic rendering and high-technology computer video simulation have several significant limitations in common. The ability to translate from two-dimensional mine plan maps to visual imagery requires considerable experience. It must also be understood that the renderings by either technique are only as realistic as the technician's understanding allows. Care must be taken to avoid misleading the viewer with "glitzy" visual images. If appropriate care is not exercised, the viewer's falsely heightened expectations will eventually result in disappointment, distrust, resentment, and retribution. Finally, the viewer should be thoroughly apprised of the time required to accomplish the mine plan and remediation, including such factors as the maturation of vegetation.

#### *6.5.1.4.2 Scale Modeling*

Another architectural technique that serves well to assist in presentation of a proposed mine plan is three-dimensional scale modeling. Models can be manufactured from a variety of inexpensive and easily manipulated materials. Professional scale modeling firms now apply computerized techniques to the generation of scale models, allowing them to be extremely accurate and rapidly produced. In combination with artistic or computer visual simulations, scale models have proven to assist many viewers in conceptualizing the mine plan. The better the viewer's understanding of the mine plan, the more likely they will be to comprehend the visual effects of that plan. Models can be developed to represent alternative mine plans and different stages in mine development or remediation. Scale modeling can be expensive, depending upon the detail and flexibility in display desired.

#### *6.5.1.4.3 Field Demonstration*

If visual simulation and scale modeling techniques fail to clarify the visual impacts of the proposed mine plan, field demonstration can provide an additional connection to reality. Photographic or artistic models or mockups positioned to allow viewing within the backdrop of the affected landscape can be informative to the viewer. The U.S. Forest Service and National Park Service have used mockup panorama signs as locating aids at scenic overlooks for decades with high viewer recognition and satisfaction. These techniques can be employed during permit review and mine operation to assist viewers in visualizing the mine's progression.

Field demonstration plots can also assist viewers in judging the effectiveness of specific proposed visual remediation techniques, such as berming, rock staining, rock sculpturing or revegetation. Demonstration plots can be established in easily accessible locations. The concerned regulators and impacted population can visit the demonstration plots and judge the potential effectiveness of proposed visual remediation techniques for themselves. Demonstration plots entail construction and maintenance expenses prior to mine permit approval. They also require reclamation, whether or not permit approval is obtained. However, they can serve as tangible demonstrations of the mine operator's commitment to visual impact remediation, which should assist in obtaining mine plan approval.

### 6.5.2 CULTURAL RESOURCES
**by F. E. Kirby**

#### 6.5.2.1 Perspective

When archaeological resources – the non-renewable evidence of past human activity – are portrayed, the largest, oldest, or most spectacular sites are often selected. Egyptian pyramids, Mayan temples, Far Eastern religious shrines, Easter Island, Civil War battlefields, and Chaco Canyon are such magnificent examples. Each of these sites, though, represents only a portion of the integrated social system that produced it.

To recreate and understand the life ways of past peoples and to "define the cultural processes that underlay human behavior, past and present" (Thomas, 1979) an archaeologist must retrieve and interpret the full range of their activities from the archaeological record. Wilson (1987a) gave us a broad view of the discipline of archaeology, "Besides being applicable in both prehistoric and historic contexts, archaeology can also be a technique, a method, or an approach to collecting

specimens and data which, through careful analysis, will tell us something about our past that we had not known before." This discussion incorporates Wilson's broad viewpoint.

Study and protection of archaeological evidence and cultural resources are not confined to archaeologists. Supporting disciplines include anthropology, ethnology, geology, and biology. Each contributes to the understanding of past life ways. Our political and social climates influence categorization of cultural resources and their preservation. The key to determining the importance of the past rests with the views, perceptions, and wishes of the public, including indigenous peoples.

Management of cultural resources has three parts: 1) identification of the resource, 2) evaluation of the importance of the resource, and 3) protection of the resource from destructive impacts. In the United States and in most developed countries, standards establish levels, priorities, and directions for the identification, evaluation, and treatment of cultural resources. Cultural resource identification and impact mitigation are commonly subject to time and money constraints. Technology may assist in overcoming these constraints.

In mining, efforts to identify cultural resources and to mitigate destructive impacts consider the particular situation. Various extraction technologies (surface, underground, in situ) and support activities (roads, facilities) cause ground disturbance and impact the resources in different ways and with differing intensities. Destructive mining impacts range from direct surface disturbance to less obvious subsidence effects associated with underground mining, blasting impacts on off-site, to the even more subtle effects such as increased accessibility allowing vandalism or looting.

Social and political environments play critical roles. In developed countries, standards and procedures for cultural resource identification, evaluation, and impact mitigation are established through national, regional, and local laws and regulations supplemented by guidance documents and professional criteria. A readily available, trained, and experienced work force has access to the most up-to-date preservation techniques and technologies.

In developing countries, the situation often is very different, especially when survival rather than public interest or cultural resource protection is critical. Practical, enforceable cultural resource standards often are not in place. A trained professional archaeological work force may not be available for needed studies and management. Cultural resource preservation technologies as well as manpower and equipment sometimes must be imported. In all situations the minimum standards of the country must be satisfactorily achieved to lessen the chances of political impact on present and future projects. It may be in the best interests of the mining company to employ higher cultural resource standards in its projects in developing countries.

### 6.5.2.2 Resource Identification

Identification of cultural resources includes descriptions of the location, the resource, and the environment where the resources are found. Complete and well documented descriptions are fundamental for the protection of a single resource or a larger resource base.

Archaeologists locate and record cultural resources within the context of a ground survey. Local people often are called on to provide information about cultural resources. These same informants may serve as a labor force, and they may have a special interest in archaeological projects since their history and prehistory are under investigation. Archaeological investigations often serve to create public awareness and to educate populations about their past.

Generally, a more intensive survey is more costly. Survey intensity, complexity, and cost depend on the goals, standards, and setting of the study. When the standard requires consideration of all cultural resources in an area, surveys are intensive. When the standard focuses on specific parameters such as architectural and structural remains, the survey may be less intensive and less costly. If sufficient information about cultural remains and environments exists for an area, surveys employing sampling strategies or predictive models may meet standards. In some situations, an archaeological survey may not be required. Two of many publications that provide a detailed discussion of survey planning, strategies, and implementation are Derry et al, 1985 and King, 1978.

Physical environments also influence survey methods and costs. Deserts and open plains are more easily surveyed than forested, mountainous, and jungle terrain. A survey of the same intensity will cost more in heavily vegetated areas than in open terrain.

In mining situations, decisions on survey need, intensity, and coverage consider the existing cultural resource base, the likelihood of locating significant new resources, and geological and engineering studies. The types of mining operations also influence survey requirements. Due to the scope of ground disturbance, surface mines pose the greatest threat to cultural resources. Underground and in situ mining tend to disturb relatively less ground. The effects of subsidence are the greatest dangers to cultural resources in underground mining. Engineering studies predict subsidence, and these findings are critical to an archaeological assessment. Other factors such as mining recovery methods, the nature of the deposits, and the amount and type of on-site processing also influence selection of proper archaeological procedures.

In addition to an on-the-ground investigation, other techniques are available to define areas that need physical inspection. Aerial photography, satellite imagery, and other forms of remote sensing aid in the location,

mapping, recordation, and interpretation of cultural resources. A variety of imagery is available including visual, thermal, ground- penetrating radar, and magnetic. The National Technical Information Service of the United States Department of Commerce prepared a series of publications describing theories, procedures, and applications of remote sensing in archaeology (Lyons and Mathien, eds., 1980, and Lyons, 1985).

Another developing technology that is proving very useful in archaeological surveys and the recording of cultural resource location is the Global Positioning System (GPS). GPS allows for the precise location of identified resources. GPS technology is advanced, and equipment is relatively inexpensive, very portable, and easy-to-use.

Remote sensing provides information on environmental, spatial, and resource patterns. This information is critical for the archaeologist interpreting past life ways, for decision makers from industry and government agencies, and for other interested parties. Although use of technology may appear to be costly, often its use is the only practical and cost- effective approach to identifying cultural resources on a broad scale.

#### 6.5.2.3 Resource Importance

Once cultural resources are located, described, and recorded, their importance is assessed. Assessment may be intuitive or structured within a set of standards of proscribed criteria. Intuitive assessments generally center on the biggest and most grandiose resources or on those remains that are closest to the heart of the investigator.

Use of structured procedures incorporates all located resources and evaluates them against the standard. The National Register of Historic Places and its criteria were developed as part of the National Historic Preservation Act. These criteria are used in the United States to evaluate the importance of properties impacted by Federal undertakings. The criteria for evaluating resource importance are presented in Federal regulations (36 CFR Part 60) supported by addi tional regulations and guidance documents developed at national, state, and local levels. One of the most recent guidance documents is "Guidelines for Identifying, Evaluating, and Registering Historic Mining Properties" (Noble and Spude, 1992). This document concerns cultural resource remains from past mining operations, how to identify and record them, and how to evaluate their importance. Many countries have similar standards and procedures in place to systematically evaluate cultural resources, either individually or in a connected group.

In the United States, the Department of the Interior developed a set of standards and guidelines, "Archaeology and Historic Preservation: Secretary of the Interior's Standards and Guidelines," that are "intended to provide technical advice about archaeological and historic preservation activities and methods." This document is, among other things, a useful overview of guidelines and standards for preservation planning, identification of resources, documentation of resources, and evaluation of resources (Anon., 1983a).

#### 6.5.2.4 Mitigation and Treatment of Impacts

Once decisions are made about the importance of a resource, consideration shifts to how the resource may be impacted by mining operations. Ideally, operations will avoid impacting cultural resources. When impacts are unavoidable, mitigation of impact to important resources likely is required. Mitigation is defined as actions taken to minimize, ameliorate, or compensate for degradation and/or loss of those characteristics that make the resource important. Depending on the nature of the resource, mitigating measures may range from simple recording of the resource to exhaustive architectural drawings and photographs, removal and curation of architectural features, physical relocation, and full-scale archaeological excavations and data recovery to the development of museums and tourist attractions.

Depending on the nature of the required mitigation, a multidisciplinary approach may be employed utilizing expertise from many fields. Ethnologists, geomorphologists, palynologists, artists, photographers, and computer scientists are some of the specialists who might be needed. As previously indicated in the section on cultural resource identification, specialists and trained personnel needed to conduct mitigation activities are usually available in advanced countries but may need to be imported in developing countries.

The key to successful mitigation efforts, as with successful identification projects, rests on up-front planning. Each step from obtaining proper permits to employing standards appropriate to the project to determining the research questions and goals must be considered prior to undertaking the mitigation effort.

In mitigation efforts involving archaeological excavations, various technologies may be selected to locate and delimit areas that require investigation. Magnetometer surveys, soil resistivity plots, metal detectors, and remote sensing techniques provide subsurface information. Walls, trenches, pits, stone alignments, and middens are among the features that may show as anomalies that deserve investigation. The accuracy of subsurface detection techniques is dependent on the resource itself and the physical attributes of the surrounding strata.

Investigation and recordation of buildings, structures, and similar features may employ laser survey techniques and photogrammetry. X-rays can be used to view the internal composition and configuration of such features.

Perhaps the greatest boon to the interpretation of

collected archaeological data lies in computer technologies. Simple data crunching and correlation of many variables, sophisticated predictive modelling, and GIS mapping are some important applications that support more complete cultural resource management. Computer applications may speed the mitigation process and minimize disruption of mining operations.

Cost for mitigation is dependent on the type and duration of the effort. Short-term projects investigating limited numbers of resources with easy accessibility are comparatively inexpensive. On the other hand, long-term, multi- resource, multidisciplinary projects can be very expensive. Excavation almost always increases the cost of mitigation.

A critical concern is emerging on a world-wide basis. This concern that must be faced by the preservation community, by politicians, and by developers is the view of indigenous or native populations. Their views encompass resources they consider sacred, ceremonial, and important to their cultural well being. The resources range from tangible remains such as burials, structures, or faunal or floral collecting areas to locations on the landscape that have no physical remains. The native peoples demand inclusion in the planning and decision processes that may affect these resources. Several laws enacted in the United States require consideration of Native American concerns (American Indian Religious Freedom Act of 1977), protection of Native American burials and associated grave goods, and repatriation of burial remains (The Native American Graves Protection and Repatriation Act of 1990). Other countries have or are developing similar legislation. Numerous recent articles and publications such as Klesert and Downer (1990), Klesert and Powell (1993), and Layton (1989) discuss historic preservation and native populations.

#### 6.5.2.5 Summary

Cultural resources are non-renewable, and information about the past must be preserved for future generations. Mining companies in particular have the opportunity to contribute to public awareness of the past through careful planning and protection of important cultural resources. Mining companies must know and understand the requirements of laws, regulations, and standards in the areas they mine. These are set in the social, political, and environmental frameworks. Papers included in two publications (Wilson, 1987b, and Wilson and Loyola, eds., 1982) resulting from conferences considering the ramifications of rescue archaeology in the new world provide insights to issues that archaeologists face "in the rapidly expanding world of international development."

Developing countries may present different challenges for the mining company. In developing countries, applications of cultural resource standards may be more difficult due to the lack of enforceable regulations and trained manpower. Expertise and technologies may be imported to reduce the risk of project delays or future project impacts.

The detrimental effects on cultural resources resulting from competing social, political, and financial interests can be minimized through detailed pre-project planning. Cultural resources must be identified, evaluated, and destructive impacts mitigated as needed. Decisions affecting cultural resources should be made in the context of resource awareness and the consequences of the actions taken.

Application of advanced technologies such as remote sensing and computer techniques and the application of predictive modelling may be cost-effective and time saving. Mining companies have a unique opportunity to be pro- active in achieving public trust. The greater reward is the better protection of the past for present and future generations.

## 6.6 MITIGATION OF THE EFFECTS OF BLASTING

**by D. E. Siskind**

### 6.6.1 INTRODUCTION

The environmental effects of blasting for mining, quarrying and construction excavation were described in Chapter 5. These are flyrock, ground vibrations, airblast, dust and gases (fumes). Generally, impacts in the immediate area of the blast are issues of occupational health and safety. If they impact areas outside the permit area and persons and property unconnected to the blasting, they are considered "environmental." Some effects are clearly environmental such as ground vibrations. Others can be environmental or safety issues depending on definitions and practices adopted at a site. Some impacts are strictly physical ones such as flyrock. Others have psychological aspects, such as vibrations. Ground vibrations shake homes and have the potential to produce damage. Even when below damaging thresholds, they are felt and heard by residents who sometimes believe that crack damage will or has occurred. Addressing psychological issues requires different measures than those used for physical problems, education and effective public relations.

Mitigation of blast effects requires two steps: 1) recognition that there is a problem and 2) taking measures available to reduce it. Recognition requires a comparison with some kind of norm. Mitigating measures sometimes create conflicts with other requirements such as cost control, fragmentation performance, and other environmental effects. Careful blasting for environmental control sometimes leads to other improvements such as reduced overbreak and better efficiency of blasting.

### 6.6.2 FLYROCK

As an issue, flyrock is not only hard to address but it is also hard to define. Each operation identifies its own blasting zone based on experience, the purpose of the blasting, and local issues such as rock hardness and the blast layout. One extreme is the difficult blasting on Minnesota's Mesabi Iron Range. There, the rock is hard, and blasting is very heavy with large holes, energetic explosive, and short benches. Their blast zones are defined in miles. The other extreme is represented by a totally confined blast such as a presplit or a trench excavation where small amounts of explosive are involved and the geometry prevents much rock movement. In a mining operation, the blast zone is defined as an area where rock throw is expected and sometimes specifically planned, for example, cast blasting in surface coal mines. Flyrock would then be material thrown outside this zone.

#### 6.6.2.1 Causes of Flyrock

There are two causes of flyrock and they appear contradictory: too much and too little relief. Relief is the path explosive energy takes to find escape from the rock mass. Good blasting consists of having the explosive do useful work in breaking up the rock and, in most cases, providing moderate rock throw to spread out the material and enable efficient handling. For flyrock purposes in bench blasting, there are two relief directions: in front of the face and on top from the blast hole collar region. These will be addressed separately using results from two survey papers (Roth, 1979 and Workman, 1994).

As a generalization, too much relief leads to excessive front-face flyrock. This simply means too much explosive for the rock being blasted and can happen in several ways. Examples are: too little burden, fissures, seams and voids, overloaded holes, and broken-up bench. Another generalization is that too little relief leads to high-angle flyrock from bench-top collar violence. This can be from insufficient or ineffective stemming, broken up cap rock, and too little time relief in back rows of holes. The two different sources of flyrock require two mitigating approaches.

#### 6.6.2.2 Controlling Flyrock Originating From the Bench Face

Burdens must be sufficient to contain the explosive energy. This means that effective or instantaneous burdens are at least 25 times the blast hole diameters. (The exact amount depends on the rock toughness, weight, explosive type and minor factors as described in various blasting texts such as Dick et al., 1983 and Anon., 1987.) Compromising the burdens are irregular and sloping faces, drilling inaccuracy, and voids leading to excessive explosive loads.

Explosive weights should be monitored to avoid overloading into void spaces. Fissures, mud seams and weaknesses should be stemmed through rather than loaded with explosive. Additional burden may be needed if the face is broken up or irregular. If the face is sloping, angled holes may help maintain the proper burden along the blast hole length. If angled holes are not possible, the explosive column may have to be shortened to avoid the lightly-burdened collar region. Special care may be needed to control drilling accuracy at some sites. A burden to diameter ratio of 14.2 or more will limit flyrock to a manageable initial velocity of 30 m/sec and range of 100 m (Workman, 1994).

#### 6.6.2.3 Controlling Flyrock Originating From the Bench Top

Violence from the top of the bench and around the collar typically occurs from excessive explosive and/or not enough relief or ineffective stemming and/or cratering and far too much relief. Burdens should be optimized for the same reasons as required to avoid face-produced flyrock.There, the concern was for too little relief. Here, it can be from too much. Additionally, sufficient time must be provided to allow relief of later-firing rows of blastholes. This means that delay timing should be at least 0.5 ms/m (2 ms/ft) of burden. Some mines have found that back rows of blastholes in a multi-row array may need even longer times to allow some movement and unburdening for both flyrock and backbreak control. Far worse than delays that are too short are delays that are out of sequence. They create too little relief initially and are followed by holes with too much. Misfires are serious flyrock generators.

Cratering results when the explosive breaks out to the top surface. One recommendation is for a "depth of burial" of at least 0.79 $m/kg^{1/3}$ or 2.0 $ft/lb^{1/3}$ (Roth, 1979). Effective stemming is required to contain the explosive energy until it has done its useful work. This means a stemming length of about 0.7 times the burden and coarse angular material that will interlock and hold against explosive gas pressure. At some sites, this may mean that drill cuttings are insufficient and that crushed aggregate must be purchased. Stemming that does not hold means pieces of material from around the collar zone will be thrown at a high angle and in all directions. It also usually means high airblast.

### 6.6.3 BLAST VIBRATIONS

#### 6.6.3.1 Blasting as a Vibration Source

Amplitudes (PPV or peak particle velocity in mm/s or in/s) and frequency (Hz) of blast vibration are primarily related to the blast design; particularly, the weight of

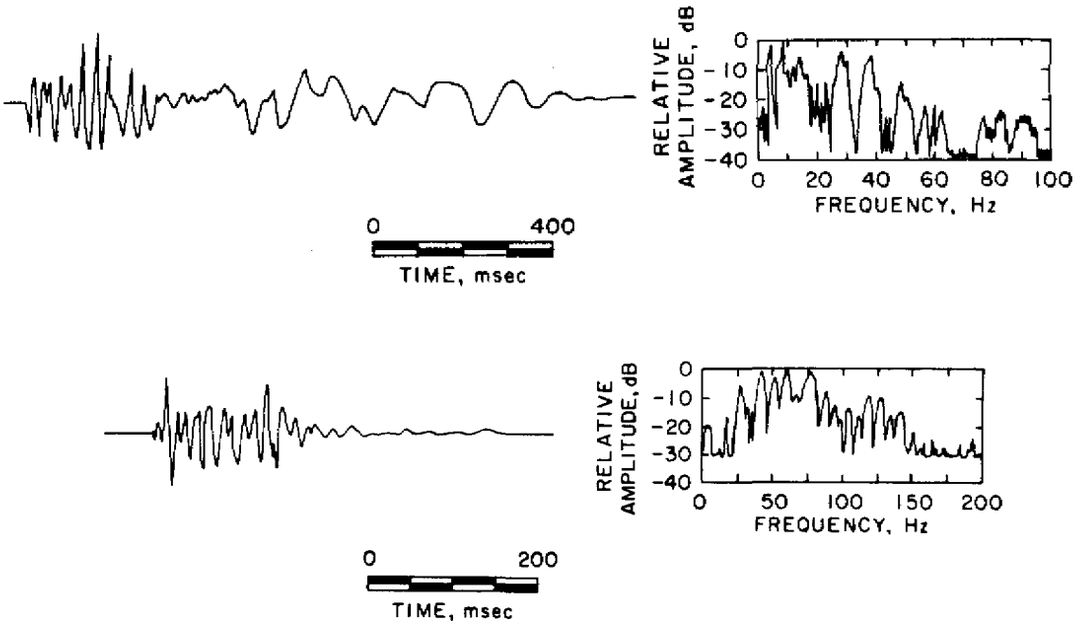



**Figure 16** Vibration records of differing complexities. Top trace is from a coal mine blast at 700 m (2290 ft) and the bottom is a construction blast at 23 m (75 ft).

explosive and initiation sequencing used, and the distance to the blast. The most important of the design parameters is the maximum amount of explosive detonating within a time interval, generally 8 ms, usually called "kg or lbs per delay" or "charge weight per delay". Of lesser importance are the blast hole size and the layout dimensions of burden, spacing, subdrilling, and how well the explosive fills the blast hole (i.e., coupling). Blasts with little relief, such as box cuts, are relatively strong vibration sources. U. S. Bureau of Mines RI 8507 (Siskind et al., 1980b, and Siskind, 1996) describes the effects of these design parameters including studies done to identify their relative importance.

### 6.6.3.2 Propagation of Blast Vibration

#### *6.6.3.2.1 Effects of Distance*

Propagation effects and geology change the amplitude and frequency character of ground vibrations as they travel from the blast region to measurement locations. The most important influence is dissipation, or "geometric spreading", where the finite amount of vibration energy fills an increasingly larger volume of earth as it travels outward in all directions away from the blast. The consequence is an exponential decrease in vibration amplitude with distance from the blast.

Other propagation effects are absorption, dispersion (where different frequency components travel at different propagation velocities), and the formation of surface waves. Generally, the strongest influence on blast vibration amplitude is simple distance and the charge weight per delay. In addition to amplitudes, ground vibration frequencies are influenced by distance and the geology through which the waves travel.

#### *6.6.3.2.2 Close Distances*

Within a few hundred meters from the blast, ground vibrations are dominated by relatively high frequencies created from the time-delayed detonations of the individual blastholes. The exact distance for this dominance is dependent on how "influential" the ground is. Current initiator and explosives technology allows limited control of ground vibration amplitudes and frequencies close to the blast.

#### *6.6.3.2.3 Far Distances and Surface Waves*

At distances beyond one to a few hundred meters, "surface waves" tend to dominate the vibration wave-train. Surface waves are particular types of low-frequency seismic waves generated by, and characteristic of, the geologic structure and composition. At large distances from the blast, typically beyond about 300 m, changes in shot design such as delays have increasingly less effect on ground vibration frequencies and peak amplitudes because of the dominating influence of surface wave generation.

The strongest sources of surface waves are low-velocity layers (particularly soil) over harder, more

competent material. Where these layers are horizontal and thick, strong surface waves will result within only a few hundreds of meters. For a strong velocity contrast between layers, the surface wave frequency will be equal to $V_u/4h$ where $V_u$ is the propagation velocity of the upper (low velocity) layer and h is its thickness.

Blast vibration studies in areas with thick soil layers, fill material, glacial or stream-bed deposits found surface waves with frequencies of 4-8 Hz and higher amplitudes compared to vibrations propagating through solid rock (with comparable distances and charge weights). In southwestern Indiana dominant ground vibration frequencies as low as 4 Hz were found in areas dominated by glacial deposits (Siskind et al., 1989, and Siskind, 1993). Similar cases of low frequencies were also found in Pennsylvania and Florida.

### 6.6.3.3 Controlling Blast Vibrations

Three characteristics of blast vibration are relevant to their impacts on nearby structures and their perceptibility by persons: amplitudes (usually PPV), frequency, and duration. Figure 16 shows examples of blast records with different frequency and durations -- blasts from a coal mine and from a construction site. They have the same PPV of 7 mm/s (0.28 in/s), but much different frequency characteristics and durations. Both records are complex, however, the coal blast has at least three significant widely-space frequencies while the construction blast is all high frequency (>40 Hz.) The lower frequency and more complex coal mine blast has greater impact and is harder to deal with than the construction blast although both have the same PPV.

Control of blast vibrations through design and adjustments in practices is not a simple process. Changing one parameter can aggravate another. For example, reducing charge weight per delay can increase total vibration duration and changing delay intervals will effect all three characteristics. Also, some parameters have significant error and scatter, such as the time of ms delay initiators. Blasting products sometimes do not function as designed (which may or may not be recognized without specialized monitoring) and occasional human error causes problems (also may not be recognized as a cause). As with flyrock, holes out of sequence or too crowded in time can produce abnormal results.

#### *6.6.3.3.1 Vibration Amplitudes*

The standard method to analyze amplitudes is to utilize propagation plots of amplitudes versus distance. Figure 17 shows three representative plots based on square root scaled distances (in English units). The highest vibrations are from the low frequency site. There, a 4-Hz wave has such a long period that the 8-ms separation

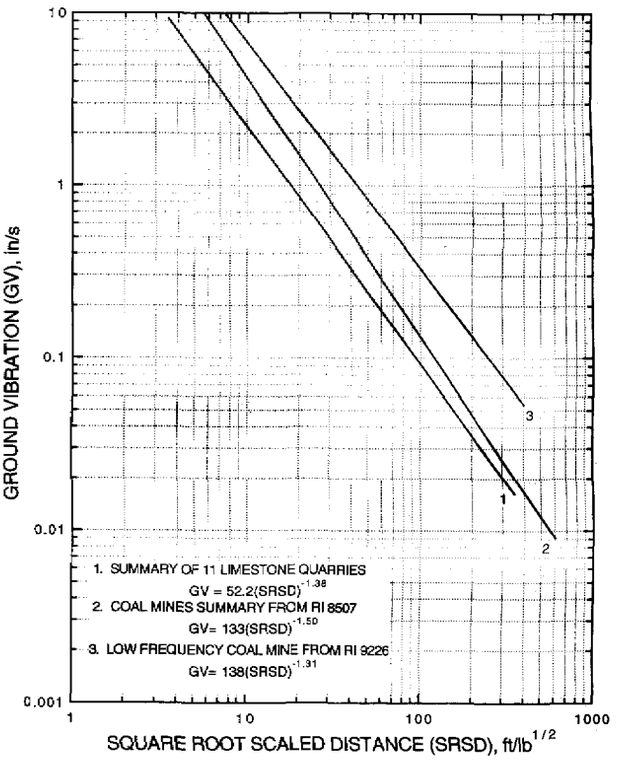



**Figure 17** Representative propagation plots of vibration amplitudes for mining and quarrying blasts.

between delays is insufficient to reduce amplitudes through destructive wave interference. Note: all three propagation lines in this figure were computed based on the 8-ms delay criteria for defining "charge weight per delay." Comparisons of measurements with these gives an indication of approximate "normalness."

Means to reduce vibration amplitudes are somewhat limited. Charge weight per delay is the most important parameter. For low frequency sites, vibration can be reduced if the minimum separation time between delays is increased to approximately 1/4 of the vibration period. In other words, at such sites, the "per delay" definition will not be based of 8 ms but on a site-specific separation based on the vibration frequency. One caution on using long delays is care that they do not produce unwanted frequencies in the residential resonance range of 4 to 12 Hz. At critical sites, it may be necessary to analyze the delays "as perceived." This will require adjustments for monitoring position including travel times across the array (or a hole-by-hole analysis). Initiations progressing towards a monitoring site are perceived as shorter separations between delayed charges (doppler effect) and can result in crowding and, in the extreme, overlap.

Other measures to reduce vibration are high relief, pits or trenches between the blast and receiver, initiation sequencing away from critical structures, and the use of

longer delays at low-frequency sites. Trenches close to the source serve as a screen to reduce blast vibrations. Trench depths affect the vibration wavelengths that are "screened" and such pits are relatively ineffective in reducing the amplitudes of low frequencies (wavelength greater than 0.7 times pit depth). Initiation sequencing away from critical structures will reduce delay crowding and overlap potential. Face orientation adjustments can orient the high-relief directions to reduce vibrations in selected directions. Relief is more than the choice of burden. Reducing subdrilling also reduces vibrations as does avoiding box cuts, tight corners, and the use of buffers in front of the face.

#### *6.6.3.3.2 Vibration Frequencies*

Some measures to control vibration amplitudes can also affect frequencies, particularly delay intervals. As discussed in the propagation section, simple distance is a strong influence on vibration character, and specifically on frequency. Control of vibration frequencies has been demonstrated at some sites. However, there is no consensus on the range at which this works for the various propagating media. For example, at hard rock sites with little overburden, the vibrations will reflect the blast design at distances approaching 1000 m. By contrast, at sites with thick low-velocity surface layers (soil, unconsolidated fill, alluvium, loess, etc) the geology will determine the vibration character at distances as short as tens of meters (Siskind, et al., 1989, and Siskind,1993.)

As a generalization, it is advisable to choose delays to avoid the ground's natural frequency when it is in the 4 to 12 Hz range. This can be done by detonating signature holes (single charges) to determine the characteristic site frequency and selecting delays accordingly. As delays are also selected for other purposes, such as relief for effective cast blasting, this option is not always available.

### 6.6.4 AIRBLAST

In addition to ground vibrations, blasting produces airborne energy called airblast overpressure or impulsive sound. Also as with ground vibrations, airblasts can produce structure rattling and, in extreme cases, cracking and other damage. In contrast to ground vibration, airblast is relatively ineffective at producing whole-structure or racking-type responses in small structures such as homes. In terms of racking response, an airblast of about 145 dB is equivalent to a ground vibration of 0.50 in/s in the structure resonance range of 4 to 12 Hz (Siskind, 1996.) Few blasts reach this level. Midwall responses are another issue, being about six times higher than racking responses for a given overpressure.

Midwall responses produce much of the secondary rattling noise and other observed effects such as movement of pictures, clocks, etc. Although not significant to structural risk, these situations result in much of the perceptible noise and the homeowners' concern that something serious and dangerous could be happening to their homes. These responses also contribute to glass breakage as the initial indicators of excessive airblast.

With vibration, low frequencies were considered as a special problem. Because airblast frequencies often peak below the range for structure responses, it is "high" frequencies that are problematic here. In all cases, it is the resonant frequencies that produce the greatest responses, 4 to 12 Hz for racking and 12 to 25 Hz for midwalls of residences.

#### 6.6.4.1 Generation of Airblast

Four sources of airblast have been identified: APP (Air Pressure Pulse) - Where rock is thrown or cast from the face, and a pressure pulse is created with amplitudes proportional to the initial face velocity. Frequencies are low because the rock face acts like a very large woofer. RPP (Rock Pressure Pulse) - The vibrating ground near the monitoring location is also a sound source. Here, the ground is acting like an even larger woofer; however, the amplitudes of motion (vertical in this case) are much lower. Far more serious and controllable in principle is the premature release of explosive energy or break outs. This can occur from two places: SRP (Stemming Release Pulse) from the bench top through ineffective stemming or holes loaded too high and GRP (Gas Release Pulse) originating from the bench face through voids, fissures, insufficient burden, overloaded holes, etc. This last mechanism is similar to the main cause of flyrock, too much relief (which is the same as too little confinement) and can influence airblast over two orders of magnitude (40 dB). These mechanisms are described by Wiss and Linehan, 1978 and Siskind, et al. 1980a.

Figure 18 gives airblast examples from USBM studies (Stachura, et al., 1981.) The top three traces are a sharp and spiky event representing close-in and line-of-sight monitoring while the bottom relatively-smooth set of traces were recorded at a large distance and/or behind the face. The three traces per set show the effects of the measurement system low-frequency roll-off on record distortion and also reductions in the measured peak values. Both sets of airblasts show RPP preceding the main event. Shot distances can be estimated from the RPP durations, being about 200 and 720 m respectively.

#### 6.6.4.2 Propagation of Airblast

As with ground vibration, airblast decays with distance because of geometric spreading. This is the mechanism where a finite amount of energy fills an increasing

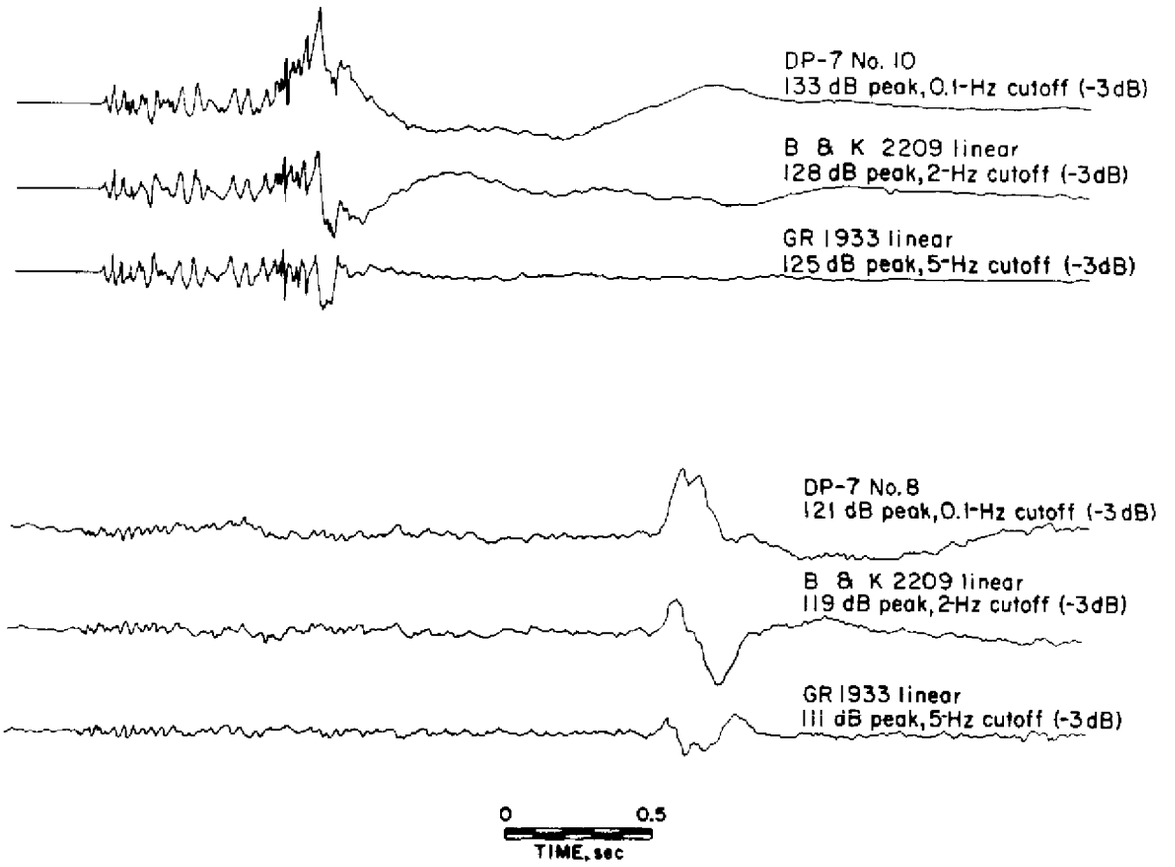



**Figure 18** Airblast record examples.

volume of space. Airblast waves traveling in a fluid are compressional in nature, making them simpler than ground vibrations. However, sound propagation including airblasts are subject to weather conditions that can create irregular and sometimes anomalous events. Temperature inversions can refract waves back to the ground producing areas of airblast focus.An inversion can increase airblast by 10 dB over what would be expected from a given blast at a given distance. Winds enhance propagation by bending wave fronts down towards the ground and reduce the normal rate of airblast decay. A 16 kph (10 mph) wind directly towards a site can increase airblast 8 to 10 dB above normal. Topography can also influence airblast with both focusing enhancement and shadowing reduction.

In an approach to assessing airblast amplitudes in a manor similar to vibrations, standard plots are given in Figure 19. The upper line is worst case: explosive placed directly on the ground with no cover and no confinement. The minimum airblast is the Rock Pressure Pulse (RPP), sound created by the ground's vertical motion near the monitoring location. The limits expected from the extremes of total confinement (RPP) and no confinement (explosive on the surface) are shown.

### 6.6.4.3 Control of Airblast

The mechanisms relating to airbast generation also suggest means to control airblast. Sufficient burden to insure good fragmentation and control flyrock will also help reduce the Air Pressure Pulse. Where strong face motion is desired, such as in cast blasting, some APP is inevitable. As with flyrock, voids, mud seams and fissures should be stemmed through. Explosives should be weighed to avoid overloading one or more holes. Burdens should be carefully controlled with adjustments for fractured, sloping and/or irregular faces. These measures should eliminate or minimize GRP. Both APP and GRP are directional, coming from the front face. Where possible, the bench should be oriented to avoid line- of-sight conditions between that face and critical structures.

Airblast off the bench top is created by some uplift (a form of APP) and, more seriously, by failure of the stemming (SRP). Measures described in the flyrock section also apply here: appropriate and sufficient stemming to contain the explosive during detonation. This may mean something better than drill cuttings.

As with ground vibrations, selection and use of

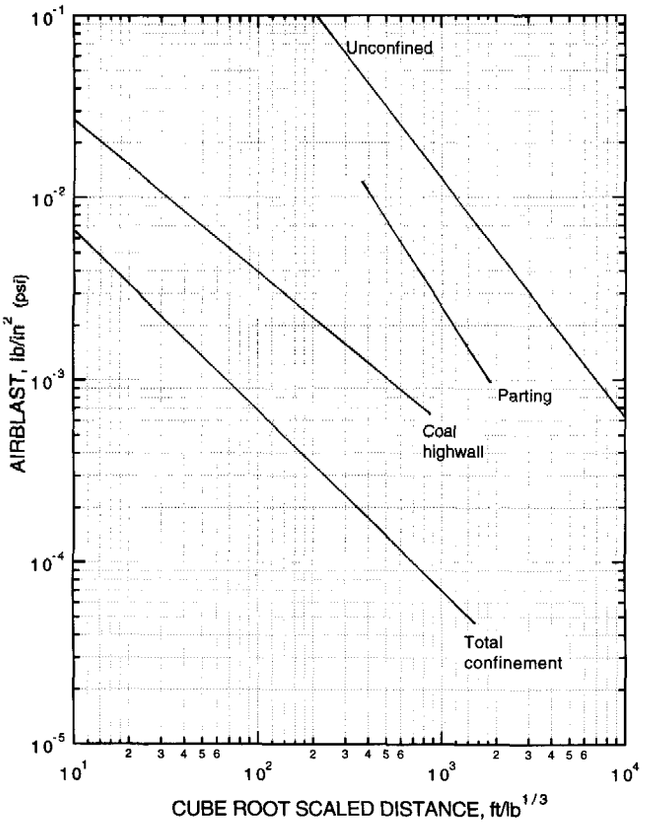



**Figure 19** Representative propagation plots of airblast amplitudes for coal mine overburden and parting blasts.

delays can strongly influence airblast. Because sound in air propagates much slower than ground vibration, at about 330 m/s (1,100 ft/s), some choices of "effective" delays can directly superimpose and reinforce airblasts. Correction of nominal delays for travel time differences for different holes is more important here than it was for vibration. One general recommendation by Andrews, 1981 was that propagation from hole to hole along an array in any direction considered critical should be less than, and preferably half of the sonic velocity in air.

### 6.6.5 DUST AND GASES

These problems and appropriate actions are described in Chapter 5. Dust is usually not a major problem outside the immediate blasting area. When necessary, it can be reduced by wetting the area. Gases (fumes of CO and oxides of Nitrogen) are from poor explosive mix, inefficient detonation and/or water in the holes. A good explosive product should be a standard requirement. AN FO is the most widely used blasting product. The ideal AN FO mix is 94.5% Ammonium Nitrate to 5.5% Fuel Oil. Any error in AN FO mix is better if it is FO-rich to reduce the oxides of Nitrogen. Practices that cause substandard detonations should be avoided including heavy detonating cord and strings of primers through explosive columns. Water proof explosive is required in wet holes unless an effective means is available to dewater the holes and protect the explosive or blasting agent. When fumes are present, time to clear should be provided, particularly in confined spaces.

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# Chapter 7

# ENVIRONMENTAL PERMITTING

edited by D. W. Struhsacker

## 7.1 INTRODUCTION

### 7.1.1 CHAPTER PURPOSE

The purpose of this chapter of the Handbook is twofold: to discuss the technical, legal, and political factors that need to be considered in environmental permitting efforts for mining projects; and to describe the specific tasks and data requirements for permitting a mine. The critical importance of a multidisciplinary approach to permitting which balances and integrates technical, legal, and political factors is a dominant theme of this chapter. Coordinating the efforts of the environmental permitting team is discussed as an important element in a successful permitting program. Discussions of pertinent examples from recently permitted mining projects throughout the country illustrate how technical, legal, and political information is used during the permitting process.

The integrated multidisciplinary approach to permitting described in this chapter is based upon the experience, insight, and expertise of the contributing authors. Numerous mining industry professionals involved with the legal, technical, and political aspects of mine permitting have contributed sections to this chapter. As a group, these authors are representative of the professional team required to permit most mining projects. This group of contributing authors offers a wealth of expertise and perspective in the field of environmental permitting for mining projects. The expertise encompassed by this group includes all types of hard rock mining projects throughout the country on federal, state, and private land. The information presented in this chapter is thus meant to be broadly applicable to all hard rock mining projects in the United States. This chapter is not intended as a step-by-step guide to mine permitting because developing a permitting blueprint which would be applicable to all projects is not possible. Site-specific environmental, regulatory, technical, and political considerations must form the basis for an environmental permitting strategy for any project. However, the general tasks involved in permitting a mine are similar from project to project, and these tasks are discussed in detail in the remainder of this chapter.

### 7.1.2 DEFINING ENVIRONMENTAL PERMITTING

Environmental permitting for a mining project can range from a fairly straightforward exercise in documenting technical conditions and design elements in permit applications, to a complex multidisciplinary endeavor which must integrate a variety of technical, legal, and political factors. The components of a mine permitting effort typically include many or all of the following: science and technology, site-specific environmental factors, laws and regulations, politics and government relations, community involvement and public relations, media management and information dissemination, and determination and commitment of the project applicant.

Given the broad spectrum of permitting requirements and the variability of permitting conditions from state to state and from project to project, it is unrealistic to develop a generic permitting blueprint because each project is unique. It is, however, possible to identify the major elements of the mine permitting process, and to outline how each of these elements must support and complement each other. This chapter describes these key elements and presents a multidisciplinary permitting approach which coordinates and balances these key elements.

#### 7.1.2.1 Regulatory Requirements and Site Specific Factors

Determining which regulations apply to a project is typically the first step in permitting a mine. Regulatory requirements based upon federal, state, and local laws initially define the permitting process for mining projects, and establish the legal basis for developing, operating, and closing a mine. Most projects require a number of permits and some level of environmental analysis to determine the environmental impacts due to the project. The permits include environmental

performance standards or limitations with which an operator must comply. Many permits also involve some form of financial assurance. Defining applicable regulatory requirements is discussed in Section 7.4.

Once the legal and regulatory framework for a project has been defined, site specific environmental factors and engineered environmental controls in response to site conditions must be addressed in an environmental permitting program. Baseline studies form the technical basis for defining pre-existing environmental conditions at the site and for assessing how mining will affect the site. Once baseline conditions and environmental impacts are defined, engineering controls are designed to minimize, monitor, and mitigate impacts and to meet the environmental performance standards mandated by regulations and specified as project permit conditions. Baseline data requirements are discussed in Section 7.3. Section 7.7 describes the relationship between the permitting and engineering design processes. Determining project impacts and developing mitigation measures are discussed in Section 7.8. Section 7.10 deals with project monitoring requirements.

#### 7.1.2.2 Political Considerations

Historically, most permitting efforts for mining projects have focused on legal, technical, and engineering factors, and political factors have not been a major consideration. However, now that mining projects commonly attract the attention of third-party and political interests, political factors are playing an increasingly influential role in defining the outcome of permitting efforts. Anti-mining third-party groups will typically rely on a distorted and unbalanced picture of mining in an attempt to convince community leaders and the general public to oppose a project.

Thus, mining projects which have the potential to be controversial or the subject of third-party attention typically need community involvement, political lobbying, and media management programs to complement and support the more traditional legal, technical, and engineering components of permitting. The goal of these communication and political involvement programs is to provide the public and elected officials with the facts about a project, and to convince them that mining is an environmentally responsible industry which can contribute jobs and economic growth and diversity to a community. Controversial projects which do not include these political components may risk a lower probability of securing project permits. The need to include communication and political involvement programs in the permitting effort is described in Section 7.5. Section 7.11 outlines the elements of a communication and public involvement program. The political involvement process is described in Section 7.12.

### 7.1.3 ENVIRONMENTAL PERMITTING TEAM

The environmental permitting team must be a multidisciplinary group comprised of professionals with an appreciation for the key environmental, technical, engineering, and political factors germane to the project, as well as being experts in one or more specific aspect of the project. Some of the more specialized technical members of the team may have narrowly defined responsibilities and their role, although important, is limited to specific phases and aspects of the permitting effort. In contrast, other members of the team may have broader but less specialized roles which may last the duration of the permitting effort. Ultimately the efforts of each team member must be carefully coordinated, and this coordination effort is usually performed by the project manager. The role of each professional in the environmental permitting team and the coordination of the team's efforts are discussed in the following paragraphs.

#### 7.1.3.1 Explorationist

The explorationist (typically the Project Geologist) is the first environmental scientist to evaluate the project. This professional contributes the most detailed understanding of the geology, mineralogy, alteration, and geochemistry of the orebody and the surrounding terrain. This background is critical in defining mineral system characteristics which may affect the environment such as the potential for acid generation, slope stability problems, water supply or dewatering considerations, and existing environmental liability due to historical mining activities. The explorationist typically also has a detailed understanding of the land ownership of the project. The data on mineral system characteristics developed by the explorationist should be incorporated into early project planning and analysis. Typically these data will indicate the likely environmental issues associated with the mineral deposit. The explorationist's expertise and perspective should also be consulted throughout the environmental permitting effort.

#### 7.1.3.2 Project Manager

The project manager must ultimately perform the pivotal role of coordinating and integrating all components of the environmental permitting effort. Typically the project manager is a mining professional with a technical background in geology, mining engineering, or metallurgy, and planning and coordinating the technical aspects of a project are second nature. However, the project manager may not be as comfortable with other critical aspects of the permitting effort such as legal or political concerns, or dealing with the media and the public. The project manager may thus have to rely on

other team members to facilitate these aspects of the permitting effort. The project manager has a demanding role which requires an understanding of the complex interrelationship of the technical, legal, and political factors affecting the project. This individual must have the ability to prioritize and handle numerous tasks, and must be responsive to any changes in circumstances which could affect permitting requirements.

#### 7.1.3.3 Environmental Coordinator/Permitting Specialist

The Environmental Coordinator or Permitting Specialist is usually an individual with expertise in one key aspect of the project such as regulatory and legal requirements, a specific environmental discipline, or environmental planning. Ideally this individual has a broad understanding of the various aspects and disciplines involved in environmental permitting. In many projects, the environmental coordinator may function as an assistant project manager and assist in coordinating selected aspects of the permitting effort. Like the project manager, the environmental coordinator plays an important role in integrating and coordinating the other environmental permitting team players.

#### 7.1.3.4 Engineering Specialists

Engineering is the basis for designing measures to minimize, control, monitor, and mitigate environmental impacts due to mining. Communicating the functions and effectiveness of design elements to the regulators and the public is a major component of project permitting. For some projects this communication role can be fulfilled by the engineers responsible for the design. Projects with a high degree of public scrutiny may require communication specialists to help the project engineers present the engineered controls to the public.

Given the fundamental role which engineering plays in controlling, monitoring, and minimizing environmental impacts, there is a critical need to coordinate the engineering design and environmental permitting efforts at the earliest stages of a project. Following project permitting, there is an ongoing need for communication between project personnel responsible for environmental compliance and systems design and operation.

Numerous engineering disciplines may be required for a mining project including the fields of mining, metallurgical, geotechnical, civil, structural, mechanical, electrical, instrumentation, and marine engineering. The need for a specific engineering discipline will be determined principally by site conditions and the need to design environmental protection controls responsive to these conditions. The roles of the various engineering disciplines and coordination of engineering and permitting are discussed in Section 7.7.

#### 7.1.3.5 Project Metallurgist

Traditionally the project metallurgist has been viewed mainly as a technical role. However, the project metallurgist is becoming an increasingly important member of the environmental permitting team, and should be involved in early project planning to evaluate the environmental ramifications of generating and disposing process waste. Future mining projects will be required to assess methods for minimizing problematic aspects of process waste such as toxicity, leachability, or acid generation potential. Project metallurgists should assume responsibility for this role and for implementing source control and waste minimization programs to reduce potential environmental hazards due to process wastes.

#### 7.1.3.6 Environmental Resource Specialists

The environmental resource specialists include the biologists, hydrologists, archaeologists, and other scientists and professionals who perform the environmental baseline studies and impact analyses, and who assist the project engineers in defining mitigation requirements. Ideally the environmental resource specialists are professionals recognized in their fields with experience in both mining and the type of site in question. It is generally important to use resource specialists familiar with the mine area and the involved regulatory community. However, finding local resource specialists with adequate mining expertise may be difficult in some areas of the country. The role of the resource specialists and a description of the data requirements for each resource discipline typically pertinent to a mining project are discussed in Section 7.3.

#### 7.1.3.7 Legal Counsel

Legal counsel during mine permitting efforts can either be provided by in-house or outside counsel. In either case, the project attorneys define all legal and regulatory requirements to obtain project permits, and develop a program for complying with these requirements. This effort is typically coordinated with the project manager and the environmental coordinator. The project attorney should also provide guidance on how to document and archive pre-project environmental data should this information be needed for future environmental liability litigation. Many law firms typically have established ties with key regulatory and political officials which may be very useful contacts for a project proponent. Thus, the project attorneys may also play an important role in

political involvement and in high-level discussions with regulatory agencies. The role of project legal counsel may be quite diversified as is discussed in Section 7.4.

#### 7.1.3.8 Communications/Public Involvement Specialist

Communication and public involvement programs to develop local support for a project can significantly benefit the project permitting effort and can expedite permit acquisition. For controversial projects, communication and public involvement programs may even be critical to the success of permitting efforts. Developing local support requires an information dissemination program to provide area residents with regular and consistent information about the project. For some projects, this program can be largely accomplished with in-house personnel, with the project manager and/or the environmental coordinator serving as principal project spokespersons. However, more controversial projects may benefit from a communications/public involvement specialist. The importance of public support and community involvement, and the role of the project communications/public involvement specialist are discussed in Section 7.11.

#### 7.1.3.9 Political Involvement Specialist (Lobbyist)

Political assaults on the federal, state, and local levels against the mining industry typically focus on restricting or even banning mining. These political actions are usually justified by their sponsors under the pretext of necessary environmental regulations. It is not unusual for proposed mining projects to galvanize mining opponents into action to seek new regulations in an attempt to thwart a project. Thus during project permitting it may be necessary to commit to a lobbying effort to influence the outcome of anti-mining legislative proposals. The role of political involvement specialists (i.e., lobbyists) during the permitting process is discussed in Section 7.12.

#### 7.1.3.10 Regulatory Community

The regulatory community forms an integral part of the environmental permitting team in their role in defining and establishing permitting requirements, in evaluating project permit applications, in enforcing regulatory requirements, in communicating regulatory controls and the regulatory process to the interested public, and in involving the public in this process. The regulatory community may consist of federal, state, and local regulatory authorities with specific project-related authority and responsibility. Interacting with the regulatory community is a key element of environmental permitting, and working with regulators is discussed throughout this chapter.

### 7.1.4 CHAPTER ORGANIZATION

This chapter is divided into sections according to permitting task. The description of each task focuses on the professionals required to perform the task, when each task is performed, and how each task is integrated into the entire environmental permitting effort.

The following is a general outline and brief overview of this chapter:

Section 7.1 - Introduction: Defines environmental permitting and presents an overview of the varied components and multidisciplinary nature of environmental permitting.

Section 7.2 - Defining Mineral System Characteristics Which May Affect the Environment: Defines mineral system characteristics and their influence upon permitting requirements, regulatory considerations, and environmental control technologies. This section discusses the types of mineral system data required and how these data are used.

Section 7.3 - Defining Environmental Conditions (Baseline Evaluation) of Project Sites: Defines issues to be addressed in the baseline studies for the following disciplines: aesthetics, air quality, aquatic biology and fisheries, blasting and vibration, cultural resources, geology and soils, groundwater, noise, recreation, socioeconomics, surface water, terrestrial wildlife, threatened and endangered species, transportation and utilities, vegetation, wetlands. This section also discusses data requirements for each resource discipline and how environmental baseline data are used.

Section 7.4 - Defining Legal and Regulatory Requirements: Discusses integrating legal advice into the permitting process and working with attorneys during mine permitting. This section discusses how to define pertinent laws and regulations which determine permitting requirements.

Section 7.5 - Developing an Environmental Permitting Strategy: Discusses developing a permitting strategy tailored to meet the specific needs of a project based upon an understanding of mineral system characteristics, environmental site conditions, legal and regulatory requirements, and community relations and political considerations. This section describes the importance of determining project-specific key issues and developing a critical path for addressing those issues. Selection of key environmental permitting project team members is also discussed.

Section 7.6 - The EIS Process: Describes the federal Environmental Impact Statement (EIS) process and discusses the differences between an Environmental Assessment (EA) or an EIS, agency Memoranda of Understanding, selecting an EIS contractor, the role of public involvement in the EIS process, the steps in the EIS process, and the format and content of an EIS. This chapter also discusses preparing state-level EIS documents and integrating the federal EIS process with state environmental permitting requirements.

Section 7.7 - Engineering Requirements for Permitting Compared to Engineering Requirements for Construction: Discusses the role of various engineering disciplines on the environmental permitting team, and explains the engineering data requirements for permitting efforts. This section describes the level of engineering detail needed during various permitting phases and stresses the importance of coordinating the engineering planning and design processes with the environmental permitting efforts at the early stages of a project.

Section 7.8 - Defining Project Impacts, Evaluating Alternatives, Developing Mitigation, and Reclamation Planning: Discusses integrating mineral system characteristics and environmental baseline data with the project design and engineering controls in order to assess project impacts and to develop mitigation and reclamation measures. This section describes a multidisciplinary approach to defining impacts and developing mitigation and reclamation measures.

Section 7.9 - Closure and Post-Closure Planning: Discusses identifying closure and post-closure requirements and integrating these requirements into the project design and permitting: Disscusses efforts. This section also discusses financial assurance requirements and outlines the various bonding mechanisms and financial guarantees available to the mining industry. Methods for reducing or minimizing long-term bonding requirements are presented. This section concludes with a discussion of ways in which to minimize the potential for future environmental damage claims.

Section 7.10 - Project Monitoring: Discusses project monitoring requirements for air quality, surface water, and ground water during all project phases (i.e., construction and start-up, operation, reclamation, and post-closure). This section describes how monitoring data are used by operators and regulators to measure the performance of the engineered environmental protection systems and to determine compliance with permit conditions.

Section 7.11 - Community Involvement and Public Relations: Discusses communicating project plans and environmental control measures to the public, and to the media. This section describes the importance of community involvement and public relations programs for controversial projects and focuses on how to design a communication program which integrates technical information and political considerations.

Section 7.12 - Political Involvement: Discusses how mining project proponents can participate in political and legislative issues affecting mining. This section describes the interrelationship between community involvement and public relations with political involvement, and presents an integrated approach to analyzing the technical, legal, and public opinion implications of proposed legislation.

## 7.2 DEFINING MINERAL SYSTEM CHARACTERISTICS THAT MAY IMPACT THE ENVIRONMENT

### 7.2.1 WASTE ROCK CHARACTERIZATION by A. Smith

#### 7.2.1.1 Introduction

This section focuses on the rationale of and alternate methodologies for defining the geochemical characteristics of waste rock. As such, the section does not provide a line-by-line account of all the various test protocols and how they might be executed, but is an overview how such a geochemical test program might be formulated to yield data for the permitting and the design of waste rock facilities.

Having considered the diverse requirements of "classification" of waste rock for regulatory compliance versus the need for data appropriate for the site specific siting and design of a waste facility, the basis of a geochemical sampling and testing program is outlined and explained. The need for a logical, technically defensible and thorough sample program, based on consideration of the entire range of potential geochemical variation in the project waste is identified, as a precursor to a multi-phased short term and longer term geochemical testing program. The need for and application of the data gained in such a geochemical testing program are described subsequently.

#### 7.2.1.2 Defining Waste Characterization

A fundamental issue which must be understood at the outset of a waste rock geochemical testing program is the meaning of "waste characterization" and the difference between "characterization" and "classification". This is not mere semantics; the difference between these two terms represents a fundamental difference in the raison

d'etre for performing geochemical testing to meet their divergent objectives.

Waste characterization, in a geochemical sense, represents an attempt to describe the nature and the behavior of the waste materials as they will occur under ambient or field conditions. This is a "real world" condition; useful, practical information for the operator, engineer and regulator alike. Waste characterization provides data that can be used in the siting, design, operation and decommissioning of a waste facility.

The term to "classify" waste in the geochemical sense, (i.e. to arrange in classes; McIntosh, 1963), means to assign the waste material to an arbitrary grouping based on numeric criteria defined and codified in an administrative code or attendant regulations. Classification of the waste does not relate to how the material might behave under site specific, field conditions, it only describes how the materials respond to the codified testing protocol. These protocols are erected to permit relatively uniform classification of waste materials, normally in terms of "hazardous" nature or as a "special" waste. It is apparent that, while it is necessary to conduct geochemical testing to satisfy regulatory classification requirements, the actual geochemical behavior that might be anticipated in the field can be gained only from a testing program which attempts to account for site specific, project conditions.

### 7.2.1.3 Program Design and Requirements

Conceptually, any waste rock geochemical evaluation program designed to provide the necessary data to support an application to permit a waste rock disposal facility should have the following three objectives:

> *"Classification"* of waste rock in terms of mandated regulatory protocols for the characteristic of toxicity by leachability, something unrelated to the actual geochemical behavior of the waste rock;
>
> Establishment of the time-dependent leachability of the waste rock, both in saturated and unsaturated flow conditions and the evolution of the waste rock geochemistry with time; and
>
> Assessment of acid generation kinetics and the long-term acid generation potential of the waste rock.

These objectives can be realized only in the framework of a rational and comprehensive test program which begins with collecting a representative suite of geochemically (as opposed to geologically) distinct waste rock types. Sample selection is based on the geochemical logging of core or cuttings, as a precursor to selecting a technically defensible sample suite for geochemical testing.

Following a rigorous sample selection procedure, the actual geochemical testing is a three-phase process designed to satisfy regulatory requirements to "classify" the waste rock; establish the geochemical properties of the waste rock on a fundamental basis using straightforward, short-term static test procedures; and to evaluate the time dependance of the geochemical processes likely to affect the waste rock behavior using kinetic tests. These three phases form Phases 4 through 6 of an overall geochemical testing program.

Accordingly, a conceptual geochemical work program for waste rock consists of the following six phases:

> *Phase 1* - Geochemical logging of core from potential waste rock areas and horizons.
>
> *Phase 2* - Identification of geochemically based waste rock domains or groups.
>
> *Phase 3* - Selection of samples representative of both a given domain and the variation of materials within that domain for geochemical testing.
>
> *Phase 4* - Geochemical tests to satisfy regulatory classification requirements.
>
> *Phase 5* - Geochemical testing, comprising short term tests to establish fundamental geochemical behavior.
>
> *Phase 6* - Long-term kinetic geochemical tests to define and quantify rates and nature of potential geochemical process including delayed acid generation from the waste.

### 7.2.1.4 Sample Selection: Basis and Practicalities

One of the most contentious issues in developing geochemical data for permitting a mining project is defining the number of samples required to determine the geochemical variability the waste rock, and satisfying project opponents and the regulatory agencies that a sufficient number of samples have been collected. What is most often omitted from consideration when developing a sample selection program is that such a program has to be truly site specific. Unfortunately, numeric, codified approaches which are sometimes dictated by regulatory agencies fail to account for the specificity of the project. Statistical approaches which

define the number of required samples based upon the anticipated number of tons of waste rock likely to be produced fail totally to consider site specific factors.

Inevitably, based on experience, there are never sufficient samples to satisfy the apparent needs of objectors to the project, irrespective the number of samples taken. Experience dictates that the project proponent and the appropriate regulatory agencies should feel comfortable that the geochemical sampling program is technically defensible and adequately represents the variation in potential waste rock materials. The project proponent may have to defend the waste rock sampling program in open forums such as public meetings and permit hearings.

The three-phase sampling program described considers the site specific nature of a project while ensuring a technically defensible sample selection program. This is not the only approach to sampling. It is, however, a guide to the type of requirements that should be included in such a sampling program.

#### *7.2.1.4.1 Geochemical logging of waste rock*

The description of the requirements for logging waste rock in this section are related to drill core. Other types of materials, such as drill chips, grab samples from surface exposures or geologic sections in open pits or underground workings can also be used. It is normal in most pre-mining permitting situations that drill core or cuttings are the only materials available which give a large enough coverage of potential waste materials for the project. Core is favored usually over drill cuttings, both for ease of logging, better definition of mineralogy and structure, and a better chance that the drilling process has not adversely affected the geochemical properties of the potential waste rock.

All core within the proposed mine workings or open pit that is not ore or low-grade ore, should be logged or re-logged as necessary as follows:

1. The mode of occurrence of sulfide minerals (i.e., within fractures or veins, or disseminated within the rock mass) should be described as well as the type of sulfide, its size, habit and amount.

2. Evidence of multiple generations of sulfides, reaction of the sulfide within the surrounding rock, obvious imperfections in the sulfide crystals that might cause increased surface area or access to oxidation reactions should be noted.

3. Carbonate minerals should be subject to the same rigorous type of description as above, where appropriate, and the reaction of the carbonate to sulfuric acid noted.

4. Existing geotechnical data on fractures should be expanded to include the percentage of the fracture covered by sulfide or carbonate minerals. Veins should be described similarly. Any interrelationships between sulfide-bearing and carbonate-bearing fractures and veinlets should be noted.

5. The nature and extent of the gross oxidation/weathering and leaching of the rock should be noted, together with an assessment of the degree of alteration and the nature and extent of secondary oxidation products.

While this phase of the sampling program normally includes all core representative of waste rock, it may be possible, based on the pre-existing knowledge of the orebody, to log only certain sections of the core for geochemical purposes and extrapolate the results to the remainder of the core.

#### *7.2.1.4.2 Identification of waste rock groups*

Based on the results of the geochemical logging program, coupled with any data from previous geological logging of the drill core, a geochemically differentiated set of waste rock groups is established and used as the basis for sample selection for testing. It is likely that the project geologists and geochemists will identify the waste rock groups.

#### *7.2.1.4.3 Selection of samples for geochemical testing*

A minimum of five samples from each waste rock group should be selected for the geochemical testing (Phases 4 through 6). It is essential that the five or more samples are representative of the range of variation of the geochemical properties of the materials in that group; for example, low apparent carbonates through to high apparent carbonates. If five samples are not sufficient to cover the variation of material properties within the group, then additional samples must be collected to ensure coverage.

Assuming, for example, that ten groups of geochemically distinct waste rocks are recognized, this would result in a minimum of fifty samples being subject to the initial phases of geochemical testing. This is the minimum number likely to be acceptable; current mining projects going through permitting in 1992 were using between about 50 and 250 samples in the primary phases of geochemical testing.

### 7.2.1.5 Geochemical Testing Program

#### *7.2.1.5.1 Waste Classification Tests*

Waste classification tests assign the waste rock into arbitrary classifications of waste material, based on testing protocols prescribed by the regulatory agencies. The protocols are used to define the waste as toxic or hazardous in terms of Subtitle C or D of the Resource Conservation Recovery Act (RCRA). The results of the waste classification tests are evaluated against the prescribed numeric criteria for definition of "toxic" and "hazardous" wastes. These tests fail to recognize the geochemical environment into which the waste rock will be placed. However, such test are often mandated, and thus must be performed.

The test protocols available for classification include EPA Method 1310, the EPA Toxicity Test; EPA Method 1311, the Toxic Characteristic Leach Procedure (TCLP); and EPA Method 1312, a test designed to evaluate low hazard/high volume wastes, as exemplified by mining wastes, under Subtitle D of RCRA. Method 1310, the EPA Toxicity Test, has now been superseded largely by the Method 1311 TCLP. Both methods involve leaching with an organic acid, (acetic acid), which causes the preferential solution by complexation of metals such as lead (as lead acetate) over and above that which would occur in inorganic waste rock systems. The protocols do not define field conditions and can be used only for regulatory compliance (i.e., waste classification) purposes. This fact must be stressed when submitting TCLP data as part of a permit application.

Method 1312 comes closest to simulating the inorganic-based leaching system likely prevalent in a waste rock dump, Smith (1989). However, regulatory agencies often require the TCLP test. Accordingly, it is appropriate to submit both TCLP and Method 1312 values noting that the former are for waste classification purposes and the latter are generally more technically representative of the long-term geochemical behavior of the wastes.

The number of samples tested will depend on the geochemical grouping of the waste rock and samples selected in Phase 3. Normal quality control and quality assurance procedures should be used to make the data defensible in any future adversarial situation. At least 10 percent of the samples should be analyzed as replicates. TCLP and Method 1312 test leachates should be analyzed for the range of metal species defined under RCRA, (normally arsenic, barium, cadmium, chromium, lead, molybdenum, mercury, selenium and silver). Other species may be added, if desired, but such additional data are not likely to be dispositive of field conditions and may be misleading.

#### *7.2.1.5.2 Short-Term Geochemical Testing*

The short-term geochemical testing of the waste rock can be divided into two parts: batch leach testing to determine likely leachability under field conditions; and static acid generation potential testing.

##### *7.2.1.5.2.1 Batch Leachability Tests*

Some of the data obtained from the EPA Method 1312 testing described above can be a useful precursor to the leachability tests. However, the low solid to liquid ratio mandated in the test means that the Method 1312 tests do not simulate the conditions likely to be found within a waste rock disposal area. It is necessary to perform additional tests with a higher solid to liquid ratio, consistent with the necessity to produce enough equilibrated leachate solution for the range of chemical analyses required. This normally implies a liquid to solid ratio of about 2:1 or greater.

The batch leachability tests should be performed on a similar number of samples to that deemed appropriate for the waste classification tests. These tests should use a 2:1 liquid to solid ratio or similar, simulating the likely leach conditions in an unsaturated waste rock dump. Other ratios such as 1:1 and 4:1 should be used on a small number of test duplicates to allow assessment of any bias in the leaching engendered by the initial leaching ratio, and should reflect the anticipated leaching conditions at the proposed project site.

All equilibrated leachates from the batch tests should be analyzed for the parameters prescribed for the TCLP tests, noted above, and a range of species which might either be anticipated from the waste rock mineralogy and/or would be of value in understanding how the geochemistry of the waste rock may evolve over time. These parameters include pH, TDS, major ions and radionuclides (gross alpha, gross beta, natural uranium and radium 226). Should the leach data indicate that there are elevated levels of species of potential concern present, then the sample(s) so identified should be subject to Phase 6 kinetic tests.

##### *7.2.1.5.2.2 Static Acid Generation Potential Tests*

The simplest means of establishing the potential for acid generation from waste rock is by determining the so-called acid/base account. The total capability of the waste rock to generate acid (acid generation potential, AGP, or maximum potential acidity, MPA) is determined from the sulfur value in the waste, and offset against the ability of the waste rock to neutralize any acid so formed, (i.e., the acid neutralization potential, ANP). The ratio between the ANP and AGP values and the difference between the two values are measures of the net acid generating capabilities of the waste.

Smith and others (1992) describe the various ways that the AGP and ANP can be determined, and the different criteria used to decide whether a waste rock can be safely considered non-acid generating or whether kinetic tests are required. Acceptable methods and criteria vary from jurisdiction to jurisdiction. The project proponent should ensure, irrespective of the criteria set currently by the local jurisdiction, that the tests performed accurately predict the long-term behavior of their waste rock. The potential for a waste to produce acid in the long term may represent one of the most significant liabilities that a proponent may face with a project.

Based on experience, the current and proposed regulations in California, and the trend of regulations in the USA, a proponent should consider using a conservative 3:1 ANP/AGP ratio for determining, without further testing, that a waste rock will not be acid generating in the long term. Samples which have lower ANP/AGP ratios may not be acid generating; they merely require kinetic tests to establish their long-term behavior.

With respect to test protocols for determining sulfur/sulfide levels and ANP, the stability of the sulfides, the variability in the type of sulfides in the waste, and the likely age of the core that will be sampled to represent the waste must be carefully considered. Firstly, if the sulfides are reactive, exposure to the atmosphere may allow rapid oxidation of the sulfide to produce sulfate; this may happen in drill core that has been stored for some time. If the waste rock is tested only for sulfides and not total sulfur, the mass of sulfides will be underestimated. Using the residual sulfide number to calculate the AGP will result in an unrealistically low estimate of the AGP because the sulfide formed from the sulfide oxidation will not report to the analysis.

Secondly, if there are sulfides present other than iron sulfides, (such as marcasite, some forms of pyrite and pyrrhotite), which are less easily oxidized in some of the analytical protocols used, their sulfur values will not report in the sulfide analysis. However, these sulfides may still be oxidizable in the waste, due to oxidation by ferric iron in the acid conditions generated by the initial pyrite oxidation process. All sulfide-bearing species in the waste must be taken into account in determining the AGP. It is not unusual for some of the drill core that must be used for testing to be already oxidized; this should be established, prior to finalizing the work program. For these reasons, and in absence of data to the contrary, it is generally more technically rigorous and defensible to use total sulfur values as the basis for calculating the waste rock AGP.

The static acid generation testing program should estimate the total sulfur concentration in all of the samples selected for testing using the LECO furnace method. The total sulfur value is converted to the AGP assuming stoichiometry in the acid producing reactions of sulfides and neutralization with calcium carbonate. The total sulfur value is multiplied by a factor of 31.25 and expressed as tons of calcium carbonate equivalent per kiloton of waste rock, TCaCO3/KT. (The object of such a conversion is to express both AGP and ANP in the same units so that their values may be compared directly.) The program should also estimate the ANP, by the method of Sobek et al, (1978), or a similar standard method, (i.e., titration with acid and back titration with an alkali). ANP values are expressed as TCaCO3/KT.

Using the above AGP and ANP values, the ANP/AGP ratio is determined. Where the ANP/AGP ratio exceeds 3:1, samples are deemed non-acid generating and do not require kinetic testing.

Some jurisdictions require a "whole rock" analysis of all components of the waste, usually determined by X-ray fluorescence (XRF), in addition to the tests outlined above. This requirement is predicated on the belief that if a species is present in the waste that it will leach from the waste. However, this is often incorrect and much time and money is wasted analyzing leachates for much of the periodic table based on an XRF analyses of the original waste material.

Should an XRF or similar analysis be required, the effort in providing this data is not great. However, it should be clear, prior to performing these analyses, that mere presence of a species in the waste rock does not constitute mobility. Analysis of leachates from subsequent testing should be only for parameters that have some chance of being hydrogeochemically mobile within the leach environment being simulated.

#### *7.2.1.5.3 Long-Term Kinetic Testing*

The Phase 5 static tests can be viewed as a screening tool to identify those samples whose properties of leachability or acid generation potential are either benign or non controversial. This is because the test methods are conservative and will overestimate the severity of field conditions. Exclusion of waste rock samples from Phase 6 kinetic tests using the results and conclusions from Phase 5 static tests are unlikely to be challenged by informed parties.

The Phase 6 long-term kinetic test focus on understanding the geochemical behavior of the waste rock materials identified by the Phase 5 static tests as being potentially acid generating, the source of potential metals-bearing leachate, or which may present a potential waste handling problem. The test protocols used in Phase 6 consider the time dependency and reaction kinetics of the waste, and thus produce results which can simulate the field conditions better than the Phase 5 static tests. However, even the Phase 6 tests are far from perfect in predicting waste characteristics, and must be interpreted carefully and thoughtfully.

Phase 6 tests may include kinetic column test

leaching of waste rock to examine chemical species concentration and loads which might emanate from the waste with time; kinetic AGP tests using either column or humidity cells; and trial columns, waste rock piles or test pads in the field.

The number and duration of the Phase 6 tests are determined almost entirely by the numbers of samples excluded from further testing by the Phase 5 static tests work and the similarities in the results from Phase 4, (i.e., it may not be necessary to subject all samples that did not pass Phase 5 screening to Phase 6 testing).

Based on previous experience, about 20% of the samples may require testing beyond Phase 5 static tests, although the actual number of samples that are tested is site specific. For purposes of assessing the extent of a program required, the 20% figure might serve as a guide. However, in very reactive sulfide-bearing waste rock, many kinetic humidity cell tests may be required to clarify the results of the static AGP tests.

*7.2.1.5.3.1 Column Leach Tests*

The purpose of a column test is to gain some understanding of the way the concentration of species leached from the waste rock varies with time. The data allows calibration of species release loads from the waste rock, and hence prediction of impacts to ground water and/or surface water quality with time.

The column test allows some better representation of particle size for the waste as compared with the small particle size of material normally required for the static tests. The maximum particle size which can be used is restricted to about 15% of the column diameter to prevent the effect of fluid channeling in the column, thereby negating the test. Therefore, the bigger the column used, both in diameter and height, the more representative the data will be of the actual waste rock disposal facility.

Column leach tests should be performed on waste rock materials representative of the range of waste rocks which were not screened out by the Phase 5 static tests. The waste rock is packed in the columns at appropriate field density and leached with simulated rainwater at a rate commensurate with, but not as low as, prescribed field infiltration into the waste. The leachate discharged from the bottom of the column is collected at intervals equivalent to each pore volume of the waste. (A pore volume can be calculated from the mass and density of waste in the column and the volume of the column occupied by the waste.)

Only specific pore volumes of leachate are subject to analysis. Usually volumes 1, 3 and 5 are analyzed, but the requirements for analysis are determined by how the materials leach and how the waste rock behaved in the static tests. The leachates are analyzed only for those species which had elevated levels in the leachates generated during Phase 5 tests, or those parameters are usually required for hydrogeochemical interpretation purposes (e.g. pH and alkalinity).

*7.2.1.5.3.2 Kinetic Acid Generation Potential Testing*

There are three common ways to do kinetic AGP tests, as described by Coastech Inc. (1989): pilot waste heaps constructed in the field; air flushed column tests; and humidity cell tests. The cost of these tests and the size of these tests are inversely proportional to the number of tests that are normally performed. Accordingly, if many kinetic AGP tests are anticipated to be necessary, then humidity cell tests are probably the best option despite possible criticisms that can be leveled at the protocol, particularly with respect to particle size and the fact that skilled interpretation of the results of the tests is required.

The humidity cell test places the waste rock in an environment conducive to air oxidation of sulfides, should the sulfides be reactive. The tests involve alternately passing moist air and dry air through the sample for periods of three days, and keeping the cells at 65 degrees F, which is likely higher than the average waste dump internal temperature in the field. These conditions enhance the oxidation process.

After six days of oxidation, the waste rock in the humidity cell is leached with water and the leachate is analyzed for chemical species indicative of sulfide oxidation and acid neutralization ability. These are normally pH, conductivity, acidity, alkalinity, sulfate and iron. The rate of production of these species over time, and their concentration variations can be interpreted to chart the nature of the acid generation and neutralization processes in the waste rock. The humidity cell tests are normally run for a minimum of twelve weeks, but often require an extended test period in the cases of marginal waste samples.

It is likely, based on previous experience, that about 20% to % of the original test samples will require humidity cell tests, but this will be project specific and is based on the initial sulfide and ANP data from the Phase 4 static AGP tests.

All of the kinetic tests require minimum run times of twelve weeks and probably over fifteen weeks in many cases. Tests will be terminated when the pH value in the cell leachate falls below pH 3.5 (i.e. potentially acid generating) or when the sulfate production rate is below 10 ppm for two consecutive weeks, with no iron or acidity found in the leachates, (i.e. non acid generating).

In addition to predicting AGP, humidity cell tests can be useful in gaining information about leachability from waste rock samples over time, with little incremental cost. Accordingly, it is suggested that leachates from the cells at weeks 1, 5, 10, 15 etc., be subject to an ICP scan to determine variation in the leachability of common major and trace cations. The differences between cell flush rates and field conditions in terms of

infiltration into waste rock must be considered in interpreting these results.

#### 7.2.1.6 Application to Waste Facilities Design

The geochemical properties and behavior of a waste impact the design of a waste facility in two different ways. They define the need to contain or control the waste to either prevent adverse geochemical reactions or to prevent egress of the products of such reactions to the environment. They also define the effect of the chemical properties of the waste or waste reaction products on the physical performance of the design elements in the waste facility.

In this respect, there are five major areas where the geochemistry of the waste material can have a potentially significant impact on waste facility design, (Smith, 1984). These five areas are:

1. The requirements for engineering drainage and runoff control or surface covers to prevent ingress of either water or oxygen to control acid generation, leaching and mobilization of potential contaminants.

2. The interception and collection of seepage to prevent the potential for surface water and groundwater contamination.

3. The potential chemical attack on the natural materials used in construction of the facility, leading to changes in their geotechnical properties.

4. The potential for chemical precipitation in the waste facility drainage system, where present, which can lead to impairment in the operation of the drainage system and potential physical stability problems with the waste facility.

5. The potential for chemical attack on concrete structures used in the construction of the waste facility.

The nature and effects of the latter four of these potential concerns in the engineering design of waste facilities are discussed in more detail by Smith, (1984).

### 7.2.2 GEOTECHNICAL CHARACTERIZATION
**by D. J. A. Van Zyl**

#### 7.2.2.1 Introduction

Geotechnical characterization of a mine site for permitting purposes is a very important activity that is typically performed in stages. In the broadest sense "geotechnical characterization" refers to obtaining information about the behavior of site and borrow geological materials under various "loading" conditions which will be imposed on them. All mining structures are constructed on geologic materials and most are constructed with geologic materials, either processed or non-processed. The "loadings" which can be imposed on the geologic materials include physical loadings, such as an embankment or structure on foundation materials; physical "unloading", such as the excavation of cuts including open pit mines; and pressures exerted by liquids, such as groundwater or tailings liquid stored in a tailings impoundment. The geotechnical site characterization must develop a complete picture of the site conditions and the materials proposed as construction materials.

Geotechnical site characterization is normally performed in a four-phase approach: *Reconnaissance investigations* during prefeasibility studies; *Preliminary investigations* during feasibility studies; *Site investigations* during final design; *Confirmation and adjustments*, as necessary, during construction

Reconnaissance investigations provide the first cursory look to identify the big picture, preliminary investigations identify the existence of fatal flaws, while final investigations provide information to develop final design drawings and specifications. It is often necessary to confirm the design specifications during construction through careful geotechnical observations.

The level of detail required in performing geotechnical characterization is dependent on the complexity of the site as well as the regulatory requirements with respect to a permitting design. Some states, for example Idaho, require that a final design with construction drawings be submitted for environmental permitting purposes. Other states will accept a more conceptual design. The underlying principal is, however, that sufficient characterization must be performed so that no fatal flaws remain which could make the design undefendable.

The two major areas where geotechnical characterization is necessary are waste characterization and site characterization. These two topics are discussed below.

It must be noted that mine design (open pit and underground) require extensive geotechnical information. However, the design of these facilities do not typically require environmental permitting. Geotechnical characterization for their design is therefore not considered in this section.

#### 7.2.2.2 Geotechnical Characteristics of Waste

The exploration drilling for a new orebody concentrates on geological information with respect to the

**Table 1** Typical Atterberg Limits and Specific Gravity

| Location | Specific Gravity | Liquid Limit (%) | Plasticity Index (%) | Source |
|---|---|---|---|---|
| **Specific Gravity and Plasticity of Fine Coal Refuse** | | | | |
| Eastern US | 1.5-1.8 | 35-50 | 0-13 | Busch, et al., 1975 |
| Western US | 1.4-1.8 | -- | -- | Backer, et al., 1977 |
| Buffalo Creek, WV | 1.4-1.6 | 20-40 | 2-12 | Wahler, 1973 |
| Great Britain | 1.7-2.4 | 30-60 | 3-30 | Wimpey, 1972 |
| **Specific Gravity of Lead-Zinc Tailings** | | | | |
| | 2.8-3.4 | | | Soderberg & Busch, 1977 |
| Idaho | 2.9 | | | Kealy & Busch, 1971 |
| Idaho | 2.9-3.0 | | | Mabes et al., 1977 |
| Colorado | 3.3-3.6 | | | Vick, 1983 |
| **Plasticity of Copper Slimes Tailings** | | | | |
| Western US | | 40 (avg) | 13 (avg) | Volpe, 1979 |
| British Columbia | | 0-30 | 0-11 | Mittal & Morgenstern, 1976 |

mineralization. Exploration geologists are concerned with gathering geological information and are usually not aware of the geotechnical information which could be gathered at this stage or their budgets do not allow for such information to be gathered. By ignoring the site geotechnical conditions during exploration drilling, large volumes of potentially useful data are not collected and this aspect can increase the overall mine development costs.

Typical data which can be collected during exploration drilling includes hardness of the rock, rock quality designation (RQD), joint spacing, depth and characteristics of overburden (weathered or transported soil) and groundwater presence and quality information. The information related to rock hardness and joint spacing can often be directly used to develop feasibility level pit slope designs, estimate the size distribution of blasted rock materials and therefore may also be an indicator of potential power consumption during crushing and grinding.

Mineralogical information, specifically, the relative amounts of sulfides in the vicinity of the orebody is also very important information as it determines the acid generating potential of the materials. This issue is described in more detail in section 7.2.1. Some materials tend to slake when exposed to the atmosphere and the rate of such slaking and other observations made during exploration can be very important in estimating the geotechnical behavior of such materials in the long-term.

Only small samples are available during the exploration phase. Even if specific geotechnical holes are drilled to obtain information for pit slope design, small amounts of rock core are available for testing. The other concern is that poor information may be available on the spatial variability of the geotechnical materials in the orebody if only selected coreholes are drilled.

In order to obtain information on the shear strength of waste rock produced from the pit, point load testing can be successfully used. The results of the point load testing can be evaluated to obtain curvilinear Mohr strength envelopes. The procedure described by Hoek and Bray (1981) can be used to derive the equation for the curvilinear envelope.

Tailings samples are typically available from pilot scale metallurgical testing. Such testing is very often done at the bench scale and laboratory equipment is used for crushing and grinding. These materials may not be an exact replication of the final tailings produced during operations but testing performed on these materials as well as published information and experience from other mines can be used to derive design parameters. The parameters which must be measured include grain size distribution, consolidation characteristics and shear strength parameters. Waste materials are often available near the surface at existing mines. Sampling and testing of such materials can be used as a supplement to information obtained from selected samples from a new orebody.

The design engineer must often use published data in combination with test results from small samples to select design parameters. A number of summary tables have been published which can be used as a basis for design. Specific tables have been presented by Vick, (1983) and Volpe, (1979). Tables 1 to 9 present summaries of some typical values. Empirical

**Table 2** Typical In-Place Densities and Void Ratios

| Tailings Material | Specific Gravity | *e* | $d_d$ (pcf) | Source |
|---|---|---|---|---|
| **Fine Coal Refuse** | | | | |
| Eastern US | 1.5-1.8 | 0.8-1.1 | 45-55 | Busch et al., 1975 |
| Western US | 1.4-1.6 | 0.6-1.0 | 45-70 | Backer et al., 1977 |
| Great Britain | 1.6-2.1 | 0.5-1.0 | 55-85 | Wimpey, 1972 |
| **Oil Sands** | | | | |
| Sands | -- | 0.9 | 87 | Mittal and Hardy, 1977 |
| Slimes | -- | 6-10 | -- | Mittal and Hardy, 1977 |
| **Lead-zinc** | | | | |
| Slimes | 2.9-3.0 2.6-2.9 | 0.6-1.0 0.8-1.1 | 93-113 80-103 | Mabes et al., 1977 Kealy et al., 1974 |
| **Gold-silver** | | | | |
| Slimes | -- | 1.1-1.2 | -- | Blight and Steffen, 1979 |
| **Molybdenum** | | | | |
| Sands | 2.7-2.8 | 0.7-0.9 | 92-99 | Nelson et al., 1977 |
| **Copper** | | | | |
| Sands | 2.6-2.8 | 0.6-0.8 | 93-110 | Volpe, 1979 |
| Slimes | 2.6-2.8 | 0.9-1.4 | 70-90 | Volpe, 1979 |
| **Taconite** | | | | |
| Sands | 3 | 0.7 | 110 | Guerra, 1973 |
| Slimes | 3.1 3.1-3.3 | 1.1 0.9-1.2 | 92 97-105 | Klohn, 1979a Guerra, 1979 |
| **Phosphate** | | | | |
| Slimes | 2.5-2.8 | 11 | 14 | Bromwell and Raden, 1979 |
| Gypsum | 2.4 | 0.7-1.5 | 60-90 | Vick, 1977 |
| **Bauxite** | | | | |
| Slimes | 2.8-3.3 | 8 | 20 | Samogyi and Gray, 1979 |
| **Trona** | | | | |
| Sands | 2.4-2.5 | 0.7 | 92 | Vick, 1983 |
| Slimes | 2.4-2.5 | 1.2 | 68 | Vick, 1983 |

**Table 3** Minimum and Maximum Densities of Sand Tailings

| $d_{d\,min}$ (pcf) | $d_{d\,max}$ (pcf) | $e_{max}$ | $e_{min}$ | Reference |
|---|---|---|---|---|
| 75-96 | 99-112 | 0.72-1.23 | 0.51-0.68 | Mittal and Morgenstern, 1975 |
| 85-99 | 105-129 | 0.99-1.32 | 0.51-0.67 | Pettibone and Kealy, 1971 |

**Table 4** Average In-Place Relative Density of Sand Tailings

| Material | *Dr* (%) | Reference |
|---|---|---|
| Tar sands | 30-50 | Mittal and Hardy, 1977 |
| Molybdenum sands | 31-55 | Nelson et al., 1977 |
| Cycloned copper sands | 33-54 | Klohn and Maartman, 1973 |
| Cycloned copper sands | 45-68 | Mittal and Morgenstern, 1977 |
| Cycloned copper sands | 10-55 | Brawner, 1979 |
| Cycloned lead-zinc sands | 30 | Sandic, 1979 |
| Lead-zinc sands | 17-43 | Vick, 1983 |
| Copper sands | 37-60 | Vick, 1983 |

**Table 5** Typical Tailings Hydraulic Conductivity

| Material | Typical Hydraulic Conductivity cm/sec |
|---|---|
| Clean, coarse, or cycloned sands with less than 15% fines | $1x10^{-2}$ - $1x10^{-3}$ |
| Peripheral-discharged beach sands with up to 30% fines | $1x10^{-3}$ - $5x10^{-4}$ |
| Nonplastic or low-plasticity slimes | $1x10^{-5}$ - $5x10^{-7}$ |
| High-plasticity slimes | $1x10^{-4}$ - $1x10^{-8}$ |

relationships can also be used to derive some geotechnical parameters, for example, the relationship between grain size distribution and saturated hydraulic conductivity (Mabes and Williams, 1977).

When expansion of facilities are designed, monitoring results from existing facilities can be used to back analyze design parameters for new facilities.

### 7.2.2.3 Site Geotechnical Characteristics

Much has been written in the geotechnical literature about geotechnical site investigation procedures and detailed approaches. A recent publication which provides a good overview is Lowe and Zaccheo (1991).

A geotechnical site characterization must be performed with the design of the facility in mind. Although a reconnaissance level investigation can be done on a generic basis, preliminary and final investigations must be done for a specific design. The designer must prepare a conceptual design prior to embarking on geotechnical site characterization.

In principle, a site geotechnical characterization must start with the big picture (regional geology) and must narrow down to the site specific characteristics. Finally, the designer should develop a conceptual, three-dimensional model of the site, so that the effects of increased or decreased loading can be evaluated.

An understanding of the regional geology and the geological history of a site is paramount to the successful site geotechnical characterization. Understanding the geological setting of the site will also highlight potentials for geological hazards which may be present on-site. Geological hazards such as landslides, collapsing soils, active faults, etc. can be characterized through a knowledge of the site geological setting. It is therefore recommended that the design geotechnical engineer be supported by an engineering geologist in the overall site characterization.

Geotechnical site investigation techniques range from geophysics to drilling and test pitting to insitu testing. Geophysical methods, a summary of which is presented in Table 10, are typically employed to obtain the depth of overburden or to evaluate in more detail other specific issues.

Drilling and sampling can be performed through coring or hollow stem augers with standard penetration testing or Shelby tube sampling. Table 11 presents some typical drilling methods employed for geotechnical characterization.

Backhoe test pits are a cost effective method of site investigation. A large area can be investigated in a short period of time and undisturbed samples of materials can be obtained. It must be noted that shallow test pits, typically in the order of 9 to 20 feet, only provide information about the near surface materials. If high loads are to be imposed and there is reason to believe that the materials will change with depth, then backhoe test pitting will not suffice as a site investigation method.

**Table 6** Typical Values of Compression Index, Cc

| Material | Initial Void Ratio $e_0$ | Compression Index $C_c$ | Stress Range (psf) | Source |
|---|---|---|---|---|
| Taconite, fine tailings | 0.37 | 0.19 | 500-20,000 | Guerra, 1979 |
| Copper slimes | 1.3-1.5 | 0.20-0.27 | 20-20,000 | Mittal and Morgenstern,1976 |
| | -- | 0.28 | -- | Volpe, 1979 |
| Copper sands (cycloned) | 1.10 ($Dr = 0$) | 0.05<br>0.11 | 200-2,000<br>2,000-20,000 | Mittal and Morgenstern, 1975 |
| | -- | 0.09 | -- | Volpe, 1979 |
| Tar sands | 1.0 ($Dr = 0$) | 0.06 | 200-20,000 | Mittal and Morgenstern, 1975 |
| Molybdenum, beach sands | 0.72-0.84 | 0.05-0.13 | 500-20,000 | Nelson et al., 1977 |
| Gold slimes | 1.7 | 0.35 | 3,000-10,000 | Blight and Steffen, 1979 |
| Lead-zinc slimes | 0.7-1.2 | 0.10-0.25 | 1,000-12,000 | Kealy et al., 1974 |
| Fine coal refuse | 0.6-1.0 | 0.06-0.27 | -- | Wimpey, 1972 |
| Phosphate slimes | >20 | 3 | 100-1,600 | Bromwell and Raden, 1979 |
| Bauxite slimes | 1.6-1.8 | 0.26-0.38[a] | 1,000-20,000 | Samogyi and Gray, 1977 |
| Gypsum tailings | 1.3 | 0.07[a]<br>0.28 | 500-5,000<br>5,000-20,000 | Vick, 1977 |

[a]Compressibility dependent on load duration

**Table 7** Typical Values of Coefficient of Consolidation, *cv*

| Material | $c_v$ (cm²/sec) | Source |
|---|---|---|
| Copper beach sands | $3.7 \times 10^{-1}$ | Volpe, 1979 |
| Copper slimes | $1.5 \times 10^{-1}$ | Volpe, 1979 |
| Copper slimes | $1x10^{-3}$ - $1x10^{-1}$ | Mittal and Morgenstern, 1976 |
| Molybdenum beach sands | $10^{2}$ | Nelson et al., 1977 |
| Gold slimes | $6.3 \times 10^{-2}$ | Blight and Steffen, 1979 |
| Lead-zinc slimes | $1x10^{-2}$ - $1x10^{-4}$ | Kealy et al., 1974 |
| Fine coal refuse | $3x10^{-3}$ - $1x10^{-2}$ | Wimpey, 1972 |
| Bauxite slimes | $1x10^{-3}$ - $5x10^{-2}$ | Somogyi and Gray, 1977 |
| Phosphate slimes | $2 \times 10^{-4}$ | Bromwell and Raden, 1979 |

**Table 8** Typical Values of Drained Friction Angle

| Material | (degrees) | Effective-Stress Range (psf) | Source |
|---|---|---|---|
| **Copper** | | | |
| Sands | 34 | 0-17,000 | Mittal and Morgenstern, |
| | 33-37 | 0-14,000 | 1975 |
| | | | Volpe, 1975 |
| Slimes | 33-37 | 0-14,000 | Volpe, 1975 |
| **Molybdenum beach sands** | 32-38 | -- | Nelson et al., 1977 |
| **Taconite** | | | |
| Sands | 34.5-36.5 | -- | Guerra, 1979 |
| Slimes | 33.5-35 | -- | Guerra, 1979 |
| | 27-32 | -- | Klohn, 1979a |
| **Lead-zinc-silver** | | | |
| Sands | 33.5-35 | -- | McKee et al., 1979 |
| Slimes | 30-36 | -- | McKee et al., 1979 |
| **Gold slimes** | 28-40.5 | 0-20,000 | Blight and Steffen, 1979 |
| **Fine coal refuse** | 22-39 | 0-6,000 | Wimpey, 1972 |
| | 22-35 | 0-25,000 | Wimpey, 1972 |
| **Bauxite slimes** | 42 | 0-4,000 | Somogyi and Gray, 1977 |
| **Gypsum tailings** | 32 ( = 500 psf) | 0-10,000 | Vick, 1977 |

**Table 9** Typical Total-Stress Strength Parameters

| Material | Initial Void Ratio $e_o$ | Total Friction Angle $\phi_t$ (deg) | Total Cohesion $C_t$ (psf) | Source |
|---|---|---|---|---|
| Fine coal refuse | 0.5-0.8 | 16-24 | 600-1,500 | Wahler, 1973 |
| Molybdenum sands | 0.8 | 14 | 800 | Vick, 1983 |
| Copper tailings, all types | -- | 13-18 | 0-2,000 | Volpe, 1979 |
| Copper beach sands | 0.7 | 19-20 | 700-900 | Wahler, 1974 |
| Copper slimes | 0.6 | 14 | 1,300 | Wahler, 1974 |
| | 0.9-1.3 | 14-24 | 0-400 | Wahler, 1974 |
| | 1.1 | 14 | 0 | Vick, 1983 |
| Lead-zinc slimes | 0.8-1.0 | 21 | 0 | Vick, 1983 |
| Bauxite slimes | -- | 22 | 100 | Somogyi and Gray, 1977 |

**Table 10** Geophysical Exploration Methods After Hunt (1984)

| Category | Applications | Limitations |
|---|---|---|
| Surface seismic refraction | Determine stratum depths and characteristic seismic velocities. | May be unreliable unless velocities increase with depth and bedrock surface is regular. Data are indirect and represent averages. |
| Uphole, downhole, and crosshole surveys | Obtain velocities for particular strata; dynamic properties and rock-mass quality. | Data are indirect and represent averages, and may be affected by mass characteristics. |
| Seismic reflection | Not used on land for engineering studies. Useful offshore for continuous profiling. | Does not provide seismic velocities. Computations of depths to stratum changes requires velocity data obtained by other means. |
| Electrical resistivity | Locate saltwater boundaries, clean granular and clay strata; rock depth. | Difficult to interpret and subject to wide variations. Does not provide engineering properties. |
| Gravimeters | Detect major subsurface structures; faults, domes, intrusions, cavities. | Normally used only for cavity information for engineering studies. |
| Magnetometer | Mineral prospecting and location of large igneous masses. | Normally not used in engineering studies. |
| Radar subsurface profiling | Provides subsurface profile; used to locate buried pipe, bedrock, boulders. | Does not provide information at great depths or engineering properties. Shallow penetration. |
| Video-pulse radar | Used to locate faults, caverns, voids, buried pipe, general rock structure. | Same as for radar subsurface profiling. |

**Table 11** Drilling Methods for Geotechnical Investigation From Hunt (1984)

| Category | Applications | Limitations |
|---|---|---|
| Wash boring | Obtain soil samples primarily for identification and index testing. | Slow procedure. Cannot penetrate strong soils or rock. Undisturbed sampling difficult. |
| Rotary drilling | Obtain samples of all types in soil or rock for identification and laboratory testing of index and engineering properties. | Requires relatively large and costly equipment. Soil samples and rock cores normally limited to 6 in. dia. |
| Continuous flight auger | Rapid drilling and disturbed sampling in soils with cohesion and greater than soft consistency. Normally sampling possible if hole remains open. Can penetrate soft rock. | Hole collapses in soft soils, dry granular soils without cohesion, and many soils below groundwater level. |
| Hollow-stem flight auger | Similar to continuous flight but hollow-stem serves as casing permitting normal soil sampling with Standard Penetration Testing or Shelby Tubes. | Cannot penetrate very strong soils, boulders, or rock. |
| Percussion drilling (cable tool) | Usually used to drill water wells. | Large cumbersome equipment. Normal sampling difficult. |
| Hammer drilling | Good penetration in boulders and cobbles. | Large cumbersome equipment. Much soil disturbance results in samples of questionable quality. |
| Wireline drilling | Fast and efficient for deep core drilling on land and offshore borings. | Equipment costly and no more efficient than normal rotary drilling for most land investigations. |

**Table 12** Typical Testing Performed on Borrow Materials

| Borrow Material | Typical Testing Performed |
|---|---|
| Structural Fill | |
| Coarse-grained (larger than 3 in.) | Particle size distribution, shear strength analysis (empirical relationship with point load strength) |
| Fine-grained | Particle size distribution, natural moisture content, Atterberg limits, compaction tests, shear strength analysis, compressibility, pinhole dispersion test |
| Rock Fill | Particle size distribution, unconfined compressive strength, L.A. Abrasion test |
| Low Permeability Soil | Particle size distribution, compaction tests, natural moisture content, shear strength analysis, Atterberg limits, permeability |
| Drainage Materials | Particle size distribution, L.A. Abrasion test, permeability (only selected cases) |

**Table 13** Geosynthetics and their Applications

| Category | Applications |
|---|---|
| Geotextiles | Cushions, filters and reinforcement |
| Geomembranes | Flow barrier to provide containment |
| Geonets | Drainage medium |
| Geogrids | Reinforcement |
| Geosynthetic clay liner | Flow barrier to provide containment |
| Geocomposites | Combination of the above materials and their applications |

However, in most cases it is the site investigation method of choice for heap leach facilities and potentially tailings impoundments and waste rock dumps. In the latter case, the information should be enhanced through targeted drilling.

Borrow source investigation must be carried out as soon as the conceptual design is developed and estimates are available of the types and quantities of materials which are necessary for construction of the mining facility. Borrow materials typically include materials for embankment construction (waste rock can be used if it is suitable), liner construction (bentonite or other amendment evaluations must often be considered), and drainage layers. Table 12 lists typical tests performed on different types of borrow materials.

#### 7.2.2.4 Geosynthetics

The use of geosynthetics have increased in mining projects. Koerner (1986) provides a thorough treatment of geosynthetics and their uses in earthworks projects. As part of the geotechnical site characterization it is important to obtain sufficient information, for example geomembrane clay liner interface shear strength, to allow detailed specification of geosynthetics. Table 13 provides summary of geosynthetics and their applications. A more complete discussion of geomembranes is presented in Chapter 8.

As part of the geotechnical site characterization it is necessary to evaluate those material characteristics which may affect the selection of appropriate geosynthetic materials. The interested reader should refer to Koerner (1986) for further information.

### 7.2.3 HYDROGEOLOGICAL CHARACTERIZATION
**by A. Brown**

#### 7.2.3.1 Introduction

The hydrogeologic setting of mineral projects includes those aspects which have an impact on the quantity and quality of ground water. This setting is greatly dependent on the nature of the mineral being developed. Fundamentally, hydrogeologic settings may be

characterized in reference to the degree and style of heterogeneity or homogeneity which is associated with the setting. Three generic types of hydrogeological systems can be defined, with real settings generally containing elements of each type:

*Homogeneous hydrogeology*, in which resistance to water flow is about equal in all directions. This condition is found in extensive granular materials (for example eolian sands), and is also approached in highly fractured massive rock materials (for example in some quartz porphyries).

*Tabular hydrogeology*, in which resistance to flow is much greater in one direction (across the tabular elements) than in the other directions (along the tabular elements). This condition is found in systems where there is layering of the geological material (for example in coal deposits and volcanic flow systems).

*Heterogeneous hydrogeology*, in which there are gross variations in resistance to flow at a scale which is significant with respect to the scale of the orebody.

The approach to characterization of each of these settings is different, and will be noted as appropriate in the remainder of this section.

### 7.2.3.2 Exploration Phase

#### *7.2.3.2.1 Objective*

During the exploration phase, the principal environmental hydrogeologic characterization task is to determine whether the project can be permitted from the ground water point of view. In particular, it is essential to identify whether or not the project is located in a critical ground water system, where project-induced ground water modification has a high probability of creating environmental impacts that cannot be mitigated economically during or after operations.

#### *7.2.3.2.2 Data Collection*

The ground water system is investigated in order to develop a conceptual model of the behavior of the ground water system in the project area and its environs. A conceptual model is a construct of the ground water flow and solute transport system which allows evaluation of the movement of water in the system with any boundary conditions. In general developing a conceptual model requires collecting and assembling information on the following topics:

*Site.* The site conditions are a critically important element in the development of a conceptual model for ground water flow at a mining site. Conditions that are important are meteorology (precipitation, evaporation, temperature, wind behavior), topography (slope, aspect, drainage), past and present land use, vegetation, and soil conditions.

*Geology.* The geological system determines the ground water flow system. As a result, information on the regional and local geology of the system is critical to the successful characterization of the ground water flow system. It should be noted that the ground water system cannot be defined by reference to the geology alone, no matter how diligently this information is collected. Indeed, many dissimilar geological systems behave in similar hydrogeological ways, and many similar geological systems behave in very different ways. The geological information that is required for ground water definition purposes includes:

Location and nature of geological units.
Location and nature of structural features.
Direction and intensity of fracturing of rock units.

*Surface water.* The flow of surface water, and the location of bodies of standing surface water (wetlands, lakes, swamps) are an important initial condition for mining environmental ground water evaluations. Surface water conditions reflect ground water conditions, and surface water is also an important input to, and output from, ground water systems. Useful information includes flow in streams, and water gain/loss from streams, lakes, and wetlands.

*Ground water.* At the time of exploration, ground water data is generally available from existing wells and other public data sources. Useful information includes water levels, flow rates, and possibly hydraulic conductivity from existing wells in the area, and the locations of springs and seeps (which indicate the locations of points where the ground water table is locally at the ground surface). In addition, mineral exploration drilling offers a wide range of opportunities for collecting ground water data including:

Flow and quality data from reverse circulation drilling.
Lost circulation information during drilling.
Rock fracture information from coring.
Packer test information taken during drilling in rock.
Water level data taken during drilling.

Further, after the drilling of exploration holes it can be advantageous to complete the holes as observation wells in the system. These completions allow more

accurate measurement of water levels, and monitor the effect of ground water removal by drilling on nearby locations. It should be noted however, that completing exploration wells as observation wells may be restricted, or may have to comply with specific criteria such as drillers' licensing and well drilling and completion requirements. Some states also require plugging of all exploration holes immediately after drilling. Most states, particularly in the western U.S. require registration of any well which remains after exploration is complete.

*Ground water quality*. Some information may be available about ground water for the exploration phase evaluation. In general this information is obtained from existing ground water wells, springs, underground mine workings, or other points of access to the ground water. In addition, ground water quality samples may be available from return flow from reverse-circulation drilling, or from completions made in exploratory drill holes.

#### *7.2.3.2.3 Integration and Analysis*

The information collected at this stage is assembled and a preliminary conceptual ground water model is developed for the site. This model is used as a framework to evaluate the extent to which ground water-related impacts will occur as a result of the project, in particular those which have the potential to prevent the project from being permitted. In the event that there is insufficient information for the exploration-level evaluation of the ground water system, this assembly will indicate where the data shortfalls occur. Data must then be collected to fill these data needs, using specific investigations. When the data is at hand, the evaluation is completed.

### 7.2.3.3 Development/Permitting Phase

#### *7.2.3.3.1 Requirements*

The development/permitting phase of the project requires more information and evaluation than the preliminary information that was adequate for determining the environmental feasibility of the project during the exploration stage. The characteristics of the mineral system are important in defining the approach to ground water information collection, and to the use of that information.

The principal hydrogeology challenge in the development/permitting stage of the project is assessing the expected and possible effects that the proposed development will have on the ground water system. These effects include: changes in the ground water flow system, possibly resulting in impacts on nearby wells, springs, and streams; and changes in water quality in the ground water system, possibly resulting in contamination of aquifers near the mine facility and reduction in utility of the water in those aquifers.

#### *7.2.3.3.2 Developing a Conceptual Model*

Developing an understanding of the ground water system for predicting the effects of the proposed project is a technically demanding exercise in any environment. Predicting the flow effects is less demanding than predicting the chemical effects. However, reliable prediction of both is necessary in demonstrating adequate environmental protection in permit applications.

The process that is generally used to develop a prediction of the ground water effects of a mine development is as follows: 1) data are assembled on the ground water flow and transport system; 2) this data are used to develop a conceptual model of the site. A conceptual model includes the important features of the ground water system associated with the mining project. These include the geometry of the hydrostratigraphic units of the system (that is the geological units in which ground water properties are similar); the parameters relating to ground water flow and transport in those units; and the boundary conditions of the model domain which are not changed by the proposed project.

A conceptual model does not, in general, include heads, flows, or concentrations. These elements are important to the analysis of impact, but not part of the concept, as they can and are varied in the evaluation phase.

#### *7.2.3.3.3 Creating the Analog*

An analog of the behavior of the ground water flow and chemistry at the site is created by quantifying the conceptual model. This is achieved by applying all the information that is available to the conceptual model. The process involves including in the model all that is known about the hydraulic conductivity, porosity, dispersivity, retardation, and other information that is required to describe the behavior of the ground water and the solutes which it transports.

The demands for information increase as the complexity of the hydrogeological environment increases. *Homogeneous environments* transport water, and any introduced contaminants, in a predictable fashion, downgradient from the point of introduction. Accordingly, the data needs for reliable prediction are a demonstration that the system is indeed reasonably homogeneous, and a knowledge of the parameters controlling flow and movement of contaminants in the system (hydraulic conductivity, porosity, dispersion, and retardation). Parameters are generally developed using standard test methods: field tests of hydrology, and laboratory tests of geochemical parameters. Experience

indicates that predictions of impacts of future development on the ground water system in these circumstances are reasonably reliable; unfortunately such systems are quite rare at the scale of a mine development.

*Tabular systems* transport water and contaminants preferentially along the plane of the layers making up the system. Because of this, it is critical to identify both the high and the low permeability features of the system. The low permeability features are often difficult to quantify, yet from an environmental point of view they are critical to determining the possible impacts of an operational facility. Leaky aquifer tests (Hantush and Jacob, 1955) and multi-point water level and water quality monitoring strategies are often required in evaluating tabular systems. Because transport is often in the plane of the tabular system, the need to evaluate the behavior of the ground water transport system across the beds (or interbeds) may be considerably reduced.

*Heterogeneous systems* transport water and contaminants preferentially through the most permeable pathways available in the system. These pathways are inherently difficult to identify during the investigation phase, as they have relatively little impact on the head patterns observed in the ground water system. In order that the model of the ground water flow and transport in the system be realistic, a considerable amount of permeability and other parametric information is required. The information that is generally input is spot data, gathered from detailed investigation of the facility and its environs.

#### *7.2.3.3.4 Calibrating the Analog Model*

In general, once the analog model has been developed, the evaluation proceeds to the calibration step. Calibration is a process that ensures that the analog of the system is adequately accurate for the purposes of predicting the outcomes of a variety of development scenarios. The process is described as follows:

*Static calibration.* This involves calibrating the flow and quality analog against the pre-mining condition (generally at steady state, or quasi-steady state).

*Dynamic calibration.* This involves calibrating the flow and quality analog against a perturbation of the system of similar magnitude to that expected to result from mining activities (such as a major infiltration event, a major chemical excursion, a pump test of the flow system, or a tracer test of the chemical system).

#### *7.2.3.3.5 Calibrating the Flow Analog*

The flow analog is calibrated against a head and flow condition for which information is available. If more than one head and flow dataset is available (for example data from prior years), then calibration against each condition is beneficial. The analog results are compared with the real results, and the parameters in the model are varied within their reasonable range (based on available test result) until the behavior of the simulation provides a reasonable fit with the real data. The resulting analog is said to be calibrated for flow.

The analog is then calibrated for a perturbation similar to that expected in mining, by changing the boundary conditions, applying the parameters measured to the conceptual model, and using the model to predict the current (or a known set of) ground water head measurements. In some cases such perturbations are not available, in which case this step must be omitted. However, many perturbations exist or can be created in most projects.

For instance, a dramatic change in infiltration due to a major rainfall, snowmelt, or infiltration event can provide a useful test of the hydraulic response of the system to inputs. In particular, such global changes in conditions can provide an excellent basis for calibrating the analog for predicting the effects of the large perturbations that are generally caused by mining.

Also, large-scale monitoring of (for example) mine dewatering may create a sufficiently large perturbation that the analog of the system can be calibrated against that change. In the case of underground mining, it is often decided to create a test underground opening, for a bulk sample or other purposes. Such an opening, if below the water table, can provide an excellent perturbation of the ground water system for the purposes of calibrating a flow analog, and also for the purposes of providing a near-full scale example of what ground water impacts the actual mine will induce.

A pumping test is the classical method of determining the hydraulic parameters of a ground water system (Walton, 1970). The utility of these tests varies depending on the kind of system being evaluated:

*Homogeneous systems.* Pumping tests should be capable of defining the characteristics of the system, providing that the departure from ideal behavior due to the probable partial penetration of the system is allowed for. The test results should be typical of the system, if it is indeed relatively homogeneous.

*Tabular systems.* Pumping tests are ideal for these systems, as the analytical approaches to interpreting the results were developed for tabular aquifers. With appropriate well completion and monitoring locations, both the major permeability (generally along the bedding) and the minor permeability (generally

normal to the bedding) can be ascertained in the same test.

*Heterogeneous systems*. Pumping tests can be used in heterogeneous systems to identify effective hydraulic conductivity and storage characteristics of the rockmass. Due to the variability of the flow system that they are interrogating, multiple piezometers are advisable in these systems, and generally speaking computer simulation analysis is required to interpret the results.

#### *7.2.3.3.6 Calibrating the Geochemical Analog*

The chemical transport analog is calibrated in a similar fashion by applying the measured geochemical parameters to the simulation model, and comparing the results predicted by the analog to the known geochemical system. If the geochemical system is large, it is possible that the evolution of the chemical concentrations in the ground water system will allow calibration of the geochemical portions of the analog. In this case, the analog is calibrated against the pre-development site geochemistry.

However, for most mining situations, such calibration is not definitive. As a result, geochemical calibration is either omitted (which reduces the reliability of the analog predictions), or is performed using a perturbation of the geochemical system. Such geochemical perturbations can be identified or created by isotopic testing, in which the abundance of the isotopes of water and other species is evaluated in order to distinguish between waters of different origins, or tracer testing, in which a marker is placed in the ground water system, and the ground water in the surrounding area is monitored to identify the passage of the marker (Davis and others, 1985). For large ground water systems, however, the time needed to perform such tests may be prohibitive, and the track record of tracer testing has not been particularly high in determining the real behavior of the systems tested.

Isotopic testing is often a particularly powerful method of identifying genesis of water. In particular, the isotopic abundances of the oxygen and hydrogen making up the water often allow definition of the rate of movement of water through the ground water system (in particular tritium analyses), and of the history of the flow of water through the system, from infiltration point to current position (in particular deuterium and oxygen-18 isotope analyses) (Freeze and Cherry, 1979; Mazor, 1991).

Tracer tests are difficult and expensive to conduct at the scale of mine projects. In existing projects, it is sometimes possible to use the result of a chemical excursion (often harmless) to act as a surrogate tracer test. This is particularly true of any significant contaminant plume identified to be leaving the property: it can be treated as a tracer test, and analyzed to provide important pathway identification and parameter quantification for the site. Other, non-mining related markers can also be used for tracer tests in certain circumstances (for example nitrate from fertilizers, tritium from bomb-test fallout, sulfate from airborne emissions from power stations and smelters, and salt from road salting).

#### *7.2.3.3.7 Evaluating Project Impacts*

Once a calibrated analog of the ground water flow and chemical transport system has been developed, the effects of the proposed development can be evaluated. This process requires two steps. First, the boundary condition changes associated with the proposed development are determined. These changes include changes in infiltration (flow and concentration), injection, extraction, permeability, porosity, geometry, retardation, and dispersivity. Then, the results of these changes in boundary conditions are evaluated using the analog of the system.

This is a relatively straightforward portion of the evaluation. A wide range of scenarios can be evaluated quickly, and the analog becomes a useful environmental and economic planning tool.

The results of the impacts that may be expected can be used to design the project elements, for example by evaluating the results of different mining and milling strategies on the ground water flow and quality regime, and then comparing these results with allowable changes in these regimes. In addition, the economic impact of a range of decisions about mining and milling practices can be evaluated by obtaining a quantitative assessment of the impacts of those decisions on the ground water system, and the cost of dealing with these impacts.

## 7.2.4 MINIMIZING PROBLEMATIC PROCESS WASTES

**by G. E. McClelland and L. J. Buter**

### 7.2.4.1 Overview

Metallurgical testing during the development stage of an ore deposit will provide data necessary to evaluate the economic recovery of the valuable metals or minerals. Concurrent testing can also provide data useful for planning and estimating the cost to close and reclaim the project area to current standards. Since cost for closure and reclamation can be significant, alternative processing options must be evaluated to select the economic optimum processing sequence for recovery of the valuable mineral and mitigation of potential

environmental impacts.

Head ore must be characterized early on to identify constituents which may become hazardous if not removed or stabilized during processing. Samples generated during metallurgical testing phases are used to predict recovery efficiency and to identify constituents which may be problematic as process and mine wastes. Combined characterization data will be useful in selecting the most economic overall process when closure and reclamation cost estimates are included. Initial processing costs may be high, but if long-term environmental problems are mitigated, overall project costs will be minimized.

This section is designed to provide conceptual considerations for process selection with closure and reclamation in mind. Conceptual considerations are generally related to the precious metals industry with some application to other processing industries.

### 7.2.4.2 Introduction

In many states, current environmental regulations require that closure and reclamation plans be submitted with the operating plan before a permit to operate will be issued. This requirement makes it necessary to develop process waste and mine waste characterization data early in the metallurgical development phase of a mineral project. Potentially hazardous constituents in head ore, mine waste, process waste, and wastewater must be identified to enable the selection of a processing sequence which is economically optimum for mineral recovery and project closure.

Closure and reclamation costs can add significantly to the costs of a project. Because most of these costs are incurred near the end of the project life, they do not have a major impact on the net present value calculation for the project during the feasibility phase. They are, however, real and are necessary to prevent long-term impacts to the environment. A well designed metallurgical testing program will provide necessary data for sound process selection, cost estimating, production, and closure/reclamation decisions. With the proper selection of a processing sequence, some potential long-term environmental impacts may be mitigated during the mineral production life of the project.

A conceptual approach for metallurgical characterization during the project development phase is summarized as follows:

1. Optimize processing conditions and sequence for economic recovery of the valuable metal or mineral.

2. Characterize head ore, mine waste, process waste streams, and wastewater streams to identify potentially hazardous constituents.

3. Re-optimize processing conditions and unit operations to help mitigate potential long-term impact on the environment by recovering or stabilizing hazardous constituents during processing.

4. Translate all data to local climatic and site specific conditions.

5. Re-estimate all processing, mitigation, closure and reclamation costs.

6. Select the best processing sequence for economic metal or mineral recovery which minimizes long-term impacts to the environment.

This conceptual approach for metallurgical characterization can be applied to precious metals and many other commodities. The following sections of this paper provide conceptual considerations for recovery of valuable metals or minerals and mitigation of environmental impacts using conventional commercial processes.

### 7.2.4.3 Commercial Processing

Concurrent metallurgical and waste characterization testing will help select the most economical overall processing sequence for a mineral deposit. Processing sequences (flow sheets) which can be evaluated range from the very simple to the very complex depending on the mineral or metal and contaminant occurrence. In general, a very complex flow sheet will be more capital and operating cost intensive because each unit operation will add to the overall cost of the project.

#### *7.2.4.3.1 Direct Shipping Ore*

The apparent least costly process for an ore deposit would be mining and direct shipping of the ore. An example would be a sand or gravel mineral deposit. Metallurgical characterization would be required to insure product specifications can be met by conventional mining and/or crushing and screening procedures. The product must be characterized to provide information for shipping classification and precautions as required. Mine waste rock must be characterized for long-term storage to minimize wind and surface erosion, and the potential to mobilize metals and produce acid. Methods for storage of mine waste should be selected based on local climatic and site specific conditions.

#### *7.2.4.3.2 Simple Upgrading*

Many ore deposits require some simple form of

concentration or upgrading before product shipment. As with direct shipping ores, the product to be shipped must be characterized to provide information to insure product specifications are met, and to identify any hazardous constituents which require categorization for transportation. The receiver of the product will also require this information for use in his processing sequence. Mine and beneficiation wastes will have to be characterized to select the proper disposal or long-term storage method. Example commodities or products may include barite, talc, and limestone.

Another rather simple upgrading unit operation is a wet or dry screening process where the commodity can be upgraded by particle size separation. The screening process would produce a concentrated product for shipment and a screen reject material. The dry screening process will have to be evaluated and characterized with respect to particulate emission during screening and wind and surface erosion of impounded screened reject. Mitigation of unacceptable air quality impacts will have to be accomplished with the design of the process and the dry impoundment. For the wet screening process, screened fines or slimes rejects will require impoundment if they cannot be sold or utilized in another process. Metallurgical characterization, using the conceptual approach summarized earlier, will help determine if a wet or dry screening process should be selected for the operation. Potential for metals mobility and acid production from mine waste rock will have to be characterized and applied to site specific conditions. Examples of deposits suitable for this processing sequence may include crushed rock, decorator rock, phosphate rock.

#### *7.2.4.3.3 Physical Beneficiation*

Gravity separation is a commonly applied simple unit operation for separating minerals or metals of different specific gravity. Gravity beneficiation techniques employ mechanical means and water to upgrade the valuable mineral to a product which may be shipped or processed on site for mineral recovery. Size reduction by conventional crushing and grinding is usually required to liberate the mineral for recovery by gravity concentration methods. The crushing and grinding circuit will have to be designed and operated to comply with air quality emission standards. The gravity circuit, for a simple ore, may be operated efficiently without chemical addition to produce a concentrate product and a benign rougher tailing waste product. Tailings must be characterized before they are impounded to insure that potentially hazardous constituents are not present.

If the rougher tailing contains unacceptable constituents, metallurgical reevaluation may be required to determine if the gravity processing sequence can be modified to recover those constituents in the gravity concentrate rather than designing and constructing an expensive lined tailings impoundment facility. Modification of the processing sequence may decrease gravity concentration ratio and concentrate grade, which would affect the economics of metal recovery. Overall processing costs may, however, be less if an environmentally acceptable tailing can be stored in a less costly impoundment. Normal mine waste characterization studies will have to be conducted. A deposit containing free milling gold in an oxidized host rock would be amenable to simple gravity concentration methods.

Heavy media separation is a processing technology suitable for beneficiation of ores with a large specific gravity difference between valuable and gangue minerals. The heavy media used for separation of the respective minerals must be of optimum specific gravity. Chemical and physical heavy media are used commercially, but chemical media are more common. Heavy media chemicals are usually toxic and require particular regeneration/recycle, characterization and disposal methods. Concentrate products, process waste, and waste solution must be treated for removal of toxic chemical before shipment or disposal. The heavy media separation process does not allow much sequence modification for mineral contaminant recovery because the system is dependent on close specific gravity control and strict concentrate product specifications. Process wastes and mine wastes require characterization before on site storage or impoundment facilities can be effectively designed and constructed. Size reduction of the ore is usually required for efficient concentration by heavy media processing. Examples of ore deposits amenable to heavy media separation are coal and iron ore.

Conventional oxide or sulfide flotation concentration technology is applicable to many types of mineral deposits. The flotation processing sequence is fairly simple, but because organic reagents are used to promote recovery of valuable minerals, environmental characterization is more complex than for other physical beneficiation technologies. Concentrate products, especially for sulfide mineral flotation, require additional processing for metal recovery and purification. Consequently, process waste streams and subsequent unit operation products and wastes must be characterized separately for potential hazardous constituents. The importance of concurrent metallurgical and waste characterization cannot be understated for flotation and other multi unit operation processing technologies to insure the best economical overall process is selected.

For example, a higher grade ore which contains small "free milling" gold particles and gold associated with sulfide mineral grains is amenable to sulfide flotation techniques. A simple processing sequence for maximizing gold recovery would be: 1) float to produce a rougher concentrate and rougher tailing, 2) clean the

rougher concentrate to produce a high grade cleaner concentrate and a lower grade cleaner tailing, 3) direct smelt or re-grind and cyanide the cleaner concentrate to recover the gold, and 4) combine the cleaner and rougher tailings for subsequent cyanidation to recover residual gold values.

This simple processing sequence may be economically feasible to maximize gold recovery, but may not be economic for containing and controlling potential contaminants in the many process waste streams. Process sequence modification may allow acceptable gold recovery into a larger volume of rougher concentrate and produce a very low-grade, benign rougher tailing which can be impounded without additional processing.

Processing in this manner would decrease concentration ratio and concentrate grade, but would maximize gold and contaminant recovery into the concentrate. The "downside" is that a larger quantity of concentrate would have to be processed for gold recovery and no attempt is made to recover unfloated gold in the rougher tailing. The "upside" is that more hazardous contaminants would report to the rougher concentrate, and because of the relatively small quantity of concentrate, contaminants could be impounded and/or stabilized economically. Also, the nearly benign rougher tailing may be impounded with substantially less capital cost and long-term monitoring requirements. Characterization of mine waste, process waste, and wastewater would be required regardless of the number of unit operations in the processing sequence.

#### *7.2.4.3.4 Chemical Dissolution*

Chemical leaching processes are used for dissolving valuable metals and minerals from whole ore and from various separation products generated by physical beneficiation processes. Oxidation may be required on the feed (ore or concentrate product) before chemical leaching techniques are effective for dissolution of the valuable commodity.

Chemical leaching processes require specific reagents for dissolution of the valuable commodity. These reagents range from water to toxic organic solvents. The hazardous nature of each chemical reagent must be understood before use in the process and long-term storage or disposal when present in the final process waste or wastewater. Reagents selected for the process must provide economic dissolution of the valuable commodity, but also must be economically removed, neutralized or stabilized before long-term impoundment or storage with the process waste solids. Specific treatment of wastewater containing residual reagents may be required if contaminated liquids are stored or impounded separately from process waste solids. Characterization of the process wastes contacted with reagents is in addition to characterization of mine waste and other process wastes where no chemical reagent was added. Common examples of chemical reagents are sulfuric acid for dissolution of copper oxide minerals and sodium cyanide for dissolution of precious metals.

Many higher grade ore deposits require a complex processing sequence to maximize recovery and minimize problematic wastes. The number of waste streams requiring characterization and environmentally sound storage and impoundment increases with the number of unit operations in the processing sequence. A sulfide mineral ore, for example, may require size reduction, concentration by gravity and/or flotation, oxidation pretreatment of the concentrates and subsequent chemical leaching for metals recovery, and separate chemical leaching for residual metals recovery from the gravity or flotation tailings. There are at least five process waste streams resulting from this processing sequence and each must be characterized and monitored separately for disposal. Ideally, each unit operation in the processing sequence is selected and designed to successively remove and stabilize hazardous constituents to enable each process waste stream to be contained or controlled in an environmentally sound manner at minimum cost.

Size reduction must be accomplished with maximum economic efficiency and minimum particulate emission. The concentration circuit is operated to produce the best feasible concentration ratio and metal recovery to produce a relatively small feed weight percentage concentrate which also contains a high percentage of problematic sulfide contaminants. If direct smelting is not applicable, oxidative pretreatment of the concentrates (autoclaving, roasting) is performed to liberate the metal for subsequent chemical dissolution and to oxidize sulfide minerals which otherwise would promote metals mobility and acid production if stored or impounded for a long period. Off gases and other oxidation products from the oxidation pretreatment method selected must be characterized and controlled. The chemical leaching process for dissolution of metals from the oxidized concentrate is selected and designed to promote economic valuable metal recovery and dissolution and/or stabilization of oxidation products (metal oxides and sulfates) resulting in less problematic process waste for separate impoundment. The rougher tailing, nearly free of problematic constituents, is chemically leached for recovery of residual valuable metals. Leached rougher tailings will be characterized, neutralized, and impounded separately from other process streams. Separate impoundment provides an economic advantage because the final tailings represent the largest percentage of the feed weight, are the least problematic waste, and can be stored in a less costly impoundment. Mine waste will be characterized and stored separately from all process waste streams.

#### *7.2.4.3.5 Commercial Production Example*

A western U.S. gold operation is discussed here as an example of a multi unit operation processing sequence which was selected based on concurrent metallurgical and environmental characterization. Where feasible, unit operations were selected to maximize economic precious metal recovery and minimize problematic wastes.

The ore deposit contains mine waste, mill grade ore, and sub-mill grade ore. All three were characterized early in the metallurgical development phase to provide data for permitting, closure and reclamation planning, and for overall economic evaluation of the project. Mine waste was characterized separately by rock type to establish the potential to produce acid and the potential for metals mobilization by meteoric water. The mine waste storage area was selected and constructed according to the mine plan, local climatic conditions, and potential for seepage from the waste dump. Sub-mill grade ore is processed using heap leach cyanidation techniques. The leach pad and solution pond system were selected and constructed to insure containment of potentially hazardous constituents. High-grade ore is milled and processed using a multi unit operation processing sequence. Process waste streams are treated and impounded separately, as required, to minimize cost and impact to the environment.

Mine waste is characterized by rock type using accepted testing and analytical procedures on an ongoing basis. Waste is moved from the open pit according to the mine plan and is stacked in a waste dump. As much as possible, mine waste dumps are recontoured and revegetated as mining occurs, to minimize infiltration and erosion. All mine waste dumps will be reclaimed by the end of the project life.

Sub-mill grade ore is stacked into heaps constructed on a double lined/leak detection pad system. Alkaline cyanide solution is applied to the surface of the heap and percolates through the ore, slowly dissolving the precious metals. Pregnant solution is collected in a lined pond. Pregnant solution from the pond is used as process water for the milling circuit. Dissolved precious metals are recovered from heap pregnant solutions during processing of the high-grade ore. Process waste (solids) and wastewater steams were characterized during the metallurgical testing phase to identify problem areas and constituents, and to insure that the selected heap leach processing sequence would remove or stabilize the maximum number of contaminants during processing. It was decided during the testing phase to process heap leach pregnant solution in the milling circuit rather than constructing a complicated pond system, a separate carbon adsorption circuit, and a separate heap leach wastewater treatment facility.

Neutralization rinsing, metals mobility, and acid generation potential tests were conducted on the heap leach residues during the metallurgical testing phase to aid in the selection of the most effective and economic closure process for the solids. Leached heaps are washed with water to remove residual cyanide compounds, dissolved metals, and to decrease wash effluent pH. Wash effluents are used in the milling circuit and a separate wastewater treatment facility is not required. The neutralized heap residue will be left on the liner system and will be recontoured and revegetated to minimize infiltration and surface erosion.

Higher grade (mill grade) ore is processed through a multi-unit operation milling circuit. Mill grade ore is composed of coarse metallic gold, fine gold associated with fine pyrite mineral grains, and a carbonate waste containing a naturally occurring organic component (preg-robbing) which adsorbs gold from the cyanide solution. The organic component must be removed from the ore during processing, before cyanidation, to minimize gold loss to tailings.

The milling circuit is composed of crushing, grinding, gravity concentration, flotation to remove the "preg-robbing" component, sulfide flotation to concentrate fine gold and sulfide minerals, and cyanidation of the flotation concentrate. Flotation tailings are not processed for precious metal recovery, and consequently, are a benign tailing for long-term storage.

The high-grade ore is crushed and then milled to the desired feed size using a ball mill circuit. Ball mill discharge is fed to the gravity circuit for recovery of coarse metallic gold and acid producing heavy sulfide minerals. Gravity concentrates, a very small percentage of the feed weight, are smelted directly to produce dor bullion. Smelter gases are scrubbed to remove hazardous contaminants.

Gravity tailings are fed to a flotation circuit where the "preg-robbing" component is removed. The organic component concentrate is disposed of in the lined sulfide flotation tailings impoundment as a benign tailing component. Carbon (organic component) flotation tailings are fed to the sulfide flotation circuit for recovery of fine gold particles and gold associated with fine-grained pyrite. Sulfide minerals, which increase potential for metals mobility and acid production, report to the flotation concentrates. Flotation concentrates represent a relatively small percentage of the ore feed weight, and contain a high percentage of problematic constituents. Consequently, recovery, treatment and impoundment of contaminants is less costly. The flotation tailing, a large percentage of the feed weight, is nearly free of problematic constituents and can be contained in a lined impoundment as a benign tailing.

Sulfide flotation concentrates are reground to a very fine size and are processed in a carbon-in-pulp (CIP) cyanidation circuit for precious metal recovery. Loaded carbon from the CIP circuit is desorbed (stripped) to

recover the gold. Strip solution is pumped to an electrowinning circuit to produce cathode gold which is refined to produce dor bullion. Strip solution is recycled. Off gases from refining are scrubbed to remove potential contaminants.

The CIP tailings slurry, by design, contains a low concentration of free cyanide. CIP tailings are impounded in a triple lined pond and clear solution (natural decantation) is recycled to the milling circuit. The triple lined impoundment is very small compared with the impoundment for storage of nearly benign flotation tailings. The impoundments were kept separate to minimize environmental impacts and reclamation costs. The triple lined impoundment was designed to insure containment of hazardous constituents, and on closure, will be prepared to insure encapsulation, topsoil will be placed, and the impoundment area will be revegetated.

Metallurgical testing and concurrent environmental characterization was done at several laboratories to develop this flow sheet which was the most cost effective for precious metal recovery and mitigation of problematic wastes. The number of unit operations in the processing sequence were costly but necessary to minimize long-term environmental impact and costs for closure and reclamation.

#### 7.2.4.4 Conclusion

Concurrent metallurgical process and environmental waste characterization during project development is very important for the mining industry to insure process selection for economic valuable mineral recovery and elimination and/or containment of problematic wastes. Production decisions today must be based on overall project economics and not solely on economics of mineral recovery.

## 7.3 DEFINING ENVIRONMENTAL CONDITIONS OF THE PROJECT SITE (BASELINE EVALUATION)

### 7.3.1 PERMITTING RISKS AND PRE-EXISTING POTENTIAL LIABILITIES
**by B. Bailey**

#### 7.3.1.1 General

The permitability and cost of permitting a proposed mining project depends on numerous factors ranging from the environmental setting to legal and political constraints. Permitting issues arise out of contemporary philosophies regarding the environment, perceived and real impacts to the environment, political preferences, and legislative mandates. Certainly, increased competition for scarce resources and the divergent opinions on how these resources should be used has complicated and extended the permitting process.

Exploration and development programs for minerals must take into consideration the problems that arise in securing permits. The permitting process is influenced by several general factors: 1) location of the project; 2) facility design; and 3) relationships with agencies and the public. These factors are related to risk. Managing these factors can help reduce risks in project development, and management of some of the factors is easier than others. Whereas there are not many options on the location of a mineral deposit, there is some flexibility in the approach that can be taken in facility design and in working with the agencies and the public.

**Table 14** Risks to the Natural Ecology and Human Welfare

| Relatively high-risk problems |
|---|
| • Stratospheric ozone depletion: Because releases of chlorofluorocarbons and other ozone-depleting gases are thinning the earth's stratospheric ozone layer, more ultraviolet radiation is reaching the earth's surface, thus stressing many kinds of organisms. |
| • Global climate change: Emissions of carbon dioxide, methane, and other greenhouse gases are altering the chemistry of the atmosphere, threatening to change the global climate. |
| • Habitat alteration and destruction: Humans are altering and destroying natural habitats in many places worldwide, by the draining and degradation of wetland, soil erosion, and deforestation of tropical and temperate rain forests. |
| • Species extinction and overall loss of biological diversity: Many human activities are causing species extinction and depletion and the overall loss of biological diversity, including the genetic diversity of surviving species. |
| **Relatively medium-risk problems** |
| • Herbicides/pesticides |
| • Toxics, nutrients, biochemical oxygen demand, and turbidity in surface waters |
| • Acid deposition |
| • Airborne toxics |
| **Relatively low-risk problems** |
| • Oil spills |
| • Groundwater pollution |
| • Radio nuclides |
| • Acid runoff to surface waters |
| • Thermal pollution |

(As prepared by the Science Advisory Board for the EPA, Sept. 1990)

### 7.3.1.2 Environmental Risks

The definition of environmental risk is subjective, but could be considered as threats to the natural environment or activities that adversely change the natural environment. The Science Advisory Board (SAB) to the Environmental Protection Agency identified environmental problems and grouped them into high-, medium-, and low-risk categories (SAB, 1990). The grouping is relative and presented in Table 14. The listing within the groups is not intended to represent a ranking.

Generally the group ranking descends from global, diverse, and difficult to measure issues to local, focused, and more easily measurable issues. High environmental risks generally are global in nature; ozone depletion and global warming are diverse, difficult to measure, but with potentially dire consequences. Habitat alteration and destruction and species extinction are high risk issues in terms of aggregate, worldwide impacts and irreversibility. There is concern about accelerated depletion of essential ecological systems and premature extinction of numerous species.

### 7.3.1.3 Mining and Environmental Risks

As with most industrial activities, there are environmental concerns and issues associated with mining operations. The development of a new mining operation generates numerous questions from the regulators and the public. One means of placing these questions in perspective is to compare them with the environmental risks identified by the Science Advisory Board. A proposed mining operation involving large surface disturbances such as open pits, large waste rock piles, large tailings impoundments, extensive roads, and lengthy power transmission lines will possibly alter habitats and impact critical habitat for sensitive native species. Habitat alteration and destruction are deemed high-risk problems by the SAB. Even without extensive surface disturbance, a project could be considered to be altering habitat by introducing or increasing the number of humans to an area.

Another significant issue is impact to high quality waters. Many new mining projects are located in remote or pristine locations and water quality in adjacent streams is likely to be higher than would be experienced in other areas. A mining operation could affect water quality through discharges of metal bearing mine water, sediment, and nutrients. These changes in water quality could adversely affect aquatic life and considered beneficial uses. Even if they did not, there are increasing expressions to maintain high quality waters for intrinsic value. Changes or degradation of these high quality waters is considered as both medium- and low-risk problems by the SAB; and a proposed mining operation in the vicinity of high quality surface waters will likely generate significant concerns.

Problems associated with acid drainage from mining operations are well known and documented. In numerous cases, mine drainage has had detrimental effects on aquatic life from dissolved metals and dramatic changes in aesthetic characteristics from the deposition of iron hydroxides. Considerable understanding of the problem has been attained and technology is developing and evolving to deal effectively with it. Unfortunately, few individuals outside of the mining industry know of the progress that has been made, and acid generation will be considered a significant environmental risk for a long time.

Abnormal sediment runoff from mining sites also represents a significant environmental risk. High turbidity interferes with the life sustaining functions of aquatic organism accustomed to "clear" water. Sediment deposition interferes with fish spawning and reduces the aesthetic value of a stream.

Elevated levels of nutrients in surface waters are a classical water quality issue, but in the past several years they have become a pronounced problem for the mining industry. The use of nitrogen based explosives results in the release of nitrogen compounds to mine waters and mine wastes. Discharges of mine water or runoff from mine sites can contain elevated levels of nitrates and nitrogen compounds and thus increase concentrations in surface waters. These increases can result in "undesirable aquatic growth" (algae) in the receiving water.

### 7.3.1.4 Magnifying Factors

The environmental problems listed above are expressed more specifically in laws, regulations, and administrative actions. These expressions often define specific uses of land or define strict water quality requirements or are strong external forces that influence the permitting process. These situations add to and magnify general permitting problems. They leave little room for natural resource development. Some of these conditions are:

- Restricted Areas (Single Use Lands)

  National Parks
  National Monuments
  Wilderness Areas
  Wilderness Study Areas
  Wild and Scenic Rivers

- Threatened and Endangered Species (and lands being specifically managed for T & E Species)

- Stream classifications (anti/non-degradation)
- Wetlands
- Zoning Restrictions
- Stringent State Regulations
- Negative Permitting Agency
- Adverse Public Sentiment

The possibility of any of these conditions should be carefully evaluated before engaging in any exploration or development program.

#### 7.3.1.5 Historically Mined Sites

Developing new operations on historically mined sites presents several potential problems. Besides potential future impacts of a proposed operation, there may be a need to address past impacts. This may range from picking up and removing debris to remediating and controlling releases of metals to groundwater or surface water. Requests for permits will provide the agencies the opportunity to request corrective actions for historical problems. Further, there could be outstanding requirements to reclaim the property. On the positive side it may be possible to incorporate these potential liabilities into a program that resolves a long standing agency problem which could facilitate the permitting of the new operation.

Releases of metals from a historical mining site may be found in blowing dust or surface water and groundwater. If there are releases they may be subject to clean up actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA--Superfund). Generally releases of hazardous substances at mining sites are low concentrations and considered low risk to human health; consequently they receive low priority treatment as far as the National Priority List is concerned. Even though the site may not be high risk to human health, there may be potential natural resource damages that would create remediation pressures.

Other potential problems that could complicate the permitting of a new operation at a historically mined area is the presence of hazardous substances. There could be contaminated soil and groundwater from misuse of solvents and other organic compounds. The historical use of solvents and other organic compounds in and around machine shops and garages often resulted in the residues being thrown out the back door. Other common hazardous substances likely to be found at historical mining sites are asbestos and Polychlorinated Biphenyl (PCB's). Also, underground storage tanks are problematic and require removal or licensing and upgrading. These situations are not likely to prevent a new operation from being permitted, but it are likely to require new programs to eliminate, clean up, or upgrade management of them.

### 7.3.2 BASELINE DATA REQUIREMENTS

#### 7.3.2.1 Aesthetics
**by D. Brown**

##### *7.3.2.1.1 Introduction*

Evaluation of project aesthetics is typically required by permitting agencies as one of the considerations during the process of assessing environmental impacts. Compared to many of the other environmental impacts associated with mining, changes to the visual character of a site are usually obvious, even to the casual observer. This issue, therefore, commonly receives a high degree of public interest. Early consideration of potential visual effects is important in project planning since requirements are often influenced by the anticipated aesthetic outcome of mining.

A visual impact analysis is accomplished to determine the type and magnitude of the effect and assess how the changes "fit" with the existing or desired character of the area. For architectural projects, aesthetic concerns may focus on developing a visually pleasing project that may or may not attract attention or conform to the existing character of the area. For mining projects, as for other industrial land uses, the aesthetic goal is typically for the project to conform with the surrounding environment and to attract as little visual attention as possible.

In order to provide an effective analysis, the existing character of the site and surrounding area must be accurately documented, and the effects of the project must be objectively assessed. The aesthetic effects should be evaluated in terms of the degree of change. Whether this change is determined to be positive, negative or inconsequential will be a matter of personal perceptions by the public and decision makers, and/or the guidelines of the permitting agency.

Mining activities usually create surface disturbances that have a noticeable impact on the visual character of a site. Vegetation is removed. Topographic changes occur from removal of ore and waste rock. The degree of impact is largely related to three factors:

- The type of mining operation (open pit, strip, underground, etc.), and the related volume of materials removed and replaced;
- The environment in which the mining is conducted (urban versus rural, arid versus mesic); and
- The planned reclamation for the site.

The changes are usually permanent or at least long term. Reclamation and revegetation, if successful, can reduce the potentially undesirable aesthetics. Proper consideration of these effects can result in a more

environmentally acceptable project and assist in the permitting process.

The following discussion provides an approach to evaluating the aesthetic impacts of mining projects. The focus of the discussion is on methods for proper characterization of the existing environment (establishing the baseline conditions), since the specific methods and requirements for evaluating aesthetic impacts must be developed on a project and site-specific basis. However, because an understanding of the analysis to be completed is critical to gathering the proper baseline data, an overview is first provided of common approaches to conducting a visual analysis.

#### *7.3.2.1.2 Visual Resource Analysis*

Although evaluation of aesthetic impacts is commonly required as part of the environmental impact assessment of mining projects, guidelines for conducting the analysis if they exist, vary among agencies, and the criteria for determining the importance of the results vary considerably. In part, this is because mining is an atypical development for many agencies. Some local agencies may be faced with mining project applications only rarely. Since the type and scope of mining activities do not typically conform to established development codes, visual guidelines (such as those common to architectural review) cannot be reasonably codified. The methods to be used and criteria for which the project will be judged will therefore generally be developed for each project. It is therefore important to coordinate with agency staff to develop and obtain consensus on the approach.

The aesthetic effects analysis should consider both the mine's operating period and following reclamation. The goal for aesthetics during the active project will typically be for the project to minimize its effect in attracting visual attention. The post reclamation goal is dependent upon the planned subsequent use of the land. For purposes of discussion, we will assume that the subsequent use will be open space/wildlife habitat, a common land use objective with the goal of visual continuity with surrounding lands.

The following sections summarize key considerations in completing a visual impact analysis.

##### *7.3.2.1.2.1 Establishing Baseline Conditions*

Characterization of the existing visual conditions for the site and surrounding area is a relatively straightforward process:

- The aesthetics of the site are described for each dominant feature (topography, vegetation cover and existing surface disturbances)
- Viewpoints that are representative are selected and the site is photographed.

This process of categorizing and documenting the existing features that make up the visual environment (including the selection of viewpoints, and timing of photographs) is discussed in more detail in Section 3.0

##### *7.3.2.1.2.2 Determining the Scope of the Project*

*The Mine Plan.* The anticipated aesthetic impacts of the project will influence viewpoint locations, since the point of the analysis will be to show project changes. A preliminary mine layout, and final elevations should therefore be known prior to selecting viewpoints.

A mine plan showing areas affected by mining, waste disposal, and processing is necessary. The locations and alignments of other ancillary facilities such as buildings, access roads, utility lines and temporary stockpile areas should also be considered. In addition to the locations of facilities, the elevations of cuts and fills are needed. Other project facilities or activities that could affect aesthetics, including lighting and the movement of equipment should also be considered.

Opportunities to address aesthetics should be considered early in the process of project design. Waste rock dumps can sometimes be planned in configurations that minimize "straight line effects", at minimal additional cost. Pit configurations for quarries can also be varied. Considering the aesthetics early in the project is important, since the cost of reconfiguring large volumes of rock later on will typically be prohibitive. Creative mine plan phasing can also be used to help mitigate aesthetic effects.

*The Reclamation Plan.* The reclamation plan should indicate where revegetation and earthwork will be performed for aesthetic purposes. Plant species that are native or naturalized and conform to the surrounding undisturbed plant communities should generally be preferred over invasive, weedy species that may be easier to establish, but compete for water and nutrients and can delay natural succession.

Other than vegetation, the factor most affecting aesthetics will be the shape of landforms created by the project. Large flat surfaces and cuts/fills with straight lines (such as building pads, waste rock piles, leach pads, benches and roads) are uncharacteristic of nature. Naturally configured drainages and effective erosion control will reduce the potential non-conforming features that attract visual attention. Aesthetic-related earthwork may include reducing slope angles to "soften" the straight line appearance, and recontouring roads and building pads.

*7.3.2.1.2.3 Evaluating the Visual Changes*

*Simulating Project Changes.* In order to evaluate the visual impact, a written description and pictorial rendering of the changes are usually prepared. Various methods can be used:

- The changes can be verbally described and supported with a minimum of graphics, such as cross sections. Photographs of project elements such as mine pits, conveyors, and waste rock piles at other similar operations may be helpful. This is the least costly method, and may be successful, depending on the complexity of the project and visual environment. Where project aesthetics are important, this method may leave too much to the imagination.
- An artist's sketch or painting simulating the project at completion (with reclamation) can offer a good mechanism for evaluating the final aesthetics and comparing the change to the existing condition. Paintings are most useful when the project changes are shown directly on a photograph of the site and in the context of the surrounding visual environment. Computer programs are also available that can be used to alter an existing photograph to show the project changes. Three-dimensional computer views of digitized project topography can also be superimposed on an electronically scanned photograph for an accurate simulation.
- Physical three-dimensional topographic models are accurate and useful where large topographic changes are planned. Models are especially helpful in public meetings as they enable people to "see and feel" the project. The model can facilitate descriptions of the anticipated physical changes; photographs of the model can be used in permit documents. The use of such models is limited by their expense, the inability to modify them to reflect project design changes, and their weight and bulk that makes them difficult to transport.

The key features that are important to show in simulations are the changes in topography, color, and vegetation. If the project operations will be long-term, buildings and ancillary facilities should also be depicted.

*Analyzing the Effects.* Many visual impact analyses conclude with the results of the visual simulation. Experience indicates that indeed, the opinions of most reviewers will be formed based upon preconceived expectations for reclamation, and aesthetic preferences influenced by the simulations. However, a critical evaluation of the aesthetic changes demands further analysis.

Using well defined and commonly accepted terms to describe the existing environment can assist in evaluating the aesthetic changes. The US Bureau of Land Management Visual Resource Management handbook (BLM, 1980) provides a list of terms, as well as a numerical method to evaluate aesthetic changes. Numerical methods can be useful, especially at sites where visual resource management is an important objective of land management practices. The primary advantage is that it provides for consistency in analysis, which is important when extensive lands and numerous projects must be evaluated. However, use of a numerical analysis may unnecessarily complicate the analysis of a single project. It is usually adequate to describe the major features (land surface, vegetation and structures) and discuss how they would change in form, line, color and texture, with the proposed project.

Important changes may include:

- Changes in topography, or construction of buildings or other man-made structures that would obstruct or degrade a scenic view.
- Changes in soils or vegetation or the introduction of structures that result in a sharp color contrast.
- Straight lines or unnatural shapes (such as roads and buildings).
- Features that change the skyline.
- Introduction of artificial lighting.
- Conditions that would produce significant windblown dust.
- Movement of vehicles and equipment.

Although most mining projects will produce some of these effects, the issue of concern is usually whether the effect will dominate the viewscape and attract the eye. Once the project effects are understood, it is appropriate to consider them in light of when, by whom, and under what circumstances the project would be observed. Considerations may include:

- From what distance will the project be seen? Is it part of the foreground or background view?
- How often will the project be seen? What degree of access is there to the site? How many passersby would there be on a daily, monthly or seasonal basis?
- What would be the duration of observance? Passersby on a freeway may only see the site for several seconds. Hikers/campers and surrounding property owners could observe the site for lengthy periods.
- By whom will the project be seen? Will the project be seen by uninterested commuters, by hikers desiring a wilderness experience, or by neighbors with different expectations for views of surrounding properties? How important will the changes be in light of viewer expectations?
- Under what circumstances will the site be seen? Will it be viewed in the context of other mining and

development, or with relatively undisturbed lands? Is the project located in an area (or on an access route to) lands managed, in part, for scenic resources (such as a National Scenic Area or Scenic Corridor)?
- How long would the visual effects be evident? How long will the project operate and how long will it be until reclamation efforts reduce the visual contrasts?

At some point, the analysis will need to judge whether the project's aesthetic changes are acceptable. This is where personal preferences often come into play. An attempt should be made, however to withhold one's own personal value judgments; the focus should be on the acceptable degree of change in accordance with the permitting agencies' guidelines, or on the degree of contrast between the site and surrounding area. Weak contrast changes that will not attract the attention of the average observer may not be an issue. Strong contrast that attracts attention may be less acceptable.

*7.3.2.1.2.4 Mitigation*

Because mining necessarily creates potentially large scale surface disturbances and introduces heavy equipment plus processing and support facilities, the opportunities to mitigate negative aesthetic changes can be limited. Obviously, underground mines, coal strip mines, open pit metals mines, and quarrying all have different design and operational requirements that dictate the larger reclamation parameters. The aesthetic management objectives and public and agency expectations will need to be reevaluated at this stage to ascertain if they are reasonable in light of what can actually be achieved.

Often the best aesthetic mitigation is a design that engineers land forms to imitate the irregularities found in nature. Differential placement of waste rock to reduce straight line effects, and the siting and orientation of buildings, roads and other features with respect to viewers can significantly alter potentially negative effects. Straight lines and flat surfaces can be recontoured, and backfilling of pits (where feasible) can modify the site at the time of reclamation. Grading for proper drainage and other surface management techniques to control erosion are important. A well conceived and implemented revegetation program can be extremely effective in reducing color contrasts.

Other measures commonly employed include:

- Selected placement of those facilities that have some design flexibility such as buildings and utility lines.
- Use of paints that blend with the landscape.
- Selective use of artificial lighting (where safety is not compromised). Use of shielded and directed lights that minimize fugitive light on adjacent properties.
- Where cuts reveal fresh rock of contrasting color, utilization of commercial rock stains can minimize the contrast.

***7.3.2.1.3 Documenting Existing Conditions***

Documenting existing conditions is typically a photographic exercise. The objective of documenting existing conditions for any environmental issue is to accurately represent the environment prior to the implementation of the project. The "existing" aesthetic conditions are, however, influenced by several factors, such as site access and the viewpoints selected, temporal conditions (including weather, season, sun angle), and the photographic equipment and printing. The manner in which the existing site is portrayed has an influence on the manner in which it will be perceived with the project changes. This section discusses these key factors, including:

- Camera and lens selection, and printing.
- Viewpoint selection.
- Timing of photographs.
- Characterizing the existing conditions

*7.3.2.1.3.1 Photographic Equipment and Printing*

The equipment used and format in which the photographs are taken and printed will affect the reviewers perceptions of the aesthetic environment. The challenge in this regard is reproducing on paper as close as possible what an observer would see if he/she were actually on the site. This is complicated since the human eyes generally have a wider field of view than a camera, as well as seeing three-dimensionally. Acknowledging these limitations, photographers should attempt to minimize distortion by selecting appropriate camera and lens. Film and reproduction scale are also important. Photographs to be used in the analysis should therefore be taken be experienced personnel, with the following considerations in mind:

- *Camera and Lens Selection*: The camera should be of good quality, typically a 35mm or larger film format. Lens distortion is generally greater in less expensive cameras. A 50 or 55mm lens will most closely reproduce the landscape as it would be viewed by an observer. Wider angle lenses (35mm or less) distort the shapes of objects to fit more onto the film.

- *Film Selection:* Since color contrast is an important aspect of aesthetics, color film is a must. The brand of film, its age, exposure to heat, and its original intended use (indoor or outdoor) will affect color. The film speed (the ASA) will affect the graininess of the print.

- *Print Format:* Although influenced by film speed, photograph enlargement quality is related to film format (size). Graininess and distortion increase as the size of a photograph increases. The maximum enlargement (while still maintaining picture quality) for 35mm film is generally 8" X 10" picture. Ideally the photograph will be printed at a scale that shows objects at the approximate scale as they would be seen if the reader were standing where the photograph was taken.

*7.3.2.1.3.2 Considerations in Selecting Viewpoints*

The viewpoints from which a site is photographed should be selected considering the frequency and sensitivity of views, obstructions, and planned mine facilities.

- *Frequency of Views:* The number of times a site is seen on a daily, monthly or seasonal basis should be a determinant of viewpoint selection. Although the aesthetic changes may be the of the greatest magnitude to an individual standing on or adjacent to the site, the most common public viewpoints will typically be on roadways surrounding the site. While the magnitude of the changes as viewed from on-site should be addressed, it is more appropriate to consider the aesthetic changes in the context of the surrounding environment from common viewpoints.

- *Sensitivity of Views:* Viewpoints that may be considered sensitive include those located on or within:

  Adjacent to privately owned properties,

  Wilderness areas or other areas managed, in part, for scenic resources,

  Designated scenic highways, and

  Locations from which a large number of people will view the site.

- *Obstructions:* For a visual analysis, what is not seen is as important as what is. Although viewpoints are often selected for illustrative purposes from the best possible location to observe a project, it should be clear as to what locations the project can reasonably be observed. Aerial photographs are therefore generally inappropriate. It may be important to take photographs from surrounding viewpoints demonstrating that elements of the project will not be seen.

- *Distance:* A landscape scene can be divided into three basic distance zones: foreground/middleground, background and seldom seen (BLM, 1980). The viewers' attention to foreground/middleground areas is greater than it is to distant views. Distance also affects an observer's parallax; so while foreground/middleground objects are seen three dimensionally, background features appear two-dimensional. The importance of project changes will therefore be diminished as distance increases. View points should be selected that are representative.

*7.3.2.1.3.3 Timing of Photographs*

Weather, season and time of day alter site aesthetics. The degree of perceived aesthetic impacts of the project can increase or decrease depending on these conditions.

- *Weather:* Some weather conditions will change the ability to see the site, others will affect its aesthetics. Fog, haze and precipitation may obscure views of the site, or obscure background views, resulting in a highlighting of project changes. Shadows cast by clouds, snow on the ground and saturated soils will affect color and texture of site features. For these reasons, the baseline documentation should indicate what the typical weather patterns are and whether the photographs are representative of weather conditions or "best case" views.

- *Time of Day:* The time of day that a photograph is taken affects shadowing and colors. Morning and late afternoon/evening periods with low sun angles produce long shadows and changes in color. Midday hours are typically the best to photograph to minimize these effects.

- *Season:* Weather and sun angle affecting site aesthetics also vary by season. Dramatic changes in vegetation growth and color can occur seasonally as well as annually.

*7.3.2.1.3.4 Characterizing the Site and Surrounding Area*

To provide a basis for the analysis, existing aesthetics (based on the photographs and viewpoints) must be described in a manner that facilitates objective comparison. This is accomplished by first segregating the landscape into its major features: land/water surfaces, vegetation, and man-made structures. The aesthetic characteristics of each feature should be described using accepted and defined terms such as form, line, color and texture. In this manner, the landscape can be described based on its individual characteristics without imposing

judgment of its overall aesthetic value.

The degree of existing surface disturbance and site development is important to note, both in terms of the aesthetic character and the ability of the site to recover. For example, past surface disturbances that have successfully revegetated will provide an indication of how effectively vegetation can be used to mitigate the project effects.

#### *7.3.2.1.4 Conclusion*

The aesthetic effects of mining are an important aspect of the environmental impact analysis, since visual resources will typically be a key consideration in the public acceptability of a project. Agency determinations for reclamation requirements will also likely be influenced by the anticipated aesthetics. Given that mining will be disruptive to the existing aesthetic environment, the issue should be considered in early planning for those aspects of the project that have design flexibility. Since the interpretation of negative and positive aesthetics varies with each observer, the challenge in completing the analysis is in establishing how important the existing aesthetics are, and ascertaining the acceptability of the degree of change.

### 7.3.2.2 Air Quality
**By R. Steen**

#### *7.3.2.2.1 What is Baseline Air Quality Information?*

The three types of information regarding ambient air that are used in connection with air quality impact analyses for proposed industrial facilities, including mines, are baseline pollutant concentrations, atmospheric dispersive potential, and air quality related values. Baseline pollutant concentrations are background regional concentrations plus impacts from existing nearby sources that exist in the area of a proposed facility prior to construction. Atmospheric dispersive potential is the ability of the atmosphere to disperse emitted pollutants, and is represented by meteorological parameters. Air quality related values include visual range, the health of commercial crops, soil quality, and biological and hydrological conditions in areas of special consideration (i.e., Class I areas).

Because most mining projects are sufficiently small that they do not have to address air quality related values, only baseline concentrations and atmospheric dispersion potential are important and will be discussed further herein.

An important concept concerning all air quality baseline information is "data representativeness," or whether a particular data set is representative of a particular place and time. Both baseline concentrations and atmospheric dispersive potential can vary with both location and time (from hour to hour, seasonally, and with longer term trends) due to factors such as variable emission rates of nearby sources, atmospheric conditions, and regional pollutant concentrations.

**Table 15** Summary of National Ambient Air Quality Standards (NAAQS)(1)

| Pollutant | Averaging time | ($\mu g/m^3$) |
|---|---|---|
| $CO_2$ | 8 hour | 10,000 |
| | 1 hour | 40,000 |
| Pb | Calendar year | 1.5 |
| $NO_2$ | Annual | 100 |
| Ozone (2) | 1 hour | 235 |
| PM10 | Annual | 50 |
| | 24 hour | 150 |
| $SO_2$ | Annual | 80 |
| | 24 hour | 365 |
| | 3 hour | 1300 |

(1) *National standards, other than those based on annual averages, are not to be exceeded more than once a year (except where noted).*

(2) *The ozone standard is attained when the expected number of days per calendar year in which the maximum hourly average concentration is above the standard is equal to or less than one.*

#### *7.3.2.2.2 Uses of Baseline Information*

Both baseline pollutant concentration data and meteorology data are useful in air quality analyses. Baseline concentration data are added to the estimated impacts from an industrial facility to demonstrate that the health-based ambient air quality and welfare standards will not be violated. Dispersion meteorological data are used in conjunction with proposed emissions information in analytical dispersion models to estimate the air impacts from a proposed facility as a function of time and location.

#### *7.3.2.2.3 In What Regulatory Processes is it Used?*

Baseline information is needed for environmental impact

evaluations, which can be required as part of the application process for air emission permits and environmental impact analyses under various federal, state, and local regulations, such as the National Environmental Policy Act (NEPA). Depending on the particular regulation, these impact analyses address impacts in relation to either absolute or incremental ambient standards. The absolute air quality standards are not to be exceeded by the total of baseline pollutant concentrations and predicted impacts from the proposed facility. On the other hand, the incremental standards limit only the increased pollutant concentration resulting from the proposed facility. The air emission permitting processes provide the more clearly defined methods acceptable for estimating impacts and exempting sources because of small size from the various impact analyses, including collection of baseline data. The degree of detail acceptable to the NEPA-type impact analyses is less well defined.

#### *7.3.2.2.4 What Are the Ambient Standards?*

Ambient standards are pollutant concentration limits that must be met in all locations to which the general public has access. Absolute standards have been defined for the purpose of protecting human health and welfare, and incremental standards are intended to prevent significant deterioration of the air quality.

National ambient air quality standards (NAAQS) (absolute standards), defined in 40 CFR Part 50, have been promulgated for the six criteria air pollutants; sulfur oxides ($SO_X$), particulates (PM10), nitrogen dioxide ($NO_2$), carbon monoxide (CO), ozone ($O_3$), and lead (Pb). These standards, listed in Table 15, are to be met in all areas accessible to the public in the United States. Individual states and air districts have the ability to instate standards more restrictive than the NAAQS for the criteria pollutants, and regulate concentrations of other pollutants as well.

National incremental standards have also been promulgated for $SO_X$, PM10, and $NO_2$ (see Table 16). These incremental standards are enforced during permitting of a major stationary source under the Federal New Source Review program. Sources not classified as major do not usually need to address the incremental standards. The incremental standards are defined separately for each basin classification (i.e., Class I, Class II, and Class III). Class I areas, designated as such in the 1977 Clean Air Act Amendments, are areas requiring special protection, such as national parks and wilderness areas. Much of the rest of the country is designated as Class II. A Class III designation is reserved for areas where greater deterioration is allowed. Few, if any, areas have been designated Class III.

**Table 16** Prevention of Significant Deterioration Incremental Standards[1] ($\mu g/m^3$)

| | Class I | Class II | Class III |
|---|---|---|---|
| Sulfur Dioxide | | | |
| Annual | 2 | 20 | 40 |
| 24-hour | 5 | 91 | 128 |
| 3 hour | 25 | 512 | 700 |
| Total Suspended Particulates | | | |
| Annual | 5 | 19 | 37 |
| 24-hour | 10 | 37 | 75 |
| Nitrogen Dioxide[2] | | | |
| Annual | 2.5 | 25 | 50 |

[1] *Short-term increments not to be exceeded more than once per year.*
[2] *Proposed increment only, not finalized.*

In addition to the air quality standards discussed above, there are incremental concentration limits called "significant impact" thresholds (Table 17) in non attainment areas and "de minimis" impacts (Table 18) in all other areas. Although these limits are not air quality standards, they are used in the federal new source review process and in many state permitting programs to determine emission control levels and baseline concentration information gathering requirements.

#### *7.3.2.2.5 When Are Baseline Monitoring Programs Required Or Advantageous?*

Baseline monitoring programs are to be established only when baseline information is required, and no information exists that is both acceptable in quality and representative of the particular location and the present time. The representativeness of an existing pollutant concentration data set is determined subjectively by considering both the location and time of the recorded measurements; the representativeness of a meteorological data need only be representative of location. The decision on the need for baseline monitoring is made separately for concentration and meteorological information.

Because an ambient air quality monitoring program is expensive in terms of both cost and time delay, it is

**Table 17** Nonattainment Area Significant Impact Thresholds

| Pollutant | Annual | 24-hour | 8-hour | 3-hour | 1-hour |
|---|---|---|---|---|---|
| $SO_2$ | 1 | 5 | - | 25 | - |
| TSP/PM10 | 1 | 5 | - | - | - |
| $NO_2$ | 1 | - | - | - | - |
| CO | | - | 500 | - | 2000 |

**Table 18** De Minimis Concentrations

| | | |
|---|---|---|
| Carbon monoxide | 575 $\mu g/m^3$ | 8-hour average |
| Nitrogen dioxide | 14 $\mu g/m^3$ | annual average |
| Particulate matter | 10 $\mu g/m^3$ TSP | 24-hour average |
| Particulate matter | 10 $\mu g/m^3$ PM10 | 24-hour average |
| Sulfur dioxide | 13 $\mu g/m^3$ | 24-hour average |
| Lead | 0.1 $\mu g/m^3$ | 3-month average |
| Mercury | 0.25 $\mu g/m^3$ | 24-hour average |
| Beryllium | 0.001 $\mu g/m^3$ | 24-hour average |
| Fluorides | 0.25 $\mu g/m^3$ | 24-hour average |
| Vinyl chloride | 15 $\mu g/m^3$ | 24-hour average |
| Total reduced sulfur | 0.2 $\mu g/m^3$ | 1-hour average |
| Hydrogen sulfide | 0.2 $\mu g/m^3$ | 1-hour average |
| Reduced sulfur compounds | 10 $\mu g/m^3$ | 1-hour average |

usually desirable to find an alternate means of obtaining any required baseline information. Oftentimes a proposed facility can provide a reviewing agency convincing evidence that concentrations are below particular values using other representative and available data sets. However, if the background values from an off-site data set, in conjunction with estimated impacts, are not low enough to demonstrate compliance with the ambient standards and there is reason to believe that an on-site monitoring program would show lower baseline concentrations, then the baseline concentration monitoring program may be a useful investment.

With respect to meteorological data sets, the U.S. EPA provides a hypothetical worst-case data set to be used with facility emissions to estimate a worst-case predicted impact. If the resulting worst-case impacts show compliance with all applicable ambient standards, there is no value to an on-site meteorological monitoring program. Likewise, if an existing data set, of acceptable quality and length, can be considered representative of the dispersion on site, and the estimated impacts using it are in compliance with all ambient standards, there is no value to an on-site meteorological monitoring program. Oftentimes however, it is the incremental standards that are the most difficult to demonstrate compliance with and on-site dispersion meteorological provides the most representative data.

#### *7.3.2.2.6 Nonattainment Areas*

Certain areas of the United States do not comply with the NAAQS for one or more pollutants, and are therefore designated as "non attainment" with respect to these air pollutants. These areas are generally in or near large cities or major industrial complexes, but can also be in rural locations. Sources located within these non attainment areas must address special non attainment permitting procedures for the pollutants designated as non attainment. Both the trigger threshold for federal New Source Review and state facility permitting, and baseline data requirements are specific to the non attainment area.

Once an area is designated as non attainment and a facility is classified as a major stationary source (MSS) triggering federal New Source Review requirements for a particular pollutant, permitting of emissions of that pollutant is subject to the non attainment permitting regulations. These regulations apply regardless of whether the concentration of that pollutant at a particular location within the non attainment area (i.e., where the facility is to be located) is actually above or below the NAAQS. One advantage of non attainment status is that there is no requirement for baseline concentration information on any pollutant for which an area is designated non attainment. However, dispersion

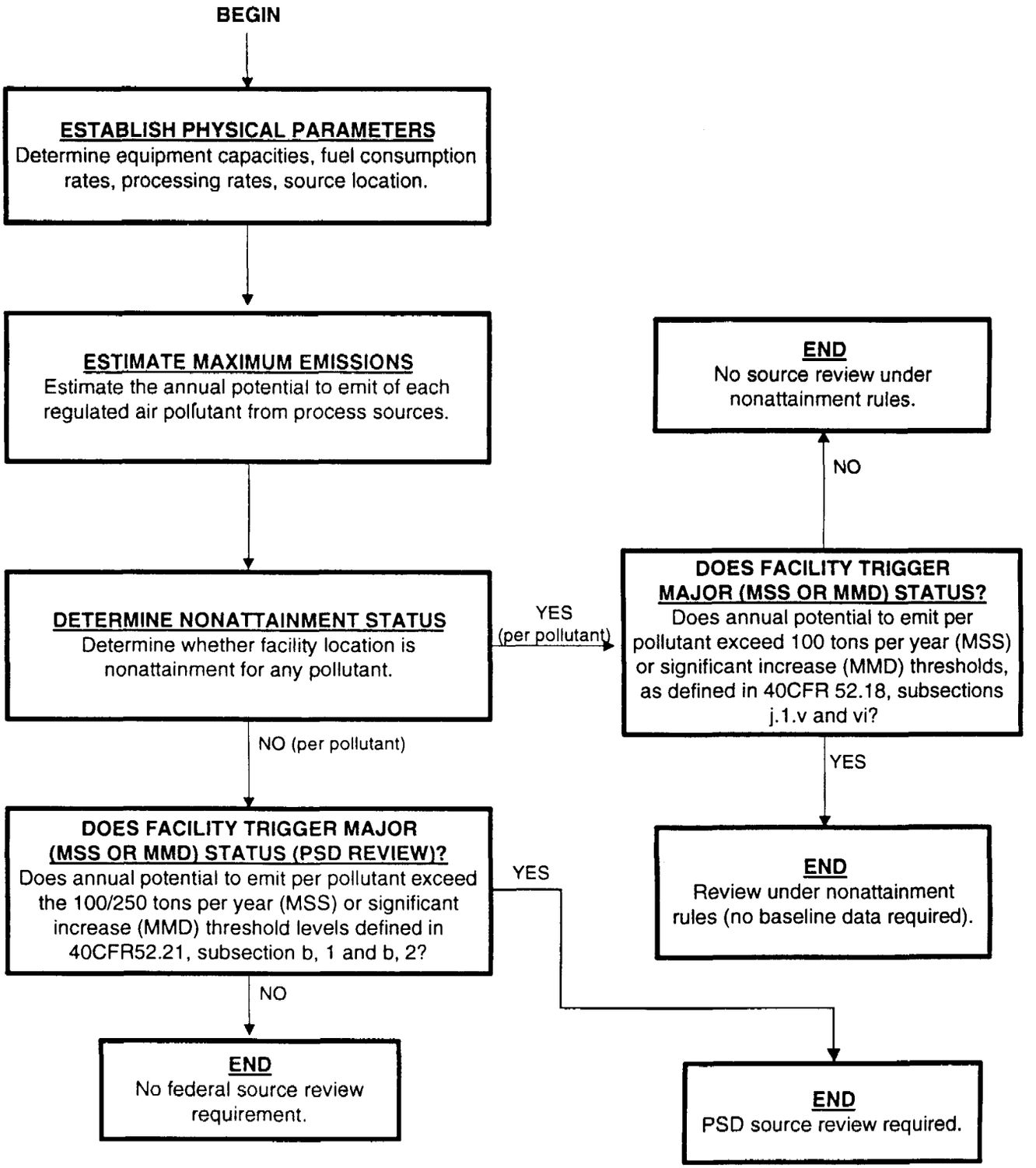



**Figure 1** Federal Program Applicability Determination.

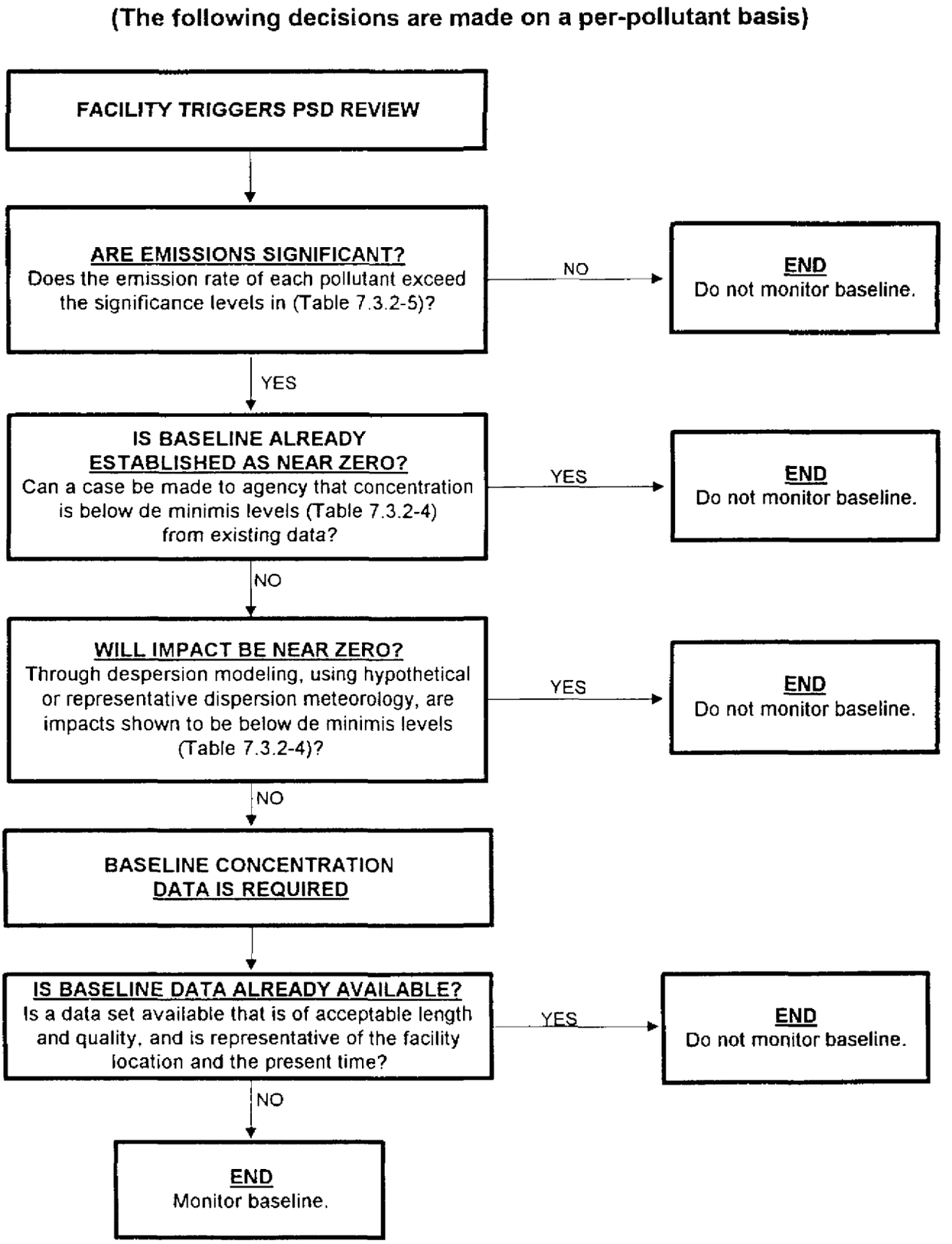



**Figure 2** Determination of Need for Baseline Concentration Monitoring (Under Federal PSD Review).

meteorology may be required to demonstrate that impacts will be insignificant.

#### *7.3.2.2.7 The Prevention of Significant Deterioration (PSD) Program, Applicability Threshold and Baseline Data Requirements*

If a proposed facility located in an attainment area is sufficiently large (most mining facilities do not meet this criteria), it will trigger the federal New Source Review program, hereafter referred to as the "Prevention of Significant Deterioration (PSD) review program." There are very specific requirements for baseline information in this program. Although this program is only applicable to large sources, federal impact analysis requirements under NEPA, and state and local permitting requirements for smaller sources are usually similar in many ways, including baseline information gathering requirements, to the requirements for PSD permitting.

The federal PSD review requirements, provided in 40 CFR 52.21, describe the logic for determining whether a source triggers the review process and the associated ambient data requirements. (The decision-making process for determining whether a facility is subject to the federal review program is presented in Figure 1.) To trigger federal PSD review a source must be classified as a major stationary source (MSS) or major modification (MMD), as defined in 40 CFR 52.21, b.1 and b.2, respectively. The trigger threshold for mining facilities (without significant associated processes such as coal cleaning, steam-generation or smelting) is 250 tons per year of any single process-generated (i.e., emitted through or reasonably able to be emitted through a stack) regulated pollutant regulated under the 1977 CAA. Road dust from traveling mine vehicles and other types of fugitive dust are not counted in this applicability determination. Particulate emissions (from crushing facilities, etc.) are most likely to trigger MSS status for new mines. A modification is classified as major when the process emissions of a regulated pollutant at a major stationary source undergo a "significant" net increase. (Significance levels are provided in Table 17.)

Once a facility triggers the PSD review program, certain baseline air quality data may be required. The decision-making process on requirement for data involves an estimate of the potential emissions and potential impact of each regulated pollutant. Baseline information and impact evaluation may be required for all pollutants with emissions above the significant level shown in Table 19. The PSD regulations also specify the incremental concentration increases (Table 18) considered "de minimis," under which no further impact analysis or baseline data are necessary. The decision-making process for determining the need for monitoring baseline concentration is presented in Figure 2.

**Table 19** Significant Emission Rates

| | |
|---|---|
| Carbon monoxide | 100 tons per year |
| Nitrogen oxides | 40 tons per year |
| Sulfur dioxide | 40 tons per year |
| Particulate matter (TSP) | 25 tons per year |
| Particulate matter (PM10) | 15 tons per year |
| Ozone | 40 tons per year VOCs |
| Lead | 0.6 tons per year |
| Asbestos | 0.007 tons per year |
| Beryllium | 0.0004 tons per year |
| Mercury | 0.1 tons per year |
| Vinyl chloride | 1 ton per year |
| Fluorides | 3 tons per year |
| Sulfuric acid mist | 7 tons per year |
| Hydrogen sulfide ($H_2S$) | 10 tons per year |
| Total reduced sulfur (including $H_2S$) | 10 tons per year |
| Reduced sulfur compounds (including $H_2S$) | 10 tons per year |

Notwithstanding the table above, significant means any emissions rate or any net emissions increase associated with a MSS or MMD which would be constructed within 10 kilometers of a Class I area, and have an impact on such area equal to or greater than 1 mg/m3 (24-hour average).

Ozone, lead, and carbon monoxide monitoring are usually not required for mining facilities. If no substantial on-site drying or metal conversion by heat or power generation facilities exist, nitrogen dioxide and sulfur oxides monitoring are usually not required either. In addition, even when such associated facilities exist, if the baseline concentration for a specific pollutant is expected to be below "de minimis" concentration levels, listed in Table 18, no monitoring is required for that pollutant. In the case of mines that are a great distance from urban and industrialized areas, it is generally understood that all listed pollutants, except dust, its natural constituents, and ozone, will be below de minimis concentrations. Lastly, baseline monitoring is not required if the source is anticipated to have an impact below the de minimis concentration. Therefore, for mining operations, it is often only the PM10 concentrations that need to be monitored.

There are no federal requirements for monitoring dispersion meteorology under any permitting or impact assessment requirements. However, there are requirements for performing dispersion modeling of impacts, and it is often to the advantage of the applicant to measure the dispersion meteorology on or near site

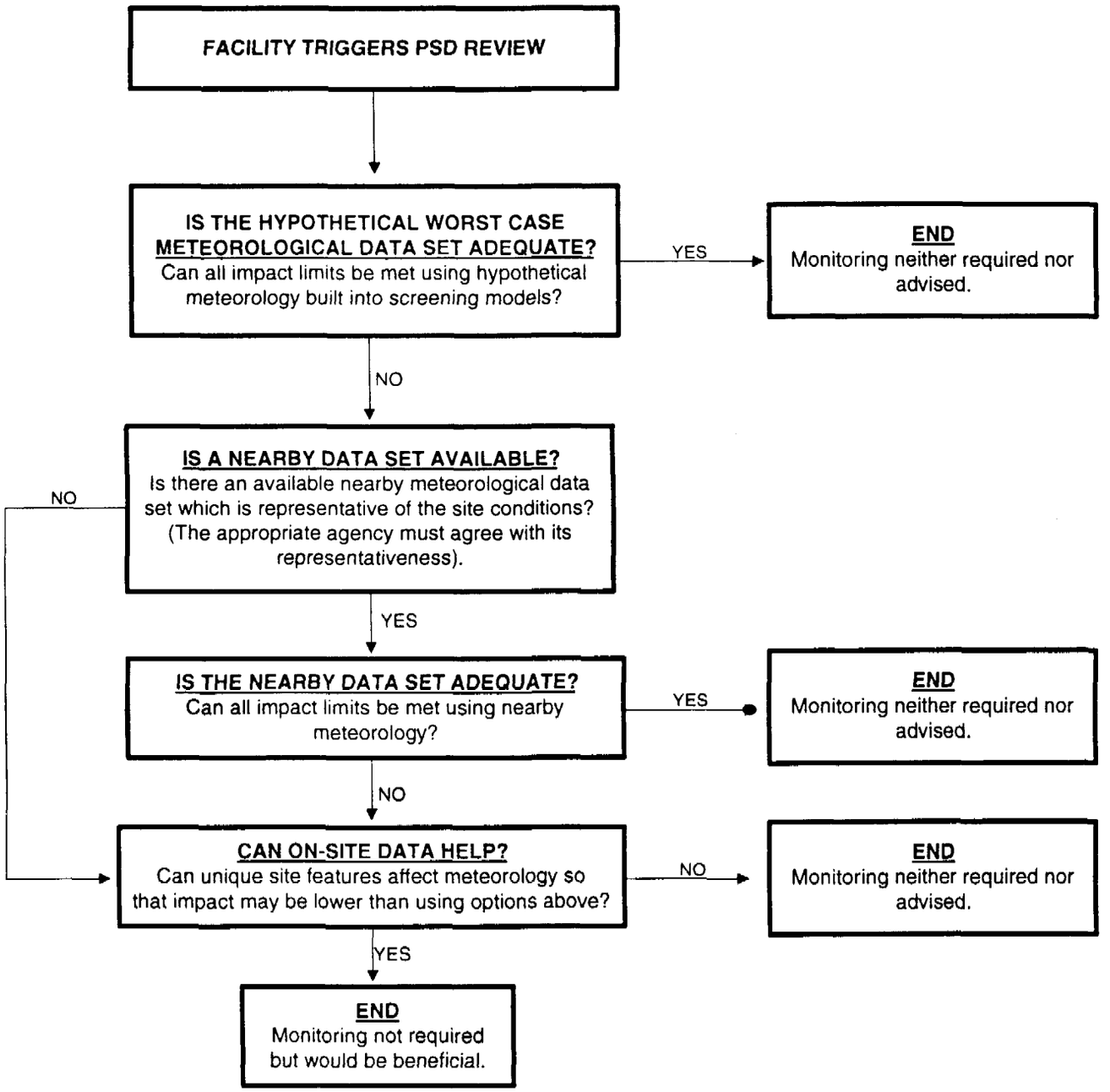



**Figure 3** Determination of Need for Dispersion Meteorological Monitoring (Under Federal PSD Review).

rather than using a more conservative hypothetical or off-site data set. The decision process for monitoring dispersion meteorology is shown in Figure 3.

#### *7.3.2.2.8 Baseline Concentration Monitoring*

Most states have developed emission permitting programs for sources well under the PSD review size and these programs include some degree of environmental impact review, generally not as stringent as that for PSD. A state or local government can assume enforcement authority of the federal program by developing its own New Source Review program with requirements at least as strict as the federal program. Oftentimes these PSD review programs are integrated into the more broadly applicable permitting programs, but with less stringent permitting requirements for smaller sources exempted from the PSD program. Baseline dispersion meteorological monitoring is routinely performed for PSD facilities because PSD facilities are subject to a demonstration of compliance with the PSD increment impact concentrations, often the most difficult component of impact analysis. Mining facilities are usually under the size trigger for federal

(both PSD and Title V) review, do not have to address increment consumption (in most states), and respond only to state or local review, the requirements of which are variable.

#### *7.3.2.2.9 How Is Baseline Data Judged?*

Whether a particular set of data is "representative" is an issue of judgment, beyond the federally established minimum quality and length requirements. For data sets not collected on site immediately prior to impact review, representativeness is a question of capturing a sequence of conditions, typical of the location and the present time. Since the more stringent ambient standards address extreme values and statistics (i.e., the worst or highest hour, three-hour, or 24-hour event to be measured or expected in a year), the baseline data set typically must cover one year. In special circumstances, where a pollutant concentration is known to peak during a single season, it is acceptable to use a four-month data set. These EPA-defined minimum limits for on-site data sets help in defining "representative" for off-site data sets. When airport data are used, EPA considers a five-year set as representative.

#### *7.3.2.3.10 Duration of Monitoring Programs*

The federal program, as well as most states, require that pollutant concentration and meteorological monitoring cover a minimum of one year of hourly averaged data collected on site. In some cases, baseline concentration data can be monitored over a period as short as four months when the applicant provides convincing evidence that the shorter period provides a high-side representation of the full year. For instance, carbon monoxide concentrations tend to be maximum in winter months and ozone concentrations tend to be maximum in the summer months, and the concentrations measured during these seasons can be considered representative of a worst-case year. Proving that other pollutants have seasonal maxima is more difficult.

The federal regulations also require that pollutant concentrations be monitored the year prior to applying for the air permit. Experience shows that this requirement is liberally interpreted, and if the data set can be considered representative of the prior year, it will be acceptable. The meteorological monitoring guidelines state that when a permit condition (i.e., an emission limit, or limit on operating hours or stack height) is developed from one year of meteorological data, additional data must be collected to insure that the permit conditions have been properly developed. However, it is unclear how the agency would retain the right to alter the permit conditions after permit issuance.

Because the data is to be collected for an impact analysis, collection must be completed before the impact analysis is prepared, which means that data collection must be initiated well before the impact analysis is to be completed. Collection of air quality data is one of the first components to be initiated for an environmental impact evaluation.

#### *7.3.2.2.11 Siting Monitoring Stations*

The guidance for locating monitoring stations states that the monitors must be in a location representative of the conditions on and around the site. For meteorology, the wind sensors are to be located at emission release height (which should be at stack-top height), or a minimum of 10 meters if the sources are surface level. Because the EPA-guideline dispersion models assume a spatially uniform wind field, there is no value in collecting wind data at multiple sites when the source location is known. Regarding baseline concentration, the guidelines require that monitoring be representative of three locations: the location of anticipated maximum impact to which the public would be exposed, the location of maximum baseline, and the location of maximum combined baseline and impact. For isolated facilities, such as most mines, the baseline is usually uniform across the proposed source site and nearby terrain, and baseline can be measured at one location to meet all of these criteria.

#### *7.3.2.2.12 Quality Standards*

The EPA provides guidelines for minimum monitoring standards. These guidelines address the minimum standards for monitor precision, operation of the monitors, siting the monitors, laboratory procedures, quality control methods, minimum acceptable data recovery rates, and minimum quality assurance. For meteorological monitoring, siting procedures, equipment sensitivity and precision, and calculation methods are presented in the guideline On-Site Meteorological Program Guidance for Regulatory Modeling Applications (EPA-450/4-87-013). For air concentration monitoring the applicable guideline report is Ambient Monitoring Guidelines for Prevention of Significant Deterioration (PSD) (EPA-450/4-87-007). The required quality assurance methods for air concentration monitoring are presented in 40CFR 58, Part 58, Appendix B.

The state and local monitoring programs generally refer to the EPA-guidelines for quality issues. As a general rule, if monitoring is to be performed, it should be performed to the specifications listed in the EPA-guidelines, regardless of the permitting agency.

#### *7.3.2.2.13 Monitoring for Compliance*

Compliance air quality monitoring by an industrial

facility is the best means of demonstrating compliance with the NAAQS. The situation occasionally arises, especially with large mines, that there are no alternative means of demonstrating compliance with the PM10 ambient standards, and ambient compliance monitoring is required as an emission permit condition. Because it is expensive, it should be required only when there is a clear issue with meeting ambient standards, and there is no appropriate activity rate or emission surrogate that can be more inexpensively monitored. Monitoring to demonstrate compliance with the incremental standards is not possible when sources are in urban areas or proximal with other sources, but for isolated sources, it is appropriate. Monitoring methods and quality standards are the same as for the impact analysis monitoring, discussed in Section 7.3. Because of the expense, it is best to establish (during the permitting process) a limited period of time during which the monitoring will continue, such as one year after the operation reaches capacity level of production.

### 7.3.2.3 Aquatic Biology and Fisheries
**by S. P. Canton, J. W. Chadwick, and D. J. Conklin, Jr.**

#### *7.3.2.3.1 Introduction*

A number of ecological issues are involved in the environmental permitting of mining projects. The extent of aquatic ecosystem coverage is determined by the scope of the project and the surrounding environs. It can reasonably be assumed that if a stream, lake, river or reservoir is on or near the project site, then aquatic biology studies will have to be undertaken. The scope of the studies will depend on a number of factors as described below. The issuance of some key project permits may depend on the results of the aquatic biology studies. In the current regulatory environment, it is difficult to overemphasize the importance of the presence or absence of key aquatic organisms.

The following discussion outlines the typical factors involved in design, implementation and reporting of aquatic biological studies for mine permit issues. While not intended to be a catchall discussion of issues for all mine sites, it presents the salient features needed to complete an effective aquatic biological study.

#### *7.3.2.3.2 Study Plan Development*

Before baseline data collection can proceed, a defined aquatic biological study plan must be developed. A study plan can be as little as a few pages up to a complete volume, depending on the complexity of the project, the quality assurance/quality control (QA/QC) procedures required, agency requirements, and other factors. However, a good study plan will:

1) Define the specific baseline data objectives of the study.
2) Delineate the study area and proposed study sites to be sampled.
3) Specify which groups of organisms (i.e. fish, invertebrates, algae, etc.) are to be sampled.
4) Propose acquisition of existing data and review of literature.
5) Outline data collection needs, such as quantitative or qualitative, field sampling or laboratory testing.
6) Describe the field sampling methods.
7) Establish a field sampling schedule, such as monthly, seasonal, etc.
8) Describe laboratory analysis methods, if appropriate, with QA/QC procedures
9) Define data analysis methods, including statistics to be used.
10) Indicate the reports to be produced, such as progress reports, draft reports, final reports, etc.
11) develop a schedule for implementation of data review, field sampling, laboratory analyses, data analyses, and completion of reports.

The development of a study plan involves the interrelationship of the eleven steps presented above. Although the steps have been presented as a linear progression of tasks, in reality the process involves continual changing and redefining of the above tasks as more information is incorporated into the study plan development. For example, the proposed study sites and organisms to be studied may have to be changed if it's learned that a threatened or endangered species may occur in the study area. This new knowledge could possibly necessitate the redefining of the study objectives, the relocation of particular study sites, and/or the specific habitats and organisms to be sampled. During the development of a final study plan, expect several changes to be made to at least some of the eleven steps outlined above.

The aquatic biology study plan should be coordinated with the study plans for other disciplines. This avoids duplication of effort and maximizes coordination and quality of concurrently collected data. In some instances, it is very important to collect aquatic biological data at the same time other data are being collected in related disciplines. For example, the distribution and abundance of aquatic organisms in many water bodies are often correlated to flow conditions and water quality. Coordinating the collection of biological data with the measurements of flow and sampling for water quality analyses maximizes the utility of the data and allows a more defined interpretation of the results.

Coordinating the study plan development between disciplines also avoids potential confusion after the data have been collected and analyzed. Baseline data often

raises as many questions as it answers. In many cases, unexpected results will be found in baseline sampling, such as new species or seemingly unusual relationships between species abundance and particular physical or chemical factors. Proper coordination between the disciplines will maximize the probability that these unexpected results can be evaluated and explained with input from the other disciplines.

A final important aspect of study plan development is the coordination with appropriate overseeing local, state, and federal agencies. It is important to review the study plan with appropriate agencies to reduce conflicts at a later date. The general aspects of the study objectives, as well as the specific study sites, methods, study organisms, etc., should be agreed upon prior to implementing the study plan. This should ensure that any questions asked by the agencies at a later date can be answered. It is much easier and cheaper to finalize the details of a study plan with the appropriate agencies prior to data collection than it is to have to conduct additional studies and collect additional data to address data gaps outlined by agencies at a later date.

#### *7.3.2.3.3 Baseline Data Objectives*

The keys to any aquatic biological study are the objectives. The study objectives should clearly define the goals of the aquatic study with specific regards to the project. They should define the potentially affected aquatic resources (lakes, streams, rivers, reservoirs), the potentially affected biota (fisheries, invertebrates, algae), and the potentially affected habitats (riparian, instream). Following development of baseline data objectives, there should be no confusion as to the goals of the baseline data collection efforts or the eventual product.

Included in most studies is the collection of basic biological data on the waters in the study area. In many cases, data will not exist on the aquatic ecosystem. In other cases, data will exist, but may be of poor quality, either due to it being too old or perhaps it was collected in a superficial manner. Also, recent changes in the environment (i.e. a new bridge or changes in land use patterns) may have changed conditions sufficiently to make the available data obsolete. In these cases, new baseline data must be collected. These new data allow appropriate interpretation of data collected in the future by providing a true baseline for the project to measure against, rather than measuring changes caused by regional or local environmental changes unrelated to the project.

Another common objective in baseline studies is to evaluate the presence or absence of threatened or endangered species, or the suitability of the existing habitat for these species. Given that these species are usually rare, there is often little data available for a particular project site. The baseline data objective in these cases is to collect site-specific data to ascertain the presence or absence of these species.

#### *7.3.2.3.4 Study Area Description and Site Selection*

Before baseline data can be collected, it is necessary to define specifically the study area. This is generally thought of as the reach of stream or river, or the lake or reservoir, that is expected to be or is currently being affected. To accomplish this step, it is necessary to know not only the actual site boundaries (the area immediately affected by the project), but also site-specific drainage patterns to account for potential impacts of runoff. In addition, delineation of the study area should consider off-site impacts, such as road construction, additional housing, sewage and garbage disposal, water supply, and other ancillary activities associated with the mine project. For most hard-rock mining projects, the study area will be relatively small and well defined when compared to other permitting activities, such as reservoir or pipeline projects.

Once a study area is defined, the next step is to establish the study sites. The actual number and placement of sites will depend on the study objectives and coordination with other disciplines. In general terms, normal site selection would include a site or sites upstream of the project, within the project area and downstream of the project. The upstream sites serve as reference or control sites for the project and are intended to track natural cycles in populations unaffected by the project. In hard-rock mining, the project is often sited in the headwater areas, precluding the use of upstream control sites. In this case, sites would be placed on nearby reference streams. The same idea is also applicable for lakes, although reference sites can often be placed within an affected lake even if a mine project is located near the lake, since in-lake currents and/or shoreline configuration often limit impacts to a specific portion of the lake.

#### *7.3.2.3.5 Study Organisms*

Once the study area has been defined and appropriate sampling locations have been chosen, the next step is to determine which groups of aquatic organisms will best measure potential impacts. In general, the types of organisms that are usually studied in baseline data collection studies fall into four broad categories roughly correlated to their location in the food chain:

1. Fish, which can include important game fish, such as trout, walleye, bass or salmon; rough fish, such

as carp or suckers; and forage fish, such as minnows or darters.

2. Aquatic Invertebrates, which can include macroinvertebrates, such as crayfish, aquatic insects, snails, clams or worms; and microinvertebrates, such as zooplankton or interstitial organisms (those that live in between the particle grains of the substrate).

3. Algae, which can include both periphytic algae growing on rocks or other submerged surfaces, or phytoplanktonic algae suspended in the water column of lakes and ponds.

4. Aquatic Plants, which generally include macrophytes or the rooted aquatic plants, such as cattails, reeds, and pond weeds.

In addition to these groups of aquatic organisms, aquatic habitat characteristics are often very important components in baseline data collection studies. These habitat characteristics can include measurements of substrate composition, riparian vegetation (stream or lakeside), bank structure, flow regime, and habitat typing (pool, riffle, run). Habitat has a direct effect on biological populations. In some cases, the impact of a project may not affect the organisms directly in a toxic manner, but may affect the habitat in such a way that it becomes unsuitable for the organisms. An example is the effect of sediment in streams. Sediment can be released from mine sites through construction activities, road building, tailings release, etc. As sediment accumulates on the stream bottom filling in the interstices between substrate particles, it can effectively smother the aquatic insects and thus limit the ability of the stream to produce food for fish. In addition, fine sediment can fill in spaces around fish eggs, depriving them of needed oxygen and thus limiting the ability of fish to maintain populations through reproduction. Thus, while habitat itself is not a study organism, habitat measurements are usually appropriate to provide data for defining the existing physical conditions that may be limiting aquatic biological populations, as well as to assess impacts of the project.

Specific populations or habitat components that are actually included in the baseline data collection study will depend on a number of site-specific factors, such as the presence of an important recreational fishery, threatened or endangered species, or critical habitats. It is important to be comprehensive, looking specifically for unusual circumstances that may be present at a project site. For example, are there any unusual organisms present? Is the study area in a portion of a state that has not been inventoried for threatened or endangered species? Are there any unusual interactions between aquatic organisms and other components of the environment, such as an endangered bird feeding on fish? Are there unique or unusual relationships between the aquatic organisms and surrounding wetlands? Do species use these waters during annual migrations or as spawning/nursery areas? These types of questions are easy to overlook, but may dictate the study organisms as well as the timing of field data collections.

#### *7.3.2.3.6 Literature Review*

Data collected in the past is always useful in both developing a study plan and later when interpreting data and looking for trends. Existing data are useful in identifying the biological groups to be sampled, delineating a proper study area boundary and defining appropriate field sampling methodologies. A preliminary review of the literature should be conducted during development of the study plan. This initial review will often be sufficient to provide information on species present and the general conditions of the study area; both key factors in study plan development. Rare species or unusual field conditions should be identified prior to sampling to avoid "surprises" that can adversely affect field sampling. In some cases, the literature review will provide adequate data for a baseline assessment and preclude the need for further data collection. However, most of the time this review simply helps point out the gaps in knowledge that a baseline study will fill.

Because of the importance of recreational fisheries, there usually exists at least some general information concerning the fishery resources for bodies of water. State fish and game agencies, rather than local or federal agencies, are generally responsible for managing the fisheries for most bodies of fresh water. The state game and fish agency will often have at least some information on almost any body of water resulting from periodic surveys inventorying the fisheries of their streams and lakes. In most states, this responsibility lies within one agency and it does not require extensive searching to determine if information is available for a particular body of water. In all but the most important fisheries, this information will usually represent a one-time survey of a lake or stream and will include only a superficial look at the fish populations and perhaps only important game fish species. Still, this type of data will aid in developing a study plan.

Federal and local agencies can also be potential sources of information concerning fishery resources. However, in many instances these agencies concentrate their sampling on a few specific streams or lakes that are special cases (i.e. National Parks, wildlife refuges). As such, these agencies generally do not have the broad range of information available from state agencies.

Other sources of information could be private companies, utilities, or universities that may have

conducted studies on a particular body of water in the past. In some cases, this information may have been collected as part of an Environmental Impact Statement or for a Master's or Ph.D. degree and may prove to be of high quality. However, finding these data requires more effort as this type of information is sometimes not made public or has not yet been published.

Information on other components of the aquatic environment, such as invertebrates, algae, aquatic plants and perhaps water quality, are usually harder to locate as they are not sampled as often as fish. Data on these components may be available from state agencies or the other sources mentioned above. However, locating existing information of this type would be the exception rather than the rule.

#### *7.3.2.3.7 Data Collection Strategies*

A number of data collection decisions will need to be made once the organisms to be studied have been chosen. Should it be determined following the literature review that new data are needed, the first decision is whether quantitative or qualitative data are required.

Quantitative sampling of organisms generally provides species lists with defined estimates of density, usually on a per unit area basis (e.g. organisms/$m^2$ ± 95% confidence interval). This is accomplished by taking multiple sample runs or replicate samples for the organisms or populations being studied. While this involves more effort in terms of field sampling, laboratory sample analyses, and data analysis, quantitative samples have the advantage of providing a measure of variability associated with density estimates. This in turn can provide data usable in robust statistical analyses to help compare study sites.

Qualitative sampling generally provides species lists, but without density estimates. In this case, sampling provides relative abundance estimates (i.e. organisms/sample). This type of sampling is generally conducted if the habitat is unsuitable for reliable quantitative sampling, or if defined population levels with confidence limits are more intensive than required by the study. Qualitative sampling usually entails some degree of effort directed at sampling a variety of habitats on a more superficial level, such as a "timed kick-net" sample for benthic invertebrates. Qualitative sampling generally does not provide data for normal parametric statistical tests, although non-parametric analyses may be run. The choice between quantitative and qualitative sampling is dependent, in part, on what data needs are necessary for calculation of statistics and desired biological metrics that would be used in the analysis. In many cases, quantitative replicate samples are supplemented with a qualitative sample to help build a species list for a particular site.

Another data collection choice includes the time-frame for sampling efforts. The common time-frame sampling scenarios include one-time sampling, two season sampling, multiple season or quarterly sampling, monthly sampling and occasionally multiple year sampling. The choice between these scenarios will depend on the level of effort needed to describe accurately the aquatic biological communities. This will in turn depend on the quality of the existing data base, the potential level of concern for the aquatic resources present in the study area, the presence of potential threatened or endangered species, and/or the potential for significant changes due to seasonal or life-history phenomena.

One season sampling is adequate to describe the general health of the aquatic ecosystem. It is also adequate if there is high quality existing information on the study area that just needs "updating." Two season sampling is appropriate in many cases as there can be substantial changes in the aquatic ecosystem during the growing season. Also, two season sampling is probably more appropriate in systems used by migratory or spawning species like trout, salmon or sturgeon. Multi-year sampling in baseline studies is warranted only in unusual circumstances where substantial year-to-year variability is known to exist in the resource due to natural or induced factors such as recreational use or construction activities.

All biological systems exhibit some degree of variability between seasons and between years. It is important to consider if data are being collected during a typical year or during an unusual year (i.e., the fourth year in a drought cycle). Sampling under unique circumstances should be avoided since this could bias the conclusions in one direction or another. One way to evaluate if sampling was conducted during a typical year is to conduct a longer-term monitoring study on a reduced scale during construction of the project. This type of monitoring helps to provide data to substantiate or modify conclusions reached during the baseline study.

When developing specific data collection strategies, it is important to remember that data are almost always used in the future for purposes not part of the original study objectives, just as a review of existing studies makes use of data from other studies not necessarily related to the proposed project. With this in mind, it is prudent to make the data collected as useful in the future as possible. This generally does not involve major additions to the field methods, but rather simply better documentation of sampling conditions. For example, when sampling fish or invertebrates, little effort would be required to also take a water temperature reading with the time of day. Also, field notes should include general conditions during sampling, such as weather conditions, time of day when sampling started and ended, flow, turbidity, substrate composition, or other organisms observed. Any unusual phenomena should be noted, such

as construction activity near or on a stream, livestock in the stream channel or a new beaver dam upstream of a site. These types of notes and simple data collection additions may not seem important, but could answer important questions that arise in the future.

#### *7.3.2.3.8 Field Methodologies*

Field sampling methodologies will be determined in large part by the study plan objectives detailed above and will be driven by 1) the organisms being sampled, 2) the habitat type being sampled, 3) whether quantitative or qualitative data are being collected, 4) the desire or need to match historic data collection methods, and finally 5) the requirements of regulatory agencies, such as permit conditions. However, the specific field methodologies employed should be standard techniques in common usage.

##### *7.3.2.3.8.1 Fish Sampling*

The techniques used for sampling fish depend in large part on the size and condition of the water body. In smaller, wadeable streams, electroshocking and seining are the common techniques. These methods can be used for either quantitative or qualitative sampling. In larger rivers and in ponds, lakes and reservoirs, boat electroshocking, gill netting, trap netting, shore seining, trawling, and creel censusing are often used. Although it is not possible to collect all the fish in these types of waters, these methods can be used to determine species composition and relative abundance. Boat electrofishing, gill nets, fyke nets and trap nets are biased to the larger fish. Shore seines and minnow traps can be used to collect smaller fish missed by these other methods. With proper techniques, such as mark/recapture methods and multiple samples, these field methods can be used to collect quantitative as well as qualitative data.

##### *7.3.2.3.8.2 Invertebrate Sampling*

The techniques used for sampling invertebrates also depend on the type of water body being sampled. For stream sampling, the common samplers generally enclose a known area and have a downstream net. Organisms are dislodged from the substrate and the current moves them into the collection net. These type of samplers include the Surber and Hess samplers and various modifications of these samplers. By enclosing a known area, these samplers can provide quantitative data (numbers/$m^2$) when replicate samples are taken. Another variation on this type of sampling is a dip net or "kick" net, which is used in much the same manner, but generally does not sample a known area. In lakes, reservoirs, ponds and perhaps slow moving sections of streams, a different type of sampler is needed. This is usually a dredge or grab sampler, which "scoops" up a sample of the substrate. Examples of these types of samplers include the Ekman grab or the Ponar dredge. These samplers also enclose a known area of substrate and, when replicate samples are taken, can provide quantitative data.

Non-benthic invertebrates, including zooplankton and invertebrates on aquatic vegetation, require different sampling methods. Zooplankton are usually sampled with a net or a plankton "trap." The volume sampled can be determined by using the net opening and distance the net is towed. Plankton traps sample a known volume of water. Both methods can provide quantitative or qualitative data, depending on if replicates are taken. Invertebrates on aquatic plants can be collected with a dip net or with samplers designed for these habitats.

#### *7.3.2.3.9 Implementation of Study Plan*

Once all of the above steps have been taken, implementation of the study plan can commence. Specific dates for sampling are determined and coordinated with appropriate personnel from regulatory agencies and other disciplines. Personnel are trained for the sampling efforts, including development of a field health and safety plan. Only then should field sampling be conducted and actual baseline data collected for eventual analysis.

#### *7.3.2.3.10 Sample Processing*

Appropriate sample processing techniques should be used when processing samples collected in the field, such as benthic invertebrates, phytoplankton, or other organisms. Rigorous QA/QC programs are an integral part of sample processing and data handling. Assistance with sample processing protocols can be found in documents produced by data collection agencies such as the U.S. Geological Survey and the U.S. Environmental Protection Agency. Representative method documents are listed at the end of this section.

In order to keep track of data collected and processed in both the field and the laboratory, a central data base should be created, again with a rigorous QA/QC program built in. The importance of error-free data can not be overstated, as the validity and credibility of all conclusions reached during the study rest on the integrity of the data.

#### *7.3.2.3.11 Data Analysis and Interpretation*

As noted earlier, the specific types of data analysis techniques to be used should be determined early in the study plan development. Results of these analyses are often integral in the development of study conclusions. Data analysis techniques must be compatible with the

data collected. Analyses often include parametric or non-parametric statistics, ordination or clustering techniques, similarity indices, diversity indices, such as the Shannon-Weaver Diversity Index, various biotic indices or a combination of these methods, such as those used in the EPA Rapid Bioassessment metrics. As with the data handling portion above, data analysis requires a rigorous QA/QC program for review of calculations for accuracy.

Interpretation of the collected data depends on a long list of factors that are specific to each project. However, there are several basic principals that should be considered. The first has already been mentioned - evaluate if the data have been collected during a typical year or under unique conditions. If it is felt that data were collected under unique circumstances, the typical conditions should be described. Another basic principle is to evaluate control sites relative to the sites in the potentially affected area. If there are any reasons to believe that the control sites may behave differently in the future than the affected sites, these reasons must be delineated. It is much easier and more credible to identify possible unusual relationships with the control sites during the baseline phase of a project than trying to explain differences after the fact during the impact phase. In many cases, the only control sites are located upstream of the project site or on another stream and the aquatic environment may be quite different than that found at the affected sites, due perhaps to smaller stream size, higher gradients, different land use, etc. In these cases, it is important to acknowledge these differences and discuss how these differences will manifest themselves over time.

#### *7.3.2.3.12 Draft Report Preparation*

The final stage in an aquatic biology baseline study is the preparation of the final interpretive report. The format and style of the report will be determined, in part, on the purpose of report. In other words, the report may be 1) strictly a baseline data presentation, 2) baseline information for use in impact assessment, 3) a sub-chapter for an EIR/EIS, or perhaps 4) biological evidence for use in environmental litigation. It is also important to coordinate the preparation of this report with the results of concurrent water quality, hydrology or other pertinent studies.

In most cases, the report represents the only means by which others have access to the information from the baseline studies. Therefore, reports need to be complete and clearly communicate the purposes, methods, and results of the study. Also, the report is the only source of data for future researchers. It is important that the reports include enough detail so that current and future users can fully comprehend what was done and understand how conclusions were reached.

### 7.3.2.4 Baseline Evaluations for Blasting by S. D. Botts

#### *7.3.2.4.1 Setting of Project Area*

Early in the project development stage, a detailed survey should be conducted to identify the environmental and socioeconomic setting of the project area. With regard to environmental aspects, the survey should concentrate on the geology of the project and surrounding area. Detailed information for the geology of the project and surrounding area is critical to the accurate prediction of blasting impacts.

With regard to the socioeconomic survey, emphasis should be placed on identifying structures, both residential and commercial, and facilities such as gas and water pipelines along with reservoirs and dams that could potentially be impacted by blasting. Any structure within the immediate project area with the potential to be damaged by blasting should be identified on a topographic map which shows the location of structure in relation to that of the proposed area of blasting. During this survey period, a review should be made of any local, state, or federal regulations which regulate blasting.

#### *7.3.2.4.2 Model Blasting Impacts*

There are three types of blasting impacts, the first being ground vibration created by the detonation of the explosive charge, the second being the air blast or "noise" created when explosives are detonated, and the third being "flyrock" or rocks projected away from the blasting area.

Modeling can be conducted to predict ground vibration and air blast. Based on the mine plan, blasting impacts should be estimated using an appropriate modeling technique. Modeling can be done either manually or through the use of appropriate computer software. In either case, variables used to determine impact are as follows:

- Distance from blast to structure.
- Size of blast being initiated.
- Length of delays between initiation of charges with a blast pattern.
- Types of rock being blasted.
- Types of rock between blasting area and proposed structure.

Based on these inputs, an estimate can be made on ground vibration and air blast impacts to the structures surrounding the proposed project area.

A detailed mine plan is critical to the accurate prediction of blasting impacts. Detailed information is required on the size of blast holes, depth of holes,

average number of holes per shot, number of shots per day, and number of days on which blasting will occur. This information will also assist in the modeling of fugitive emissions from blasting.

#### *7.3.2.4.3 Conduct a Pre-blast Survey*

A pre-blast inspection should be conducted on all structures within the zone of potential impacts identified in the computer modeling exercise. These surveys should be conducted in accordance with United States Bureau of Mines guidelines. The purpose of these surveys is to determine the baseline condition of the structure, to record any pre-blasting damage, and to document any factors associated with the structure that could be impacted by blasting, such as type of construction.

These survey reports should include a photographic or video record of the inspection and any recommendations on any changes in the blast plan that are required to ensure the safety of the structure. The pre-blast survey should be performed by a qualified experienced contractor. A well documented survey is critical to the project in that it serves to determine which blasting claims are real. Even with this level of investigation, from time to time claims of blasting damage may be made against the company which are difficult to refute. A copy of the pre-blast survey should be provided to the regulating agency to assist in the determination of blasting damage.

#### *7.3.2.4.4 Establish Mitigation Measures*

After blasting impacts have been predicted by modeling, appropriate mitigation measures should be developed to reduce impacts to an acceptable level. These acceptable levels should be determined by comparing predicted impact levels to applicable regulatory limits. If no limits apply to the project, the Office of Surface Mining and United States Bureau of Mines limits for ground vibration and air blast should be applied as a safeguard.

Mitigation beyond regulatory limits is directly dependent on the number and proximity of persons in the potential impact area. The presence of one close resident can justify the need for additional mitigation measures. Potential mitigation measures include but are not limited to the following:

- Limiting the time of day at which blasting occurs. This can also reduce dust if certain times of day are less windy of if the wind blows in favorable directions at different times of the day.
- Limiting the number of blasts per day.
- Limiting the days of week on which blasting can occur.
- Requiring certain areas away from the property to be cleared if there is a danger of fly rock.

#### *7.3.2.4.5 Monitoring in Accordance with Regulatory Requirements*

Once the impacts from blasting have been predicted, regulatory limits established, and mitigation measures have been chosen, a long-term monitoring program is required to ensure that blasting operations are being conducted in compliance with the terms and conditions of the operating permit.

The monitoring of both ground vibration and air blast can be accomplished using a programmable blast monitoring device equipped with a seismograph and a microphone. These instruments should record and store all blast events and should be set to trigger from either ground vibration or air blast. The instruments should be factory calibrated on an annual basis.

Blast monitors should be placed appropriately between the blast and the closest structure. A combination of permanent blast monitoring stations and the use of the instruments in a portable manner can often be the best approach.

A detailed blasting report should be filled out by the blaster for each blast. These reports should include the following: identification number for the blast; date and time; number of holes; pounds of explosives per hole; the depth of stemming in each hole; the type of delay used; the distance to the nearest blast monitoring station; and the distance to the nearest structure.

The blaster should also predict, using the "scaled distance method," the ground vibration expected at both the nearest monitoring station and the nearest residence. A designated person should review this information prior to the initiation of the blast to ensure that the shot is designed properly and that regulatory limits can be met.

Data collected from each blasts should be reviewed and compared to the blaster's predicted ground vibration. Any discrepancies should be investigated. Air blasts in excess of the limits should also be of concern in that they are often the result of a "rifled" hole, a symptom of inadequate stemming or burden in the shot. All blasts should be video taped. These tapes should be reviewed to ensure that the blast went off as planned. This information along with the blast monitoring record should be compiled in a report for internal review and if necessary submission to the appropriate regulatory agency.

#### *7.3.2.4.6 Additional Mitigation*

Additional mitigation measures may be required after the commencement of operations if impacts are greater than expected or unacceptable to the persons residing within the potential impact zone. Actual experience has shown that operations which comply with all regulatory limits still receive complaints about blasting. Each operation must fine tune its blasting program to meet the concerns

of those affected.

### 7.3.2.5 CULTURAL RESOURCES
**by T. D. Burke**

#### *7.3.2.5.1 Defining Cultural Resources*

Cultural resources are a nonrenewable resource consisting of the physical remains and places associated with human activities. These can include artifacts such as arrowheads, chips, and tin cans, or places and things such as bridges, mill footings, headframes, mining towns, waste rock dumps, sacred mountains, pueblos, and prehistoric archaeological sites.

#### *7.3.2.5.2 Pertinent Laws*

The U.S. Congress has established various laws over the years protecting cultural resources on federal and Indian lands, although federal protection can be extended to sites on private property as well. In addition, some states and local governments have also instituted measures to protect such resources on private and other non-federal lands. This discussion pertains to federal lands, although definitions as well as many of the processes of identification, evaluation and treatment discussed here are widespread throughout the cultural resources disciplines and are often applied by other levels of government.

The primary federal legislation is the *National Historic Preservation Act* of 1966 (as amended) and its accompanying Section 106 regulations, as the latter are set forth in Chapter 36 of the Code of Federal Regulations, Part 800 (Identification of Historic Properties). Other legislation that may be invoked includes the *Native American Graves Protection and Repatriation Act*, and the *American Indian Religious Freedom Act*, depending on what kinds of remains and resources are encountered. Compliance with the NHPA and its regulations will largely satisfy requirements of the *National Environmental Policy Act* for determining the affected environment as well as a project's environmental consequences.

Federal agencies are responsible for implementing Congress' laws and ensuring that important cultural resources are identified and protected. Agency personnel should be qualified to accomplish the necessary work but may have too many other obligations to conduct field work and analysis, necessitating the miner's use of contracted cultural resource services. Persons conducting contracted services must have prior agency approval in terms of qualifications and agency permits. The federal agency will use a contractor's results to fulfill its legal requirements, including consultation. However, the agency may impose different conclusions than those presented by the contractor.

The miner should remember that the federal agency is committed legally to completing the Section 106 process before the mine project can be authorized. However, no outcome is predetermined by the Section 106 process. Preservation in-place is not mandated for any resource type under NHPA. Further, NHPA is not used for determining whether a mining project application should be approved or denied; it is a process to be satisfied on the way to mine development.

The NHPA requires that a federal agency consult with the pertinent State Historic Preservation Officer (SHPO) regarding the importance of identified cultural resources as well as appropriate means to mitigate a project's effects.

#### *7.3.2.5.3 Cultural Resources Studies*

Cultural resources are usually investigated by persons qualified in the professions of archaeology (prehistoric and historic), history, ethnography, architectural history, or historical architecture, although various specialists in related disciplines also may become involved.

Two phases comprise the essential work--inventory (including evaluation) and protection of *historic properties*; historic properties are those objects, sites, buildings, structures or districts eligible for the National Register of Historic Places. The NRHP is the standard or threshold used by federal agencies to define importance of cultural resources. Various levels of inventory can be defined; however, the important thing is to implement a level of inventory fulfilling the federal agency's obligation to determine whether historic properties are present in the mine project area. This is referred to as a Class III inventory by the Bureau of Land Management and by some offices of the U.S. Forest Service.

Inventory entails efforts to determine what, if any, cultural resources are in or near the project area as well as assessment of their importance (i.e., evaluation). Protection incorporates measures such as avoidance (perhaps including site burial), historical research, ethnographic research, oral history, detailed written and photographic documentation of buildings and structures, and archaeological excavations.

Inventory normally includes consideration of existing documentary information regarding previously recorded cultural resources, NRHP listings, and the potential for unrecorded resources based on maps, historical documents, distributions of archaeological sites in similar geographical and environmental settings in similar areas, etc. There will also be a physical inspection of the property to establish the nature, extent and significance of cultural resources in the area. The inspection may be accomplished by professionals such as archaeologists, architectural historians, historians, ethnographers, or a combination of such persons, who will record the resources using written forms, photographs, and other descriptions. Some form of

limited excavation, referred to as probing, testing or by other terms, may be necessary to obtain sufficient information to complete evaluation of archaeological sites.

Some types of cultural resources, such as old mining towns and mining districts, can be extremely complex in terms of the number and kinds of features and artifacts to be recorded. Such sites require extensive time to document in the field and during the inventory reporting phase. A high density of standing buildings or prehistoric archaeological sites may have similar time requirements.

As noted previously, historic properties normally are the only cultural resources meriting some form of protection from a project's effects. However, the presence of a historic property does not preclude development such as exploration drilling or mine development; such presence means the federal agency must first take the project's potential effects into account prior to allowing the mining activity to proceed. Second, the federal agency must also provide the Advisory Council on Historic Preservation (ACHP) the opportunity to comment on the project and its effects on historic properties. Under the Section 106 process, this prior consideration of potential impacts is the essence of what a federal agency must accomplish prior to authorizing the miner to proceed. The objective of the process is to seek ways to avoid or minimize damage to historic properties. This prior consideration requires time for completion that may become a constraint on the miner's plans if sufficient lead time is not allowed in planning.

When taking into account the effects of a project, the federal agency also must consult with the State Historic Preservation Officer (SHPO) regarding adequacy of the inventory, NRHP eligibility, and protection measures where historic properties are involved. Like the federal agency, the SHPO can be a source of valuable information about cultural resources within an area.

Protection of historic properties may involve avoidance through project redesign; documentation of buildings and structures by means of historical research, measurement, description and photography; historical investigations involving documentary research and oral informants; archaeological investigations; a commitment to provide future access for religious practices by Native Americans; or some combination of these or other measures. Protection measures normally will be established in a written Memorandum of Agreement signed by the federal agency, SHPO, ACHP and possibly the mining company.

#### *7.3.2.5.4 Working With The Section 106 Process*

Cultural resources must be considered at an early stage of development to limit potential time delays and to maximize cost effectiveness. These studies must be initiated prior to the onset of ground disturbing activities such as exploration-phase drilling or road building to avoid damage to potentially important cultural resources. Thus, time will be necessary before the mining can begin for the federal agency to define the scope of work, for the miner to select a contractor (if necessary) meeting the agency's requirements, to complete the cultural resources inventory, for consultation by the federal agency with the SHPO regarding NRHP determinations, and for consultation, development and implementation of measures to minimize project-related effects to historic properties in the mining project area, if any.

What should the miner expect to have inventoried? Minimally, the areas of disturbance will require investigation since the loss of integrity through destruction or through the introduction of visual or audible intrusions will constitute an adverse effect if historic properties are present. Time and cost savings may be realized during the exploration phase if the agency requires that only the access roads and pads be inventoried. However, this limits flexibility (e.g., a drill pad probably could not be moved outside the area of inventory) and may require additional start up costs if more cultural resources studies are necessary. Inventory of larger areas (e.g., block survey) may cost more initially but the miner may realize certain advantages, especially in terms of time and possibly costs.

Cultural resources obviously are an "upfront" cost. These costs may not proceed apace with the miner's development of information about the value of a potential ore deposit. That is, the exploration phase of mining, with its associated risk costs (rather than investment costs of actual mine development), may be concurrent with extensive cultural resources costs, especially if the project is in an older mining district or in an area particularly sensitive for prehistoric archaeological sites. Exploration managers should assess and should budget according to the potential for complex cultural resources projects with regard to exploration schedules and costs .

The federal agency determines what efforts are necessary to inventory and protect historic properties. An agency head or agency archaeologist should give direction to the miner. Many agencies have their own written guidelines regarding cultural resources studies which can be used by mining personnel to help develop scopes of work. An agency head may determine that agency employees cannot perform the cultural resources studies and may recommend that the miner obtain services of a private sector contractor to accomplish the cultural resources studies. The agencies may also have lists of qualified persons or firms, or lists of permit holders. In any case, the agency somehow will have to approve of the persons contracted to do the work, usually accomplished by means of a cultural resources permit

issued to the contractor.

The federal agency's requirements must be understood when seeking services of a private contractor. In most cases, the agency will direct the miner to have an inventory completed. The area of inventory should be clearly understood and will usually be determined by a federal agency based on a plan of operations or similar information provided by the miner. Inventory procedures should be established if written agency guidelines do not exist already.

Potential contractors should be selected on the basis of qualifications, experience and cost. The least cost approach may not yield acceptable results. Qualifications must reflect the federal agency's personnel requirements which, in most cases, involve a graduate degree in history, anthropology, architectural history, or a closely related field for supervisory personnel in addition to certain levels of experience. Experience is extremely important and should be determined with regard to the type of work needed (e.g., inventory, testing, oral history), the resources expected in the project area (e.g., historic period archaeological sites, prehistoric archaeological sites, or both), and the history of the person or firm in completing the required work on time and in the necessary manner.

Cost estimate solicitations should be based on the agency's or the miner's written scope of work to ensure comparability. In many cases this may be no more than a request for a Class III inventory of a specified acreage, accompanied by a map. Maps should include the project boundaries or alignments on current versions of 7.5-minute US Geological Survey maps showing topography, elevations, springs, access, etc.

Contractors responding to the solicitation may list assumptions used in developing the cost estimate accounting for variations in the estimates. For example, does the contractor expect archaeological sites to be numerous or complex? Will extensive library and other documentary research be necessary to prepare a historical context to be used in site evaluation? Has a reasonable amount of time been allotted for the inventory based on expectations? Could weather be a factor affecting the timing of field work?

The miner might consider incorporating cultural resources locations and NRHP evaluations into a database and digitized mapping system for purposes of planning and presentation. However, the federal agency must give prior approval for release of such data to the miner since archaeological site locations are confidential and are protected from public disclosure under federal law.

In summary, the miner should begin early, insist on clear guidance from the responsible federal agency, understand the potential array of cultural resource types and their respective complications, and work with qualified contractors. The miner should establish a basic familiarity with the Section 106 process.

## 7.3.2.6 Geology and Soils

### *7.3.2.6.1 Geology Baseline Investigation* by A. D. Cox

#### *7.3.2.6.1.1 Introduction*

Evaluating existing geologic and soils conditions at a potential mining development site is critical in terms of determining project requirements. Knowledge and understanding of the limitations and characteristics of the geologic setting and soils characteristics are important at every phase of a mining project from the initial planning, design and construction to the final stages of the project life when post-mining closure and reclamation are planned and executed.

An understanding of the geologic setting and characteristics of the property are key to the design and placement of practically all project facilities. Geologic considerations are of utmost importance when making decisions regarding waste rock management and placement, location of tailings disposal facilities, location of processing facility buildings, ponds, ore storage and processing sites, and in the design of the mine itself (whether open pit or underground).

Soils investigations are also important for collecting data which are integral to the design and placement of project components. An early understanding of soils resources and characteristics can have an effect on location of various facilities and can have an impact on construction and development plans in terms of time necessary to properly manage soil resources that are to be stripped and stockpiled for post-closure project reclamation efforts.

Given these general needs for evaluating and investigating geology and soils in the project development site, a checklist of specific information and data requirements can be developed to help assure that baseline data collection efforts are complete and comprehensive in terms of both present and future needs for the project. The following sections outline the information needs; it should be cautioned, however, that this discussion is general in nature and should be augmented by a careful review of the individual site circumstances and tailored to the specific site and the development plans that are contemplated.

#### *7.3.2.6.1.2 General Considerations*

Initial geologic evaluations of almost all mineral properties include a general geologic setting description of the area and region. This is to set a reference for the property in relation to other known deposits or mineralized regions, and is the basis for all other discussions or understandings regarding the geology of the project area and the impact that the general geologic

setting may have on project development and future operation.

All surface geologic surface mapping efforts in the planned project development area should include complete and comprehensive information on the general rock types in the area. Geological fault mapping and interpretations concerning the structural geology in the area should be documented. This will assist greatly in the early stages of the project concerning overall placement of project components such as leach pads, tailings ponds, overburden and interburden rock piles, etc.

In addition, any and all data concerning geochemical and trace element data collected during the project exploration phase should be assembled and consolidated. This information can be useful in evaluating water quality information during project operations and planning during the closure stages of the project. In many cases, geochemical information collected in the early stages of the project can greatly assist in projecting water quality characteristics related to waters that either contact waste rock or processed ore materials or that are in contact with or contained within the open pit or underground mine workings upon closure.

*7.3.2.6.1.3 Ore Deposit Characterization*

Understanding of the geology of the ore body to be mined and processed is critical not only from the standpoint of the economic resource to be extracted but also from the standpoint of waste material management and insuring chemical and physical stability of mined materials. The geology of the deposit may also influence the quality of the water that comes in contact with mined or processed materials. As such, information concerning geology of the ore deposit should encompass many types of data including various rock types, their location, orientation and geometry within the mineral reserve area, and any pertinent information concerning the geology of the mineralizing system.

Exploration drilling efforts, whether initial drilling phases or final deposit delineation drilling, should carefully document the oxide-sulfide zonation of the ore reserve. This is crucial not only in terms of metallurgical implications of ore processing, but also in terms of waste rock management that may be required during active mining operations to assure that oxidation of sulfide waste materials is minimized or managed such that acid rock drainage (ARD) generation does not become a major issue. In ore deposits where there is zonation or intermingling of oxide and sulfide materials, it may become critical that materials are physically managed or segregated such that sulfide oxidation is controlled or minimized. Detailed discussion of ARD issues are discussed in Section 7.2.1.

Sample collection and preservation methodology for drill cuttings and rock samples collected during drilling and bulk sampling efforts should be carefully reviewed to assure that the materials are stored or otherwise preserved such that they can be used for future investigative needs. Additional rock geochemistry evaluations may become necessary during the project and materials obtained from original ore deposit delineation efforts may become invaluable to reduce the cost of re-sampling or re-drilling areas that already have sample materials available. Preservation and storage techniques for these materials should be reviewed to insure that sample integrity is assured for future investigative work. As an example, core materials from sulfide zones within the deposit may be valuable from the standpoint of evaluating acid generation characteristics and any resultant mobilization of heavy or trace metals from waste rock materials. Core used for these purposes would need to be preserved and stored such that oxidation of sulfides within the sample is minimized until test work is undertaken.

*7.3.2.6.1.4 Seismicity Evaluations*

All mine development projects, regardless of location, should undergo review and evaluation for potential seismic activity and the possibility of project impact. Facility component location, as well as design and construction, will be weighed and evaluated on the basis of historic seismic and earthquake activity in the area.

In many locales, a certain amount of information on regional seismic activity already exists. As such, one of the first steps in completing a seismic baseline evaluation of a project would be to conduct a thorough literature review. This information will usually provide information concerning historic epicenter and earthquake magnitude data for the region which will result in some expectations concerning the relative seismic activity that can be expected. On a more localized project basis, aerial photography can prove valuable in terms of air photo interpretation of geological faults, slides, etc. which can be used to arrive at decisions regarding facility siting and location. This information can also be useful in determining the potential for natural material instability or liquefaction in certain areas should a significant seismic event occur. Again, facility siting decisions can be affected by this type of seismic related data.

*7.3.2.6.1.5 Physical Soils Characterization*

Physical characteristics of soils materials at the development project site can have a significant impact on decisions relating to building site and project component location. In most cases, it is important to characterize the general shrink-swell capabilities of in-place soils as well as developing plasticity indexes for different soil types in the immediate project site. With this information in hand, siting decisions for project components can be made during the project development

stage and can also effect placement of facilities in relation to post-closure and abandonment of the property after ore reserves are depleted and project reclamation is undertaken.

#### *7.3.2.6.2 Soils Baseline Investigations* by D. Williams

##### *7.3.2.6.2.1 General Considerations*

Natural soils, because of their superior chemical balance, exchange complex, tilth, biological activity, etc., are generally considered superior to waste rock and other alternative materials for reclamation. For this reason, soils are commonly salvaged and reapplied over waste rock, tailings, and disturbed areas as a key aspect of reclamation. Developing information concerning the amount of soil required to be salvaged, the manner in which soils must be handled, and the inherent limitations and consequent amendment requirements of the soils, and other key soils characteristics are the major objectives of baseline soil investigations.

##### *7.3.2.6.2.2 Baseline Investigations*

The level of detail required in soil baseline investigations is dependent upon the scope of planning questions. Therefore, before defining the scope of soil investigations, the information required from the soil survey must be defined. By defining first the information required, the soil survey and associated investigations are focused, resulting in a more cost effective soils baseline study.

Soil surveys can be made at several intensities. The procedures, standards, and purposes are discussed in the Soil Survey Manual, U.S. Department of Agriculture (USDA). Because most mineral development projects are relatively land intensive (most of the disturbance area is concentrated into a few key areas), a relatively high level of precision is required concerning soil characteristics such as depth and horizonation so that mine and reclamation planning can be meaningful. For this reason, detailed soils information is normally required for the area within the immediate vicinity of the proposed mine and associated facilities. This level of soils information is not normally available from public resource agencies such as the Soil Conservation Service, U. S. Forest Service, or Bureau of Land Management, and must be acquired by the project developer.

Besides obtaining detailed information concerning soil depth and location, soil investigations characterize productivity limitations such as rockiness, particle size, soil structure, water holding capacity, salinity (electrical conductivity), sodicity (sodium adsorption ratio), organic content, and fertility (nitrogen, phosphorus, potassium, and micronutrients). These characteristics, interpreted by a reclamation scientist, form the basis for understanding the inherent productivity potential and limitations of existing soils, and for defining reclamation strategies. More detailed descriptions of sampling procedures, analytical methods and results interpretation and significance are provided in Williams and Schuman (1987).

Chemical and physical soil characteristics are normally defined by soil taxon (Soil Taxonomy, Soil conservation Service USDA, Ag. Handbook No. 436). Characteristics are normally defined by a range of characteristics that are based upon a number of samples collected from "modal" (concept) examples of the taxon within the mapped area. When interpreting the significance of soils information it is critical that it be kept in mind that soils are a multidimensional continuum, and that outliers of the modal soil may in fact predominate. Gold mapping unit descriptions, however, overcome this problem by defining the range of chemical and physical soil characteristics. These thresholds, if known prior to the onset of investigations, serve to focus the investigation to ensure that meaningful information is collected for reclamation and land use planning. Examples of soil chemical and physical thresholds are available from most agencies responsible for mine regulation.

### 7.3.2.7 Ground Water by A. Brown

#### *7.3.2.7.1 Introduction*

For a useable ground water resource to exist there must be two factors present: availability of the water (quantity) and utility of the water (quality). Accordingly, the baseline characterization of ground water resources at a mine site involves evaluating both of these aspects.

#### *7.3.2.7.2 Ground Water Quantity Baseline Studies*

The availability of ground water depends on a wide range of factors:

*Sources.* The ultimate source of ground water is recharge from precipitation or surface water bodies. If recharge in the vicinity of the project is large, then the ground water resource which is available will also be large. In addition to recharge, ground water can be obtained by depleting storage within the subsurface system.

*Accessibility.* For a ground water resource to be useable it must be accessible. This is determined by the nature of the material in which it is located. For saturated granular materials, ground water is generally available in useful quantities, provided the material is of sand size or greater.

For saturated rock materials, accessibility depends on the primary conductivity of the rock material itself, and the permeability of the fracture system. Only a few rocks have significant primary permeability, so accessibility in rock materials is largely a function of fracture permeability.

The importance of the resource depends on the quantity of the resource, the use of the resource, and the availability of an alternate water supply. These factors may have an impact on the permitting process, particularly in areas where the ground water system provides the only available potable water, a common situation in the western United States.

The information required to develop a baseline of the quantity of ground water can be divided into the direct flow baseline, indirect flow baseline, and storage baseline.

*7.3.2.7.2.1 Direct Flow Baseline Studies*

The amount and availability of ground water is indicated by the presence (or absence) of evidence of ground water emerging from the subsurface domain. These indications provide both a measure of the condition of the ground water system (both for quality and quantity), as well as an indication of the amount of ground water which is available for consumptive use (other things being equal). Observation of the hydrologic features described below provides important direct flow baseline information.

*Wetlands.* A wetland is, in general, a location where the ground surface is at or close to the water table. Knowledge of the presence, nature, and persistence of wetlands in the pre-development condition is a critical element of the ground water baseline (and of the surface water baseline). From a ground water perspective, baseline information which is required about wetlands includes area, depth of water, evaporation rate, vegetative types, catchment, inflow, outflow, and water level.

*Lakes.* Lakes are generally locations where the local ground water table is above the local ground surface, and drainage from the location is restricted or non-existent. As such, lakes often provide an opportunity to evaluate the ground water system. Baseline information about lakes for the purposes of ground water evaluation includes area, depth, evaporation rate, inflow, outflow, and water level.

*Springs.* A spring forms at a location where the water table exits the ground surface, and the topography is such as to allow drainage from this point. Springs are often sensitive indicators of the nature and condition of ground water flow systems, and are therefore an important part of any ground water baseline evaluation. Baseline information from springs which is important for baseline purposes includes flow, location, evaporative area, evaporation rate, vegetation types, aspect, and use.

*Streams.* Some streams are perched above the ground water system, and can supply water only to the system. Most streams, however, are in direct contact with the underlying ground water system, and provide water to that system when perched, and receive water from ground water when the stream elevation is lower than the ground water table. Baseline information that is important from a ground water perspective includes flow, slope, bed material, aspect, vegetation, and evaporation rate.

Ground water flow to and from these features can be directly measured or readily estimated. Information about these features is therefore critical to ground water system baseline studies. In general, one of the first signs of mining-related impacts to ground water is observed as changes at these points of ground water egress.

Direct flow conditions are generally very time sensitive. Therefore a baseline survey should evaluate flows and conditions at the relevant locations frequently. Monthly measurements for a full annual cycle are generally necessary to capture the full variability of the flow system. Monitoring locations which are indeed indicative of ground water conditions should show more stability in flow than locations where the surface water component is significant.

*7.3.2.7.2.2 Indirect Flow Baseline Studies*

Ground water flows occur below the ground surface, and therefore cannot be directly measured for flow or quantity, other than at the points of egress (and sometimes at the points of ingress). For this reason, indirect measurement of ground water flows is an important part of a ground water baseline study. Ground water flow may be estimated by the following methods.

*Water balance.* Ground water flow can be estimated by water balance methods (Driscoll, 1990). This approach requires estimating the inflows to the system (infiltration, seepage from surface water features, gains from storage, and injection), and estimating outflows or losses from the system (production from wells, losses to surface water features, and losses to storage). If done carefully, it is possible to estimate ground water flow using this approach; both the inflows and the outflows provide independent estimates of ground water flow.

*Aquifer flows.* Ground water flow can be computed from Darcy's Law (Darcy, 1856). The flow is determined by the head gradient, the cross sectional area of the flow, and the hydraulic conductivity of the material through which the flow is occurring. Although this is an attractive concept for measuring the baseline flow in a ground water system, it generally is of limited application in

most baseline studies, due to the difficulty of measuring the conditions at enough points to provide confidence in the flow computations.

*Analog.* The analog approach to estimating ground water flows combines both of the above methods. An analog of the ground water flow system is constructed using the approaches outlined in Section 7.2.3, and the available information on surface flows and subsurface parameters is input into the analog. After calibration, the analog provides information about the probable pre-mining flow conditions in the aquifer. In general the use of all the known data on ground water provides an adequate level of confidence that the baseline conditions are correctly described by the analog.

Indirect flow conditions change relatively slowly. As a result, it is generally adequate to measure the parameters which control ground water flow only once in a baseline study. The exception to this is ground water elevations. These may change rapidly, particularly in shallow aquifers, and should be measured at least quarterly for a year to develop a baseline set of information.

*7.3.2.7.2.3 Aquifer Storage Baseline Studies*

The storage available in the system is the amount of water that can be removed from system storage. In locations where the water stored in the aquifer is an important source of water, this can be estimated by considering the ground water available by desaturating the aquifer. The quantity of water that would in fact be available (leaving aside considerations of the impact of desaturating the aquifer) can be computed by the volume of the aquifer, multiplied by the drainable porosity of the aquifer. Measurement of the drainable porosity of the aquifer is difficult in field situations, so values of 10%-25% for granular aquifers, and 0.5%-5% for rock aquifers are generally appropriate for estimating ground water availability from this source (Walton, 1970).

### *7.3.2.7.3 Ground Water Quality Baseline Studies*

There are two principal issues with respect to developing ground water quality baseline data for mining projects: characterizing the existing ground water quality, and determining the sensitivity of the ground water system to change.

*7.3.2.7.3.1 Water Quality Sampling*

Characterizing ground water in the vicinity of a mining project involves collecting ground water samples and analyzing the samples for water quality parameters. The locations from which ground water samples should be taken in a project is particularly project-dependent; however some guidelines can be stated:

- The sample domain should recognize the three dimensional nature of ground water flow systems; while the majority of samples should be taken near the surface, some samples should be taken from depths up to 1.5 times the depth of the proposed mining project.
- Sampling should favor the materials which provide the greatest ground water resource; in particular saturated, near surface granular materials should be sampled with sufficient frequency to allow full characterization of these generally high-value resources.
- Sampling should favor the materials with the highest permeability; these materials are the principal conduits for both water and dissolved species.
- Sampling should favor downgradient locations over upgradient locations to ensure that background conditions in the locations which may be impacted by mining activities are appropriately recorded. It should be noted that the mining project may change the positions of "upgradient" and "downgradient" locations. Consideration should thus be given to conditions during mining and after reclamation, and not only the pre-mining condition.

*Sampling frequency.* Sampling frequency is a difficult issue for ground water quality baseline studies. In general, natural ground water quality does not change significantly on a seasonal basis. However, there are a range of classes of ground water conditions which do show seasonality (for example in or near acid generating materials, near salt-water intrusion areas, and near intermittent streams). Accordingly, it is generally prudent to collect a minimum of quarterly samples for a year for ground water baseline purposes, and to evaluate the extent to which the values change. Thereafter (if the baseline extends beyond that point), annual or semi-annual data collection may be justifiable.

*Sampling parameters.* Selecting the appropriate sampling parameters in a ground water quality baseline study is to some extent project related, and to some extent mandated by the need to obtain a comprehensive baseline, regardless of what the species of interest may be. Accordingly, it is normal for the first year of baseline sampling to collect information on a wide range of parameters, and to reduce the parameter set to a more project-specific list when the initial baseline has been performed.

The parameters that are generally sampled for in a baseline evaluation include the following (Hem, 1990):

*Gross parameters.* These include pH, Eh, conductivity, temperature, total dissolved solids, total alkalinity, total acidity, and hardness.

*Major ions.* These include the major cations (calcium, magnesium, sodium, potassium) and the major anions (sulfate, chloride, nitrate, carbonate, bicarbonate). In some projects, other ion groups may be significant (fluoride, arsenate, silicate), and these ion groups may be part of the baseline for this reason.

*Metals.* In many mining-related baseline studies, the metals that are associated with the orebody are of critical importance to the baseline evaluation. Such metals may include iron, manganese, copper, zinc, lead, mercury, silver, and (possibly) gold. In general, the mobility of these metals is a function of pH and Eh. The importance of monitoring these constituents may vary as a function of distance from the orebody.

*Other constituents.* In some cases other constituents may turn out to be critical, for example cyanide, chromium, selenium, uranium, molybdenum, and the rare earth elements.

*Radionuclides.* Radionuclides constitute a class of elements of concern for uranium mining and some other mine types. In this case, it is important for the principal element and the decay chain elements to be tested for, in order to obtain a baseline of the pre-development conditions.

*Organics.* The organic constituents of ground water can be important if there is pre-existing contamination at the site. It is very rare to find any significant organic constituents in virgin mining projects. However if the project is located at a site previously used for industrial activities, then a baseline sweep for hazardous organic compounds is essential in defining the extent to which the site was contaminated prior to the current use.

In summary, a baseline sampling program for water quality at a mine site should include a set of wells that interrogate the three dimensional ground water system; should perform quarterly water quality sampling; should analyze parameters which characterize the full spectrum of the ground water system, while concentrating on the species which would be released from an upset at the proposed project; and should identify parameters which define the pre-development condition, regardless of future use.

*7.3.2.7..3.2 Sensitivity Characterization*

The final water quality baseline issue is defining the sensitivity of the ground water system to changes. Some systems are insensitive to ground water quality changes, having a high capacity to modify the chemistry of the water passing through them, which renders these systems relatively insensitive to mining-induced changes. Other systems have essentially no capacity to change the quality of water which passes through them, and are therefore more sensitive to potential degradation due to mining. The significance of project-related changes is in considerable measure a function of the nature of the system in which the project is located.

Sensitivity of a ground water system depends in large measure on the nature of the host material, and can be evaluated by determining the capacity of the system with respect to buffering, neutralization, oxidation or reduction, ion exchange, dissolution, and biological activity. This evaluation is extremely site specific, and the investigation requirements should be determined based on site conditions. The evaluation influences the extent to which mine-related impacts pose a threat to the quality of ground water in the vicinity of the mine. For sensitive mine settings, the requirements for environmental protection measures to be built into the mine plan may be greater than for settings with a greater ability to protect ground water quality against the effects of excursions from the project.

### 7.3.2.8 Noise
**by S. Botts**

#### *7.3.2.8.1 Establish Setting*

Noise baseline studies should start by performing a detailed survey to identify the environmental and socioeconomic setting of the project and surrounding area. This survey should be conducted early in the project development stage and should focus on identifying potential sensitive noise receivers. This involves determining the number of residences and population densities around the project area. For the most part, these sensitive receivers will be residences, although schools and hospitals, and certain types of commercial establishments may also qualify as sensitive receivers. This survey will also provide data for evaluating other impacts such as blasting. A topographic map should then be created which shows the identified sensitive receivers in relation to the proposed project.

During this evaluation period a review should be made of any regulations, zoning etc., which regulate noise in the project area. Many communities and counties have such regulations.

#### *7.3.2.8.2 Establish Pre-Project Noise Levels*

A series of extended noise surveys over multiple days should be performed within and around the areas with sensitive receivers. Careful thought should go into the placement of the noise monitoring equipment. Detailed

information should be collected about each monitoring location such as distance from any major noise source (roads) and any other nearby existing or potential noise sources. Care should be taken to avoid non-representative local noise sources within the area of sensitive receivers.

Instruments used in the surveys can be mounted on a variety of structures such as telephone poles and power poles. Windscreens should be used on the microphones. The instruments should be protected within steel security cases and chained to the structures to which they are attached. A 110-volt power source is usually required, although battery-powered equipment for use in remote sites is available. The noise dosimeters used in these surveys should be programmed to measure and store the energy averaged A-weighted sound level for each hour of the measurement period. Additionally, for each hour, statistical exceedance levels should be collected for each hourly period.

These statistical data will be used to determine the ambient background noise levels in each area monitored. Noise dosimeters used in the survey should be consistent with the type 1 specifications for precision sound level meters as described in ANSI specification S1.4. These instruments should be calibrated prior to and after each of the monitoring periods. Data collected from each instrument can be down loaded into a computer, and specialized software used to process the data.

Data collected should be plotted as hourly exceedance levels and hourly averages for each full 24 hour period at each monitoring location. Data should be summarized in tabular format by measurement location in terms of day, evening, and night and community equivalent noise levels (CNEL) for weekday and weekend periods. The analysis of data will provide the ambient sound levels for the various areas measured at different times.

#### *7.3.2.8.3 Model Noise Impacts*

Estimated noise levels for equipment expected to be used at the project should be collected from manufacturers and/or from actual equipment operating in the field. Data should also be collected on mining equipment which has been especially designed for noise reduction. This data may be useful in the design of mitigation measures for the project.

Estimated noise levels are then input into the appropriate noise modeling software, several types of which are commercially available. The noise levels are converted to sound pressure levels and are used by the computer program to calculate noise level contours. Depending on the type of software used for modeling, the computer program can evaluate the following variables: distance of the source to the receiver, shielding by terrain, atmospheric attenuation, ground attenuation, attenuation by vegetation, and wind and temperature gradients. Generally speaking, the greater input of variables provides for a more accurate prediction of noise levels. Projected noise levels should be evaluated for various stages of the project due to the changes of topography and levels of mining activity that can take place during the life of the mine.

#### *7.3.2.8.4 Predicting Noise Impacts Based*

After the noise level contour map has been generated, an assessment can be made as to the number of receivers which will be affected. An evaluation can then be made as to the degree of impact (i.e. the change from baseline). These evaluations should be conducted for day, evening, and night periods as the ambient and project noise from the project will be different for each time period. Predicted noise levels can also be compared to any noise regulations which may apply to the proposed operation and affected community.

Predicted noise levels should be compared to guidelines and recommendations on acceptable noise levels published by applicable regulatory and scientific sources. These guidelines and recommendations will provide a more realistic impact assessment than just a numerical calculation of noise increase or a comparison of predicted noise levels to regulatory limits.

#### *7.3.2.8.5 Establish Appropriate Mitigation*

Based on the level of noise impact and regulatory constraints, appropriate mitigation should be developed. There are numerous ways to reduce noise impacts to sensitive receivers. The most straightforward of which is to reduce noise at the source. This can best be accomplished by using mining equipment designed with noise reduction in mind. Engine powered heavy equipment can be ordered and equipped with the following noise reducing features: high performance mufflers, air intake silencers, specialized cooling fans, and acoustical absorption material within the engine compartment. Selection of haul truck drive mechanisms is an important factor. Electrically driven trucks can be much louder than mechanical versions of the same size due to the braking systems employed on the electrical models.

Backup alarms used on mobile heavy equipment can be one of the most objectionable and irritating noises generated at a mine site. Federal and state safety regulations require that these alarms be designed to produce 85 to 90 dBA at 50 feet from the equipment. Due to the higher frequency of sound generated by these alarms, the backup alarm noise can easily be distinguished from other ambient noise sources, even if the sound level of the alarm is less.

Strobe lights should be considered for night time operations in lieu of acoustic alarms. The strobe lights can be switched on and off by the equipment operator at

the appropriate hours. Radar controlled back up alarms are also available. The alarms employ a sensor which detects the presence of objects behind the equipment only turning on the alarm when an object is detected. Any of these alternate back up alarms must be acceptable to the federal and state agencies which regulate the facility.

Electrically powered fixed equipment such as crushers, scrubbers, and compressors can best be controlled through motor selection, and screening. Lower RPM motors for this equipment should be selected if possible. Noise from generated from conveyors can be reduced through the use of enclosed rubber lined hoppers and transfer chutes.

All equipment used in the proposed operation should be placed in a position to take maximum advantage of natural screening by terrain. The mine plan should consider noise generation. For example, when mining into a hill or mountainside, mining should begin on the least inhabited side first, if possible, to allow for screening, versus a top down approach where noise will radiate in all directions. Once mining progresses below the pit rim, there will be less noise generated due to screening created by the pit.

The mining schedule may also have to be adjusted to reduce impacts in the evening and night periods when ambient noise levels are generally lower, with night being the lowest. Reduced levels of overall activity, the elimination of noisy pieces of equipment, or not operating in particularly exposed areas are all options which should all be considered. Once mitigation measures have been selected for the operation, another modeling effort should be performed to predict the noise impacts from the mitigated operation. If these impacts are not acceptable further mitigation will be required.

#### *7.3.2.8.6 Implement Long-Term Monitoring*

Once impacts have been predicted and determined to be acceptable, permit conditions for the operation must be negotiated and consideration given to a monitoring program that will determine if the operation is in compliance with its operating permit. The operating permit may contain performance and/or prescriptive standards. Prescriptive standards, for example, may contain conditions that certain pieces of equipment not be operated during the nighttime period, whereas a performance standard might contain a provision that noise generated by the mine not exceed 45 dBA at the property boundary during the night. Monitoring for compliance for the prescriptive standard is straightforward whereas monitoring for the compliance with the performance standard can be extremely challenging. Standard noise monitoring equipment such as those used in the baseline evaluations cannot readily distinguish mine generated noise from non-mine noise, and this can lead to regulatory problems in determining compliance. Tape recorders which are activated at preprogrammed levels can be attached to this standard monitoring equipment. These tapes can then be interrogated to determine what noise caused the elevated noise levels. This, however, is an extremely time consuming process.

Careful consideration should be given to the standards agreed upon to make sure that the operation can comply and monitor compliance with the standards.

### 7.3.2.9 Socioeconomic Assessment by G. Blankenship, L. E. Levy, and R. Dutton

#### *7.3.2.9.1 Socioeconomics in Environmental Permitting*

Socioeconomic studies for environmental permitting of mining projects have to do with people and human organizations, institutions, community infrastructure, customs, values, and social well-being -in other words, the "human environment." The requirement for socioeconomic assessment imposed by federal and local government agencies who lead permitting processes derives from the National Environmental Policy Act (NEPA) and the implementing guidelines and regulations of the Council on Environmental Quality (CEQ). In Sec. 101(b)(2), NEPA requires considerations that "... assure for all Americans safe, healthful, productive and aesthetically and culturally pleasing surroundings." CEQ guidelines of 1973 bring socioeconomic issues directly into the picture by stating that, "Secondary or indirect ... consequences for the environment should be included in the [environmental impact] analysis," and calling out such consequences as population and economic growth and their effect on land use, water, and public services. Although the 1978 CEQ regulations say that "economic or social effects are not intended by themselves to require preparation of an environmental impact statement," they do require that socioeconomics be considered whenever an environmental impact statement is prepared. This requirement is reflected in the guidelines and regulations for impact assessments utilized by virtually all public land and resource management and administrative agencies likely to be involved in the permitting of mining projects.

#### *7.3.2.9.2 How Mining Projects Affect the Socioeconomic Environment*

Mining projects can produce positive and negative socioeconomic effects. Potential positive socioeconomic effects of mining projects are largely economic. Potential negative socioeconomic effects of mining projects may be economic, too, but they also may include conflicts over lifestyles, attitudes, and opinions. On the positive side, mining projects provide new jobs and stimulate

economic activity through the project's own purchases of goods and services and through payrolls to local employees, who in turn also purchase goods and services. Local and state government also may benefit from taxes paid by the mining project and its employees. An enriched economy and increased government revenues can result in social benefits as well, through growth in locally available consumer goods and services, or new and improved public facilities and services. The most common of the potential negative effects of mining projects are the short-term bursts of growth and decline associated with the "boom" or "bust" phases of the mining project life cycle. This typically occurs in small- and medium-sized rural communities when a single mining project is large in comparison to the local economy in terms of jobs created and income generated.

The boom part of the cycle creates negative impacts when project-related growth outstrips the ability of a community to provide housing and public infrastructure. The problem often occurs because of, or is compounded by, the fact that offsetting positive effects, such as local tax revenues, do not flow until after project-related growth has already occurred and imposed its costs. The bust part of the cycle creates negative impacts when mining projects close and mining employees leave. Both private and public sectors of a community suffer losses of revenue when a mining project closes and communities that have added capacity to accommodate a mine work force are left with underutilized facilities and insufficient revenue for maintenance and operations. In extreme cases in small rural communities, where mining has dominated the local economy, mine closure can mark the beginning of a descent into "ghost town" status.

#### *7.3.2.9.3 "Quality-of-Life" Effects*

An elusive but important type of potential negative effect occurs when social conflict threatens to emerge over a proposed mining project. These effects are often referred to as potential "quality-of-life" effects, in contrast to the standard effects on a community's population, economic base, public services, and fiscal resources. Although resistant to facile quantification and less easily characterized than potential economic, demographic, and fiscal effects of a project, the potential for quality-of-life effects on the social environment is increasingly a crucial stumbling block for mining projects seeking permit approval.

Community conflict over a mining project may have many points of origin. The conflict may center on activities perceived as competing with the project for use of land, labor, or other resources. Such uses may include residential development (including second home development), tourism, and recreation. Conflict also may focus on the perceived potential for conflict between the mine work force and the existing population. Such conflicts may emerge over perceived differences in lifestyles, attitudes, and opinions between existing residents and mine-related in-migrants. Finally, conflict may emerge over the perceived potential for negative effects to community social structure and organization due to the growth and change induced by the mining project. This potential is especially large when the project work force is large enough to represent a significant bloc of the population.

Potential conflicts between mining projects and competing land uses, economic activities, social values, and social structure, are often apparent. However, widely accepted methods for analyzing and quantifying the impacts have yet to be developed. Nevertheless, they must be addressed because in recent years more and more mining projects have faced their most significant controversies over quality-of-life effects instead of standard effects. The growing need to consider, assess, and perhaps proactively manage potential quality-of-life effects has added new dimensions to the baseline socioeconomic data requirements for a mining project facing the permitting process.

#### *7.3.2.9.4 Baseline Data Requirements*

The scope of baseline socioeconomic data for a mining project necessarily includes detailed information about the mining project itself. Information needed about the proposed project includes detailed economic, labor force, and land use estimates. Also needed are other estimated effects of the project on air, water, visual, aesthetic, and biological resources in the local environment.

A minimally adequate profile of the project should include a relatively detailed timeline for construction, including a projected date for commencement of operations. The construction and operations work forces should be profiled in terms of numbers of workers by occupation, craft or skill, by wage category, and by union membership status. Detailed information is required on the timing and level of project spending. Spending projections must include expenditures for both capital purchases and the purchase of equipment, materials, supplies, and services. To estimate the distribution of benefits due to direct project spending, it is also useful to collect a distribution of vendors by geographic location. Information on project management policies also is useful. This includes stated or intended practices in the areas of local hiring preferences, shift scheduling, and company sponsorship of transportation or housing.

#### *7.3.2.9.5 The Scope of Data*

When defining the scope of data to collect about the study area, one considers the relationship of the project to the socioeconomic context. A number of questions

must be answered. What geographic area should be included in the study area? Which socioeconomic topics must be considered? How much effort should be given to data gathering and analysis of each topic? Which analytical methods will be used, and what data do they require?

To answer these questions adequately, it is important to conduct a preliminary reconnaissance of the area around the proposed site to obtain community size, distance from the project site, size of available labor pool, a rough outline of the economic base, capacity of existing infrastructure, and a general reading of prevailing attitudes toward mining projects. The preliminary reconnaissance helps to anticipate the level of potential impact. For example, if a mining project with a relatively small work force (50 to 60 operations workers) is proposed for siting 20 to 30 miles from a community of 20,000 or more, one would expect little population growth and, as a result, a small impact on housing and local government. On the other hand, a large project within commuting distance of several small communities would potentially cause impacts in all communities.

*7.3.2.9.5.1 Study Area*

In geographic terms, the study area is an aggregation of the places, jurisdictions, and service areas potentially affected by the proposed mining project. The units to include usually are defined as being within commuting distance of the project gate, as measured in road miles and adjusted for local transportation and weather factors. Plans by the project or the ability of others to develop housing or temporary living quarters near the project site can limit the geographic spread of impacts. Other adjustments to the study area may be dictated by data availability, local concerns, and governmental mandates. Sometimes the study area concept is two-tiered, the first tier being a region large enough to contain most of the expected potential impacts and the second tier being the locality expected to bear the greatest population impact.

*7.3.2.9.5.2 Topics to Consider*

Preliminary reconnaissance assessment should consider every socioeconomic topic and evaluate its potential vulnerability to impact. However, the scoping process may show that some aspects of the socioeconomic environment are less susceptible to impact than others. For example, the existing social environment may be less prone to conflict over a new project where a number of mines already exist, unless there is something unique about the new project to touch off controversy. Aspects of the socioeconomic environment found less vulnerable to impact may be given less scrutiny and occasionally may be omitted from the study altogether, given the concurrence of the lead agency.

*7.3.2.9.5.3 Level of Effort*

The appropriate level of effort accorded each aspect of the socioeconomic environment depends on its potential vulnerability to impact. This in turn depends on the size and characteristics of the project in comparison to those of the study area. For example, if a mining project will employ relatively few persons in comparison to the existing local population, it probably is not necessary to conduct a detailed inventory of housing availability, or to go to great lengths to quantify the capacity of community facilities and services. The reverse may be true if the same mine were placed near a very small community.

*7.3.2.9.5.4 Methods of Analysis*

An array of analytical methods is available for each socioeconomic topic ranging from the simple to the complex in terms of data requirements and application. Vulnerability to potential impact is the main criterion in choosing an appropriate method, since each method will require a certain level of effort to implement. For example, economic impacts may be estimated by using multipliers readily available from general-purpose tables or by using complex and customized economic-demographic models. Where population impacts are expected to be small and the local environment is seen as robust, using the multiplier approach may suffice. When the local environment is presumed to be more sensitive to population impacts, the more complex approach may be required. Although elaborate models do not guarantee accuracy, a rigorous process requires the explicit identification of assumptions and linkages among various aspects of the project environment. This in turn tends to improve the quality of the estimates and enhances their credibility among reviewers and interested publics.

***7.3.2.9.6 Baseline Economic Data***

Baseline data describing the local population and economy drive the socioeconomic study. In all but the most extreme cases, baseline demographic and economic data may be obtained from secondary sources. The U.S. Bureau of the Census is the main source for secondary data on the size and characteristics of the population. State and sometimes local government agencies may also produce demographic information.

Total population from the three or four most recent past decennial censuses will illustrate how the population has changed over time. Population may be presented for the county or counties and other places

within the study area to the degree that they are available in the census reports. Estimates of total population for the years since the last census are available from the Census Bureau and often from state and local governments. When inter-censal estimates are not available, which is often the case in rural areas, local population may be estimated by using housing stock and occupancy data or utility service data.

The most recent decennial census is often the only available source of information on detailed demographic characteristics such as age, sex, race, and ethnicity. These may be available for counties and a few places. Inter-censal information on detailed demography usually is not available. If it is required, this information must be estimated.

The U.S. Bureau of Economic Analysis (BEA) is the main source for secondary data on local economic activity down to the county level. The BEA has prepared annual estimates of income (including total personal income and per capita income) and employment by industry for every county in the U.S. since 1969. However, there is an almost two-year lag in the release of BEA data (i.e., 1993 data will be available in 1995). More recent information on employment and income, plus information on labor force size and unemployment, is available from the state employment agency. The decennial census also provides detailed information on personal, household, and family income, plus detailed worker characteristics such as occupation and commuting. However, census information becomes increasingly out of date as the decade progresses. In any case, care must be taken in comparing census, BEA, and state employment data because many similar concepts are in fact defined quite differently.

Often, secondary sources of economic data must be augmented by primary research. This may consist of interviews with officials in the key industries of the study area. The purpose of the interviews is to develop a more thorough understanding of the activities that dominate the study area's economic base. Information collected from local sources also may help localize county data to the community level, if necessary.

#### *7.3.2.9.7 Housing Data Requirements*

The housing information needed to assess availability for future population growth, including growth associated with the proposed project, is collected in terms of an inventory of housing or a housing count, housing values, and occupancy or vacancy rates. Housing data are available from the decennial census, but local housing information from government or private agencies is likely to be more accurate and reliable. Where housing data are not readily available, it may be necessary to collect the required information directly. This usually involves a survey of real estate agents, apartments, mobile home parks, hotels, and motels. An alternative is to interview local utility personnel (e.g., power, water, sewer, or telephone) or to review the classified advertising sections of local newspapers.

When inventorying housing, it is important to keep in mind that housing types appropriate for construction workers may be different from those appropriate for the longer-term operations phase workers. While the latter may buy or rent houses, construction workers may prefer accommodations in hotels and motels, or require space to park their own travel trailers or recreational vehicles because they may only be needed on site for a few weeks or months.

In communities where housing is in short supply, the potential to expand housing supplies should be assessed. This can be done by inventorying the supply of appropriately zoned land and evaluating other conditions that facilitate housing development. For example, is developable land served by or within extension distance of access roads and water and sewer mains? How much lead time is required to obtain the needed permits to construct housing? Are there investors, developers, and construction contractors interested in and capable of developing new housing? Information on these characteristics may be assembled to evaluate whether local housing supplies can expand to meet new demand.

#### *7.3.2.9.8 Infrastructure Data Requirements*

For mining projects anticipated to have a large work force, it is advisable to inventory community facilities and services. The conventional facilities and services to be inventoried are schools, public water and sewer, fire protection, law enforcement, ambulance and other emergency responders, courts, criminal detention facilities, hospitals, parks, other recreation facilities, and general government facilities such as county court houses and city halls. Increasingly, human service agencies and facilities are seen as "front line" agencies in the local government response to growth. Agencies in this category cover child care, social services, mental health and other forms of counseling, domestic violence crisis center and safe houses, and substance abuse treatment services.

The inventory should consider service availability, service area, capacity, condition, staff, equipment, sources of funding, and the adequacy of current funding. The best available source of information about community infrastructure is ordinarily the local official or administrator responsible for the particular facility or service under consideration. Recent reports, such as needs assessments or service evaluations, may be available but should be used with caution because they go out of date rapidly.

#### *7.3.2.9.9 Local Government Finances Baseline Data Requirements*

The ability of a community to accommodate a mining project will depend largely on the financial condition of the jurisdictions within the study area. Increasingly, local fiscal capacity is a key pressure point as local governments are whipsawed by federal and state governments mandating more local responsibility for service delivery but transferring less revenue to the local level.

Baseline data requirements for analysis of local government fiscal conditions are local government budgets, revenues, expenditures, tax bases, and tax rates. Data from local government budget documents and annual reports should be assembled to develop trends in revenue levels, sources of revenue, expenditure levels, categories of expenditures, and other statistical information about local government finance. The same documents should provide information on the property tax that finances a large proportion of local government activity. Interviews should be conducted with local officials to interpret the fiscal information and identify issues that are not immediately obvious from the standard reports.

#### *7.3.2.9.10 Social Conditions Data Requirements*

Much of the information required for the social assessment is also required for other aspects of the socioeconomic analysis. This includes demographic data (age, sex, race, ethnic origin) and economic data (occupation and earnings). In addition, it is useful to gain an understanding of the social organization of the area and communities. This can be obtained by collecting information on churches and social and service organizations and by reviewing newspaper articles. All of these data sources can and should be illuminated by interviews with key informants. Key informants are essentially individuals with knowledge about specific aspects of the socioeconomic environment. Examples of key informants would be local officials (e.g., county commissioners, mayors, etc.), community organization leaders (e.g., chamber of commerce, League of Women Voters, civic and service club officers, clergy, etc.), and representatives of interest groups (environmental, recreational, industrial, etc.). Key informant interviews are more than casual conversations. Such interviews are typically designed and administered by professionals to elicit reliable responses on specific topics. Key informant interviews often identify further topics for research.

#### *7.3.2.9.11 Existing Land Use Data*

Inventories of adjacent and surrounding land use are necessary to identify areas of potential conflict. They are also good sources for identifying lands for relocating displaced uses. County land use plans are the best source of data on the county level, and a visual inventory of lands adjacent to the project site is obviously a good idea. Federal land management agencies such as the U.S. Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) prepare resource management plans for lands under their administration. These plans are another good source for land use data.

#### *7.3.2.9.12 Recreation Resources*

Recreation resources can include both recreational facilities provided by local governments and private organizations, and resource-based (e.g.. lake, river, stream, forest, mountain) recreation opportunities. Mining projects have the potential to affect recreation resources in two ways — first, by increasing use of recreation resources through the increased population associated with a project; and second, by a direct effect such as the development of a mine or ancillary facilities on or near land previously used for recreation purposes. Recreation inventories should identify the area's recreation resources and quantify and characterize recreation use.

#### *7.3.2.9.13 Baseline Data as a Resource for Impact Management*

As it is for other technical disciplines, the scope for socioeconomics is driven by the preliminary identification of areas of potential impact. The fact that areas of potential impact are identifiable at this stage of the environmental permitting process offers mining companies an opportunity to take steps to avoid or minimize the impacts through project redesign or other proactive intervention.

With increasing frequency, socioeconomic issues are key obstacles to the permitting and developing of mining projects. Just as there are opportunities to avoid or minimize environmental effects of projects at the design stage, there are numerous opportunities to avoid or minimize socioeconomic issues. Examples of such design alternatives include the location of mine facilities and access roads to avoid conflicts with other land uses, and leaving buffers to screen mining activities from other land uses such as tourism attractions and recreation facilities. An intriguing design alternative that is beginning to receive some consideration is the post-closure reclamation of mined lands and facilities for new recreation facilities. Obviously these alternatives have associated costs that must be weighed against the costs of project delay and additional permitting and legal costs resulting from local and third-party interest group opposition.

Social impacts also are amenable to intervention. Although mining projects potentially affect social conditions, particularly in small rural communities with no recent history of mining activities, there are opportunities for mining companies to influence whether the social effects of a particular project are perceived as positive or negative. Identification of social issues occurs during baseline data collection. These data are the information base required to develop an understanding of the social conditions susceptible to controversy, public opposition, or public support. In turn, analysis of these susceptibilities can lead to strategies that, if implemented by the mining company at an early stage of the permitting process, may minimize the costs of potential delay or litigation during permitting.

### 7.3.2.10 Surface Water
**by J. Kreps**

#### *7.3.2.10.1 Introduction*

Baseline investigations describe the physical and chemical qualities of surface water resources located within or flowing through the project area. Special interest should be paid to those resources that are likely to be affected by project development, such as process water and drinking water supplies and surface water bodies that coincide with or are downstream of project components. Existing non-project related disturbances to surface water quality or availability should be well-documented during the baseline investigation to avoid post-startup liability concerns.

A common way to define the baseline study area is to determine the major surface water drainage in the project area and to designate the baseline area as all or part of the watershed for that drainage, depending on the area of the watershed and distance between project components. Defining the study area in this way has obvious benefits in simplifying the analysis of surface water and groundwater data. In areas of higher topographic relief, watershed boundaries are frequently ridges or mountain tops that may also serve as biological divides, thereby providing a convenient coincident boundary for the flora and fauna baseline investigations as well. Some projects may have components located in more than one watershed, in which case all or part of the applicable watersheds may be included in the baseline investigation, depending upon the size of the areas involved and the time and resources allocated to the baseline study.

#### *7.3.2.10.2 Physical Parameters*

Physical data relevant to the surface water baseline include location information of surface water resources, flow rates, impoundment pond levels, flood volumes and recurrence intervals, evaporation rates, construction and operation data for diversions, and constrictions on inflow or outflow to impoundments in the study area. The baseline should include a map (or table, if maps of the area are not available) indicating the known surface water resources within the study area, including rivers, perennial and relevant ephemeral streams, lakes, ponds, springs, and seeps, wetlands, reservoirs, and other man-made impoundments, adit drainage, canals, and surface water diversion structures such as aqueducts and pipelines. Flow rates, impoundment levels, and diversion rates are frequently obtainable from the local or regional water management districts, and are very useful for planning and design purposes further into the feasibility stage of many projects. If the study is performed in a remote area or with no existing stream measurement database, flow estimates can be easily made using a v-notch weir (for small creeks) or flow meter. Categories of previous and current water usage should be documented, including sources and rates of withdrawals for domestic, agricultural, and industrial use, and any areas of special use by terrestrial or aquatic wildlife should be documented.

Much of the surface water baseline data has direct applicability to other stages of project development. A properly constructed surface water baseline investigation can form the basis for ongoing routine surface water monitoring during project development and operation. Surface water flow velocities and flood magnitudes and recurrence intervals obtained during the baseline study can be used during the engineering design phase to determine which nearby surface water resources are capable of meeting project needs (such as drilling, drinking water, process water, and dust suppression) and in design of diversion structures and catchment basins. Flow rate data can be used to allocate surface water resources in areas of high demand and/or limited resources or when calculating demands from aqueducts or irrigation diversion canals, and are thus important in ascertaining environmental impacts of project development. In areas where adit drainage or pit lake formation is a concern, exploration drilling logs and field notes documenting water shows are useful.

#### *7.3.2.10.3 Chemical Parameters*

Documenting the qualities of surface waters in the baseline study area before project development is a critical part of the baseline program. Any existing sources of contamination should be fully documented at this phase of the project to allow proper assessment of the potential environmental liabilities associated with the site. This is particularly important where baseline surface water quality differs from background (or natural) surface water quality, or in highly mineralized areas where

elevated concentrations of some parameters such as metals occur naturally in surface waters. Delineating baseline conditions before project development will set background values for non-degradation standards, should those apply to the project, and will create a database of water quality information against which water quality impacts during operation can be measured, and provides a standard for closure commitments.

Ideally, a sufficient number of baseline analyses to document seasonal variation and consistency should be compiled before actual or potential disturbances to the project area begin, such as construction activities or mill start-up. After review of the baseline water quality database, some monitoring points may be dropped from the program and others added, or the frequency of monitoring may be increased or decreased, depending on the importance of the monitoring points. When documenting non-project-related discharges, less frequent sampling can often suffice, for example, one sample collected during the wet season or during high-flow conditions, and another sample collected during dry season or low-flow conditions.

The choice of analytical parameters for surface water quality analyses depends upon a number of factors, factors, including surficial geology, mineralization, existing impacts to surface water quality, current and future surface water uses, and process chemicals to be used at the project. For instance, if cyanide will be used for precious metal recovery, the surface water baseline should document existing levels (or non-presence) of cyanide and nitrates in downstream surface waters prior to actual usage of cyanide at the site. Surface waters are typically analyzed for the following types of parameters: field parameters, major components, and metals (total and/or dissolved). Special parameters may be added depending upon the particular concerns involved with individual projects, and could include biological parameters like enteric bacteria, organic compounds, cyanide, or radiologic parameters. Bacteriological parameters including total and fecal coliform can become important to the baseline study if potential contamination sources like stockyards are located adjacent to project components, if fisheries are nearby, or if sanitary facilities are to be included as part of the project; for instance, if a man camp has an associated water treatment facility, or if the mining company contributes to operations of sanitary facilities and then assumes partial liability for their discharge.

Temperature, pH, total dissolved solids, conductivity, and Eh should be measured in the field or as soon after sample collection as possible, as these parameters change with time after sampling. These parameters can be measured easily and inexpensively in the field, and can be used as indicator parameters during the reconnaissance phase of the baseline studies to assist in selecting sites for the baseline sampling program. Other parameters typically measured in the field include alkalinity, acidity, and hardness.

Major components include the cations calcium, magnesium, potassium, and sodium and the anions chloride, nitrate, orthophosphate, and sulfate. Depending on local conditions additional parameters such as ammonia, bromide, fluoride, iodine, nitrite, sulfite, dissolved oxygen, and biological oxygen demand may be determined. Holding times for the major components are sufficient for transport to the laboratory and analysis in most areas, however some parameters (such as nitrate, nitrite, and orthophosphate) have shorter holding times which may require analysis in the field or at the project site, if the project is located in a remote area.

The metal ions selected for analysis depend upon local lithology and mineralization, and should also include those species for which health-related standards exist in the state, province, or country of interest. More common metals included in many surface water sampling programs are aluminum, copper, iron, manganese, lead, and zinc. Additional metals including arsenic, cadmium, chromium, mercury, selenium, and silver may be included in areas with suitable mineralization trends or existing industrial contamination. Metal concentrations are generally measured as either total (on an unfiltered sample) or dissolved (on a sample passed through a 0.45 micrometer filter). Choice of filtration or total analyses depends upon regulatory requirements and standards, surface water usage, suspended sediment levels, and predicted metal concentrations. Many baseline sampling programs will measure one type of metal analysis each month, and add the other analysis on a quarterly basis; for instance total metals are analyzed monthly and every third month a filtered duplicate sample is also provided to the laboratory for dissolved metals analysis. Since the use of different filter types and filter sizes is a topic of ongoing debate in the aqueous geochemistry and regulatory communities, total metals analyses generally represent a conservative alternative, although they may not be suitable for all situations.

#### *7.3.2.10.4 Quality Assurance and Control*

All sampling programs should include some level of quality assurance and quality control (QA/QC) if their results are to be meaningful. This is generally accomplished by submitting blanks and duplicate samples with the regular surface water samples for analysis. These QA/QC samples are called "blind" samples and labeled in a similar fashion to the regular samples to avoid any potential laboratory bias. Blind QA/QC sample types include a field and equipment blanks, which consist of the deionized water used to rinse equipment and to perform field analyses. These samples can determine whether field techniques including handling and transportation and equipment maintenance procedures

are contributing any contamination to the samples. At least one blind duplicate sample should be collected for every ten to twenty surface water samples to determine the precision of the analytical laboratory. Samples of known composition can be submitted periodically for analysis to determine the laboratory's accuracy. Standard composition solutions for QA/QC are widely available through commercial suppliers, although they tend to be somewhat expensive, and are thus best used sparingly. Cation/anion balances can also be calculated to determine the accuracy and completeness of field and laboratory analyses.

### 7.3.2.11 Terrestrial Wildlife
**by L. Sharp**

#### *7.3.2.11.1 Introduction*

This section discusses baseline data requirements for terrestrial wildlife. Terrestrial wildlife typically includes amphibians, reptiles, birds, and mammals; however, terrestrial invertebrates are also of increasing concern to state and federal agencies. There is a need to work closely with individuals working in related fields, particularly vegetation, wetlands, T & E species, aquatic biology, and fisheries in performing terrestrial wildlife baseline studies. Information shared between these disciplines is important to developing a complete picture of the terrestrial wildlife inhabiting (and possibly inhabiting) the project site.

#### *7.3.2.11.2 Habitats*

A description of the habitats present on the project area is essential. The habitat map should be based on the vegetation map, and also include other important features such as migration or other seasonal movement routes and corridors, special breeding sites, winter range, summer range, caves, cliffs, rock outcrops, wetlands, open water, intermittent streams, forest areas with snags and/or dead and down woody material, vernal pools, leks, raptor nest sites, bat hibernaculae, bat breeding colonies, springs, and so forth. Abandoned buildings and mine shafts can be important for some species. Mine highwalls can provide raptor and other cliff-user habitat and preserving them as part of a mine closure plan could benefit wildlife in areas where cliffs are scarce, particularly in areas where trees are absent.

The landscape scale aspects of habitats should be identified on a regional map showing the distribution of the various local habitats. The report should show how this site fits into the regional picture. For example, information should be provided on whether the area of impact comprises a relatively large proportion of a unique, limited habitat within the region. Similarly, the spatial relationship of the project area to sensitive habitats such as migration corridors, big game winter or summer range, grouse winter range or lek sites, or nest sites of a threatened or endangered species should be evaluated.

#### *7.3.2.11.3 Literature Review*

The appropriate ecological services office and/or species office of the U.S. Fish and Wildlife Service (FWS) should be contacted by phone, followed by a letter requesting information about whether any Threatened or Endangered species are known to occur in the project area. A legal description of the project area (Township, Range, Sections) and a map should be included. Most States have a system, often termed a "Natural Heritage Database", for tracking wildlife and plant species of concern, and should be similarly contacted for information. The state organizations often charge for this service. Sometimes this information is considered to be privileged and sensitive, and specific locations of sensitive species will not be divulged. A waiting period of at least 2 or 3 weeks to obtain this information is common, so it should be ordered immediately to be available prior to initiating the field study.

Local and regional state wildlife agency personnel should be contacted and interviewed in person if possible. A site visit with the local representative and anyone from a regional or central office who is involved in the permitting or permit review process is always a good idea. Other sources of information to be contacted include Audubon Society members, universities and colleges, high school teachers, environmental learning centers, U. S. Forest Service (FS) and U. S. Bureau of Land Management (BLM) offices.

Many state highway agencies keep records of the large mammal road kills for as long as 3 years; this can be extremely useful in identifying migration or movement corridors. Technical journals should be reviewed for studies done in the region (good literature search capabilities exist at most university and college libraries, as well as FS and FWS offices). Nearby National Wildlife Refuges, state game areas, National and state parks should be contacted. Spending a day or two discussing the site is often the best way to discover relevant publications and unpublished reports. The local public and university/college library will have copies of government documents, such as Environmental Impact Statements.

A work plan should be prepared and peer reviewed by the local and federal wildlife agencies so they know what is proposed; their comments and suggestions should be addressed. Wildlife biologists at the local level often have a great deal of unpublished data. Scientific collecting permits may be required from state and federal offices; the

permit applications should be submitted with the work plan. Local experts should be contacted about the site. It is often quite cost-effective to contract with local experts, or experts on specific groups or species, for literature reviews and/or field studies.

#### *7.3.2.11.4 Conduct Field Surveys*

The intensity of field surveys will depend in part on the state of existing knowledge about the area and the level of concern about various groups of wildlife by state and federal regulators and the public. If possible, field surveys should span at least an entire year so that seasonal use patterns can be identified. Ensuring that field studies are conducted using acceptable methods and by experts who have good credibility with state and federal wildlife agencies is essential. There are numerous publications describing the various wildlife field survey techniques, their results, advantages and disadvantages, and applicability in various habitats for various species. One of the best initial references is The Wildlife Society's *Wildlife Management Techniques Manual* (Schemnitz, 1980).

Searches of specific habitats for reptiles and amphibians, such as time-area searches, placement of artificial cover where it is lacking, to be followed by later surveys are some of the most effective methodologies. Dipping in aquatic sites to look for adult and juvenile amphibians, and surveys on rainy nights for adult amphibians are effective. Pitfall traps can also provide information on these species as well as small mammals and invertebrates.

Birds should be inventoried during the spring and fall migration seasons, the spring breeding season, later in summer, and one or two times during the winter to identify seasonal patterns and species present. Surveys of likely habitat for nesting raptors, displaying grouse, aquatic habitat, or other special sites should be conducted at the appropriate time of day and year. Dawn breeding bird surveys should be undertaken during May and June. Night surveys for owls should be conducted. Surveys using taped calls to elicit responses from difficult to detect species, such as owls, some raptors, and even some woodpeckers are also useful.

Mammal surveys can include ground transects, aerial surveys of big game, ground/car surveys of raptor nest sites, big game, and other mammals (including nightlighting) if permitted by the habitat and visibility. Trapping of small mammals is expensive in terms of time, but should be conducted to determine baseline conditions because small mammals provide the food base for many other predators, and are indicators of the quality of the environment in general. Smoked metal plates laid on the ground, winter track counts in the snow, and scent post surveys for carnivores are other techniques to consider.

Surveys for invertebrates can include pitfall traps and searches of specific habitats at appropriate times of year.

#### *7.3.2.11.5 Report*

Baseline data should identify all wildlife species (by common and scientific name) occurring or possibly occurring in the project area, their habitat affinities, information on habitats (including maps), whether the species is a permanent resident, summer resident, migrant, or vagrant, known or suspected to occur, known or suspected to breed, estimated relative abundance, and distribution regionally and locally. Areas, sites, and features of specific importance to those groups must be identified. The baseline data should also provide a separate tabulation of rare, threatened, endangered, candidate, sensitive, Management Indicator Species, and otherwise special-status species that are known to occur or that might occur on the site. This tabulation should include the species, its status (state, federal, FS, BLM, etc.), and comments on whether suitable habitat exists in the study area, whether it was observed, and if not known to occur, the probability that it occurs. In addition to the Endangered Species Act, implemented by the FWS, many states have their own legislative programs of listing, monitoring, and protecting rare species, game species, endemics, or peripheral populations and all of these should be addressed in the baseline report. Threatened and endangered species are addressed in additional detail in Section 7.3.2.12.

### 7.3.2.12 Threatened and Endangered Species by P. V. O'Connor and W. J. Clark

#### *7.3.2.12.1 Introduction*

The Federal Endangered Species Act (ESA or Act) was enacted in 1973 to protect threatened or endangered plant and animal species as well as their designated critical habitat. The ESA is applicable to all lands (public and private), especially in light of a recent United States Supreme Court decision (*Sweet Home Chapter v. Babbitt*). While the ESA is relatively brief (i.e., encompasses only 18 sections) in comparison to more recently enacted environmental laws (e.g., the Clean Air Act encompasses 175 sections), the law is a constant focus at mine sites. This chapter provides a synopsis of pertinent section of the ESA and some examples of mitigation that have been required at mine sites.

#### *7.3.2.12.2 Background*

##### *7.3.2.12.2.1 Section 4*

Section 4 of the ESA requires the listing of any species

that is determined to be threatened or endangered based on the best scientific and commercial data available. An "endangered" species is an animal, fish, or plant species that is in danger of extinction throughout a significant portion or all of the species' range. A "threatened" species is that animal, fish, or plant species that is likely to become endangered in the foreseeable future.

Besides listing a species, Section 4 requires a designation of the species' critical habitat based on the best scientific data available after taking into consideration economic and other relevant impacts. Critical habitat is to be designated concurrent with listing of the species, subject to several exceptions. Moreover, areas that would otherwise be considered critical habitat can be excluded from designation if the benefits of excluding the area outweigh the benefits of designation. Areas designated as critical habitat can include private lands as well as Federal and State lands.

Once a species is listed or its critical habitat designated, the protections and requirements of the ESA are triggered for projects — existing and proposed. The triggering occurs whether or not a Federal agency or Federal lands are involved, as addressed below.

*7.3.2.12.2.2 Section 7*

The ESA can be triggered if some form of Federal action is required. That is, the consultation mandates of Section 7 are triggered if a Federal agency proposes to authorize, carry out, or fund an action (i.e., an "agency action") that is likely to jeopardize the continued existence of a threatened or endangered species or result in the adverse modification of that species' critical habitat. An example of an agency action is the approval by the Department of Interior--Bureau of Land Management (BLM) of an applicant's Plan of Operation submitted pursuant to 43 C.F.R. Subpart 3809 to disturb Federal lands in excess of five acres. Consultation is between the Federal agency proposing to take an agency action (e.g., the BLM) and either the Department of Commerce--National Marine Fisheries Service (NMFS) for marine life and anadromous fish or the Department of Interior--Fish and Wildlife Service (FWS) for all other plant and animal species.

The consultation process typically involves a multi-step procedure:

*First*, the Federal agency initiates informal consultation by requesting information from the FWS or NMFS of whether a species listed or proposed to be listed may be present in the area of the proposed action. The identification of a listed species in the area of the proposed action does not automatically mandate formal consultation. The FWS or NMFS may determine during this informal process that the listed species will not be affected by the proposed action (e.g., the abandoned adit in which endangered bats reside will not be disturbed by the proposed mining operations). As such, the requirements of the ESA are not triggered. Formal consultation is required upon an informal determination that the proposed action may jeopardize a listed species or adversely affect critical habitat.

*Second*, assuming formal consultation is mandated, the Federal agency involved with the proposed action develops a Biological Assessment. No specific format must be followed for this document. However, a Biological Assessment typically identifies the species or critical habitat of concern, addresses the proposed action (e.g., open pit mine), determines the impact(s) that may occur if the agency action is implemented, and identifies mitigation procedures to lessen or avoid potential impacts from the proposed action.

*Third*, the FWS or NMFS utilizes the Biological Assessment to develop a Biological Opinion. The Biological Opinion presents FWS' or NMFS' determination of whether the proposed agency action will jeopardize a listed species or adversely modify its critical habitat. Reasonable and prudent alternatives shall be suggested if a listed species will be jeopardized or critical habitat will be adversely modified.

*Finally*, a permit authorizing a "take" of the listed species, subject to specific conditions, can be issued if the proposed action cannot be modified to avoid jeopardy to the listed species and the FWS or NMFS determines that the allowed "take" will be incidental. Section 3 of the ESA defines "take" based on a litany of verbs: "harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct." "Harm" has been defined by the FWS (50 C.F.R. § 17.3) to include actual death or injury from "significant habitat modification, which interferes with significant behavioral patterns." The United States Supreme Court upheld the validity of this "harm" definition in a 1995 decision (*Sweet Home Chapter v. Babbitt*, 115 S.Ct. 2407 (1995)). Thus, a permit issued under this section would address the specific listed species as well as adverse modification of the species' critical habitat.

*7.3.2.12.2.3 Sections 9 and 10*

The ESA also is triggered at mine sites that are entirely on private lands where no Federal nexus exists if the proposed activity may result in the take of a listed species. (As noted above and confirmed by the United States Supreme Court, take includes both a listed species as well as designated critical habitat.) Section 9 of the ESA provides a blanket prohibition for any person to

take an endangered plant or animal species. However, a permit can be obtained under Section 10 allowing an exemption to this blanket prohibition, if the take is incidental to an otherwise lawful action.

An applicant must develop a habitat conservation plan (HCP) to support the issuance of a Section 10 permit. The HCP is an extensive document that must address, among other matters, the proposed action, the impact that may likely occur from the proposed take, the mitigation to be implemented to minimize impacts of the take, the source of funding to assure mitigation is implemented, and any project alternatives that were considered but eliminated from further consideration. (Congress suggested that a HCP should be measured against the *San Bruno Mountain Habitat Conservation Plan*--the HCP developed for a listed butterfly species found in southern California.) A Section 10 permit is issued upon a determination by the FWS or NMFS that, among others, the take will be incidental, the applicant will minimize to the extent practicable the impact of such take, the applicant will provide the funding noted in the HCP, and the proposed take will not appreciably reduce the likelihood of recovery and survival of the listed species.

#### *7.3.2.12.3 Mitigation*

No one set of mitigation techniques is or can be applicable to mining operations that trigger the mandates of the ESA. Mitigation techniques and requirements vary due to, among other factors, the ingenuity of the applicant, the listed species potentially impacted (e.g., fish versus plant versus bird), the sophistication of the Federal agencies involved, and the type and extent of critical habitat to be potentially adversely impacted. As such, only examples of mitigation that are being undertaken at mine sites can be addressed herein.

##### *7.3.2.12.3.1 Desert Tortoise*

The desert tortoise (*Gopherus agassizii*) is a threatened species found in the desert regions of southwestern United States--Arizona, California, Nevada, and Utah. Mitigation required by the FWS of, and currently being implemented at, mine sites in southern California includes the following:

- Purchasing and prohibiting development of other lands containing suitable tortoise habitat to compensate for areas to be disturbed by mine operations.
- Fencing the entire mine site with tortoise-proof fence to reduce the migration of tortoise onto the mine site.
- Surveying the entire mine site to find tortoises to be relocated away from proposed mining areas.
- Employing specially trained individuals to handle or capture and remove encountered tortoises for relocation from the mine site to designated sites off the mine proper.
- Enforcing posted reduced speed limits on mine access roads to reduce vehicular collisions with tortoises.
- Requiring attendance at classes to educate employees about the tortoise and its habitat.
- Removing accumulated trash to reduce food source of species predatory to tortoises.
- Authorizing by permit the take by relocation of tortoises found on the mine site.
- Authorizing by permit the take by incidental killing (e.g., inadvertently driving over a tortoise that attempted to traverse a haul road).

##### *7.3.2.12.3.2 Bald eagle*

The bald eagle (*Haliaeetus leucocephalus*) is a threatened species found throughout the continental United States. Some of the mitigation required by the FWS includes the following:

- Seasonally restricting mining activities to avoid impacts during mating, nesting, and brood-rearing season.
- Constructing new roosting/nesting sites away from the mine site.
- Relocating existing nests to areas off the mine site.
- Installing raptor-proof electric power transmission poles.
- Conducting regular surveys to determine if bald eagles are being impacted by mine activities.

### 7.3.2.13 Vegetation
**by B. Garrett**

Vegetation analysis is an important aspect to the development of mining activities from the preliminary phase through the final stages of a mine's life. A complete analysis of the vegetation community will identify its characteristics including the presence of protected plant species, their frequency of occurrence, and their location within the project area. Additionally, the characteristics of the vegetation are used to determine wildlife habitat types and values, as well as in the development of the reclamation plan. Therefore, it is important to establish an accurate and thorough accounting of the vegetation prior to disturbance within the project area.

Prior to conducting analyses to determine the vegetation characteristics of the project area, consultation and coordination with the affected governmental agencies is recommended. This step is integral to the development

of an effective strategy for environmental compliance. Consultation should begin with the lead federal agency, which is responsible for consulting with all participating agencies. The lead federal agency will also coordinate consultations with the U.S. Fish and Wildlife Service (USFWS) if threatened , endangered, or sensitive listed species are determined to be affected. These agencies should provide guidance for developing a strategy for field investigations as well as in the development of a revegetation plan.

Additionally, state agency consultation and coordination is also recommended. In recent years, many states have passed legislation to protect and monitor populations of plant species unique or rare to their state. This legislation enables the state to enforce protection measures for plant populations to the same degree afforded to protected wildlife species. Therefore, it is essential to consult both federal and state agencies at the development stages of a proposed action in order to avoid any potential delays and/or permitting problems.

Subsequent to consultation with the lead federal agency and state resource agencies, the proponent should conduct a thorough literature search to determine potential sensitive plant species, and provide an overview of the habitats which may be affected by the proposed action. The literature search should include a review of agency files, federal and state databases, and personal communications with agency personnel, local residents, and environmental action groups. Information obtained through the literature search and consultation with all participating agencies should provide the proponent with the baseline data. Thereby, a strategy for further investigations can be formulated.

Based on the results of the literature search and consultation with relevant resource agency personnel, the level of effort required for investigations can be defined. Since the vegetation characteristics of the project area are relevant to the determination of wildlife habitats and development of the revegetation plan, a thorough understanding of this resource is required. Therefore, at a minimum, it is necessary to obtain the baseline data on the vegetation characteristics of the project area. Additional analysis may be required if protected plant species were identified as occurring or potentially occurring within the project area. Acquisition of baseline data of the vegetation characteristics of the project area is generally collected through off-site and on-site analyses.

Off-site analysis includes the review of available aerial photography and topographic maps in order to determine preliminary vegetation boundaries. Aerial photographs are especially useful for large projects since dramatic changes in vegetation can be identified. From the information gathered during the off-site analysis, an appropriate on-site analysis method can be developed.

On-site analysis generally consists of completing linear transects across the project area. Prior to conducting the field work, it would be pertinent to discuss the field methods with all relevant agency personnel. This will assist in the determination of the appropriate level of effort necessary to execute the project at hand. The main purpose of the linear-transect survey method is to identify the species present, determine their relative abundance and to verify preliminary vegetation characteristic boundaries established during the off-site analysis. Transect intervals for the baseline data acquisition varies depending on the results of the literature search, resource agency consultation, off-site analysis, project size, topography and vegetation homogenicity. In addition, determinations regarding wildlife habitat types and their extent can be assessed. Generally, information regarding habitat types (for example; desert scrub, woodlands and wetlands) are either defined in current publications or by relevant resource agency personnel. Moreover, the culmination of these data will aid in the development of appropriate seed mixtures for the revegetation plan.

Supplemental data to the baseline data acquisition is generally necessary if any protected plant species are identified as occurring or potentially occurring in the project area. Information regarding the presence or absence of the protected species will need to be obtained. This information can be obtained by completing transects at appropriate intervals (20-30 feet) so as to accomplish 100% coverage of areas identified as being suitable for the protected species to occur. These transects must be completed during the appropriate seasons when the plant is evident in order to determine absence.

All information collected during the literature review and the field surveys should be presented to the lead federal agency in the form of an environmental assessment/evaluation. If listed wildlife species are going to be affected, a biological assessment should be prepared for the proposed action to initiate Section 7 consultation with the USFWS. The information obtained on listed plant species should also be included in the document. If listed wildlife species are not affected by the proposed action, the information should be included in a biological evaluation, which will be submitted to the USFWS. Further consultation and coordination with the lead federal agency should continue throughout the preparation and execution of a revegetation plan.

### 7.3.2.14 Wetlands
**by S. Foreman**

#### *7.3.2.14.1 Introduction*

The presence of wetlands at a mining site can have significant implications with respect to the environmental review and permitting of facilities. Wetlands are transitional between well drained uplands

and deep water aquatic habitats such as rivers and lakes. Wetlands have traditionally been considered to be features such as marshes, swamps, and bogs; however, many wetlands, particularly wetland communities dependent on seasonal rainfall in the arid west, are visually less distinct from the surrounding upland communities to the untrained observer. These include habitats or features referred to as vernal pools, prairie pot holes, playa lakes, wet meadows, seeps, springs, and seasonal wetlands.

Wetlands are characterized by the presence of hydrologic (water) conditions which saturate the soil for a sufficient period during the growing season to develop anaerobic conditions. This in turn allows only plants adapted to this anaerobic environment to persist.

Wetlands are considered important because they typically perform many important functions such as:

- Water quality protection.
- Hydrologic functions such as groundwater recharge, shoreline protection, flood water storage and desynchronization, and hydrologic support for maintenance of low stream flows.
- Biological functions such as fish and wildlife habitat including habitat for many threatened and endangered species, food chain support and biomass production/nutrient export.
- Socio-cultural functions such as economic values for recreation, education, aesthetics, and other industries such as fur harvest and commercial fisheries.

Many different federal agencies, including the Soil Conservation Service (SCS), Environmental Protection Agency (EPA), U.S. Army Corps of Engineers (Corps), U.S. Fish and Wildlife Service (USFWS), Bureau of Land Management (BLM), and U.S.D.A. Forest Service (USFS) have responsibilities to protect wetlands. These responsibilities include regulatory authorities (permits) while others involve use of federal lands or monies. At least 19 states and many local jurisdictions (cities and counties) have additional regulatory programs involving wetlands.

The primary legislative authority to regulate wetlands is based in Section 404 of the federal Clean Water Act (CWA) which regulates the discharge of dredged or fill material into "waters of the United States." Waters of the United States has been defined by CWA implementing regulations (33 CFR Part 328, Vol. 51, No. 219) developed by the Corps and EPA to include wetlands and other waterbodies of which the use, degradation or destruction could affect interstate or foreign commerce. In addition to wetlands, "other waters" also includes territorial seas, lakes, rivers, and streams (including intermittent and ephemeral streams) and the tributaries to such waters.

If wetlands are to be impacted by a project, mitigation for the impacts is commonly required. However, before mitigation will be considered by the Corps, the applicant must demonstrate that there are no feasible alternatives to the impacts and that the total area of impact has been minimized to the maximum extent practicable. The federal agencies (USFWS, Corps, EPA) and many state agencies have adopted "no-net loss" policies for wetlands. This typically translates into no net reduction of acreage or extent and no decrease in value of impacted wetlands. Mitigation required for impacts typically takes a hierarchial approach of avoidance first, followed by compensatory replacement to minimize unavoidable impacts.

Following is a discussion of the typical baseline data requirements and approaches for addressing potential environmental and regulatory requirements associated with wetlands.

#### *7.3.2.14.2 Literature Review and Agency Contact*

An important first step is to define precisely the limits of the study area. This should include the primary project area or mine site as well as associated ancillary facilities such as access roads, haul routes, work pads, water supply features (stream diversions, wells, ponds, etc.), and waste or mine burden storage areas. This can be depicted on available maps. In most cases this information can be at least initially displayed on standard 7.5 minute U.S. Geological Survey (USGS) quadrangles maps. Mapping in this manner will facilitate discussions with appropriate agencies and allow easier comparison of planned activities with typical background sources of information.

Background sources that in many cases can provide useful information regarding the presence of wetlands or other regulated waterbodies include USGS quadrangle maps (marshes, wet areas, depressional or flat areas, standing water, and streams are often depicted), SCS soil surveys (certain soil types are associated with or developed under wetland environments), and USFWS National Wetland Inventory (NWI) maps. The NWI maps use standard USGS quadrangle maps as a base and have been completed for much of the country. Although the information presented on the NWI maps is useful as a first step, the level of detail in most areas is unsuitable for delineating jurisdiction or identifying all wetland environments in an area. Local and state agency personnel are also a good source of information. In many states, the state fish and wildlife agency has permit requirements concerning stream and lake alterations which often overlap with federal jurisdictions. These programs are typically administered by the local game warden.

Once background information has been assembled, contact with appropriate agencies should be initiated. The regional Corps district office should be contacted to

inform them of the location and type of planned activities. This notification should also request a determination of Section 404 jurisdiction. Procedures vary between Corps districts. Some districts will perform the site investigations and provide the jurisdictional determination. The use of qualified consultants, however, is becoming increasingly common for preparing the background information and site investigations for submittal to the Corps for review. If possible a scoping meeting onsite should be arranged with the Corps and other relevant agencies to determine the extent of the field investigations as well as probable permitting requirements and related study needs to comply with other regulations such as endangered species and cultural and historic resources. The Corps must address these issues and others when evaluating permit applications.

#### *7.3.2.14.3 Field Surveys*

Because wetland analyses are important components of both successful mine planning and reclamation, it is most efficient and economical to evaluate wetlands in the earlier stages of project planning. Initial or preliminary surveys and review of background sources discussed above can be very valuable in avoiding costly unanticipated constraints, mitigation requirements, or regulatory delays. Such preliminary surveys typically do not provide definitive information on the extent of jurisdictional areas.

The determination of regulatory jurisdiction depends on the ability to identify and draw boundaries around wetlands and "other waters." The current primary guidance for this is the Corps' 1987 Wetland Delineation Manual. This manual, as well as other versions which have been proposed or are under review, rely on what is termed the three-parameter approach. This approach requires that positive indicators of all three wetland parameters (soils, hydrology, and vegetation) must be present in most cases for an area to be considered a jurisdictional wetland. For "other waters," Corps jurisdiction extends to the ordinary high water mark (OHWM) for streams, rivers and lakes and to the highest predicted normal tide in tidal areas.

The Corps' Manual provides technical guidance for considering each of the three parameters and a methodologies for the application of the technical guidelines. This ranges from routine onsite determinations to comprehensive determinations for more complicated sites. The Manual also provides guidance for problem areas and what are termed atypical situations where certain parameters may be absent or obscured because of natural or man-induced conditions such as drought, certain soil conditions/types, illegal or unauthorized activities. All procedures require examination of onsite conditions for soil characteristics, vegetation/plant cover, and hydrologic indicators.

The Manual procedures allow for data collection and jurisdictional determination to be made almost any time of the year. In reality, however, it is often important to conduct field work during appropriate seasons when plants are identifiable and typical or normal hydrologic conditions are present. This means field studies should be conducted in the primary growing season for the project area, usually spring and early summer.

In certain areas, state and local jurisdictions may have different criteria for delineating and describing wetlands subject to local regulations. These differences should be determined and considered when conducting the field studies and analyzing the results.

If wetlands will be impacted and mitigation is required, additional field studies and baseline information is usually required to develop mitigation plans. For compensatory mitigation, suitable mitigation sites for re-creation of wetlands need to be identified and evaluated with respect to their suitability for wetland creation. Sites need to be evaluated for hydrologic conditions, soils, compatibility of surrounding land uses and conditions, plant and animal communities present, and other factors. An assessment of wetland functions and values is often also required.

The most common approach for assessing functions and values is the Wetland Evaluation Technique or WET Analysis (Adamus et al. 1987). The current version of the procedure, WET 2.0, was developed by the Corps for use throughout the country to reduce the need for costly detailed studies or reliance on strictly professional judgment which is often impossible to reproduce. Several regional methodologies or modifications to the WET 2.0 analysis have been adopted to address more specific regional conditions. Again, local regulatory authorities should be contacted for the proper or desired methodologies to use in a particular situation.

#### *7.3.2.14.4 Report*

Baseline data reporting involves presentation of a jurisdictional delineation report to the Corps and other appropriate regulatory agencies. The reports should provide maps of sufficient scale (generally 1 inch = 100 feet) to clearly depict the jurisdictional area and sampling sites. Reports should provide rationale for the choice, number, and location of data points and signed and completely filled out data sheets (standard data sheets are provided in the Delineation Manual). Other supporting information that should be provided includes a discussion of aquatic plant and animal species present, cultural and historic resources, endangered species, toxics, and other relevant environmental clearances or permits. Maps also should be provided, if available, to depict jurisdictional areas to be impacted by the proposed activity.

Baseline reporting should also contain the functional assessment of the wetlands to be impacted and other data

relevant to baseline conditions and proposed compensation procedures at the mitigation area if mitigation is required. This will assist in the review and analysis of permitting and reclamation requirements.

## 7.4 DEFINING LEGAL AND REGULATORY REQUIREMENTS

**by P. Mitchell**

### 7.4.1 DEVELOPING A COMPLIANCE PROGRAM

#### 7.4.1.1 Preparing a Checklist and Timeline

Chapter 3 deals with the specific federal legal requirements needed to permit a mine operation. This subsection is intended to discuss particular issues encountered in the application of those legal parameters in the process of acquiring permits. Whereas, Chapter 3 is a cookbook of particular legal requirements, this subsection of Chapter 7 is meant to raise some practical concerns encountered from a legal perspective and how those concerns can be addressed.

The most important item to prepare at the beginning of any proposed mining project is a checklist and time frame for all necessary project permits and legal requirements. Such a checklist should be prepared after reviewing all applicable federal, state, and local laws and contacting the appropriate agency personnel. For the BLM, the agency hierarchy (from local to national) is: Resource Area Office, District Office, State Office and Washington, D.C. headquarters. For the Forest Service, the agency hierarchy from local to national is: Ranger District office, National Forest office, Regional office and Washington, D.C. headquarters. Table 20 is a list of typical environmental permits and approvals that may be required for a major mine, depending on the location, size and type of mining operation.

The majority of major mine projects require one to three years to obtain all of the necessary permits. During that time frame, there can often be regulatory changes such as the listing of an endangered plant or animal species, additional air quality or water quality controls, new hazardous waste laws, or new mine reclamation requirements. Although the precise nature of such regulatory or statutory changes is always uncertain, it is always best to plan some additional time in the timeline of mine permitting for such unpredictable changes. Likewise, staff turnover at many local, state and federal agencies is relatively high due to either attrition, layoffs, or in the case of federal agencies, transfer to other areas of the state or nation. It is often the case that mine company personnel must deal with different agency personnel over the time frame required to permit a mine. This agency turnover frequently results in additional delays as the new governmental employee in charge of the project is educated regarding the project.

An important procedural aspect of permitting a mine operation is to recognize that the environmental groups often use the procedural aspects of various laws such as the permit hearings in front of Air Quality Management Districts and the land use approval hearings before the local governmental agencies and federal agencies to delay a project. An appeal can drag the process on for several months, even if not successful, and if successful, over one year. In many cases, projects cannot afford that delay and in those cases, the environmentalist may use the delay procedure as blackmail to demand various monetary or additional environmental mitigation measures from the applicant. Therefore, including potential appeals in the time frame may assist a company, in practical terms, by avoiding time pressure in later defending the appeal.

#### 7.4.1.2 Reviewing Case Law

When submitting mining plans of operation and reclamation plans to federal agencies such as the Bureau of Land Management (BLM) under FLPMA (43 CFR Part 3809), or the U.S. Forest Service under the National Forest Management Act (36 CFR Part 228), it is important to understand more than just the applicable statutes and regulations. In this respect, two important resources to be aware of are: (1) agency policy memoranda and solicitor opinions; and (2) an attorney who is knowledgeable in that area of the law. The first is important because both the BLM and the Forest Service and their federal attorneys have policy memoranda or opinions which you may not be aware of until an issue arises and then discover, possibly, the existence of the memorandum. The agency memoranda often come from the regional, forest or district offices for the Forest Service, depending on the breadth of the issue. These memoranda generally have the equivalent effect of a regulation; however, they are not formally promulgated and therefore are not easily found. In many cases, people are not aware of their existence. They usually involve more detailed implementation of the existing regulatory program.

An attorney can help because they have often dealt with these types of issues before and have the applicable memoranda or know where to obtain them in an expedited manner. In addition, having an attorney work with the mine company can be helpful if various issues arise, given their contacts with the Department of Interior, Office of the Solicitor (the attorneys for the BLM), or the U.S. Department of Agriculture, U.S. Forest Service, and the Office of General Counsel (the Forest Service's attorneys). In addition, there may be numerous federal, state or Interior Board of Land Appeal cases impacting the interpretation and implementation of a given statute or regulation. A person relying strictly on

**Table 20** Environmental Permits and Approvals Required for Mining Projects

**AGENCY REQUIRING PERMIT, APPROVAL OR NOTIFICATION**

**Federal**

U.S. Dept. of Interior: Bureau of Land Management and or U.S. Department of Agriculture

(a) Final Environmental Impact Statement (EIS) and Record of Decision

(b) Archaeological Clearance/BLM 106 process; often completed in connection with the EIS process

(c) Plan of operations

(d) FLPMA Title V Right-of-Ways for utility (e.g., electric power lines and pipeline) access

U.S. Department of Interior: Fish and Wildlife Service

(a) Federal Endangered Species Act: Biological opinion (usually issued during the EIS process)

(b) Compliance with Bald Eagle Protection Act (as part of mitigation measures reviewed in the EIS and required in Project approvals)

U.S. Army Corps of Engineers

(a) Clean Water Act, Section 404 Permit ( possibly per Nationwide Permit)

U.S. Environmental Protection Agency

(a) EPA Hazardous Waste Generator I.D. No.

**State**

Department of Fish and Game (e.g. California)
Department of Game and Fish (e.g. Wyoming)
Department of Wildlife (e.g. Nevada)
Department of Natural Resources (e.g. Minnesota)

(a) Stream Alteration Permit

(b) State Endangered Species Act Permit, if applicable (e.g. California)

(c) Artificial Industrial Pond Permit

State Historic Preservation Offices (in conjunction with BLM-106 as required by federal law)

(a) Archaeological Clearance (normally obtained in conjunction with the EIR/S process)

Regional Water Quality Control Board (or equivalent)

(a) Final Environmental Impact Report

(b) Conditional Use Permit/site approval/mine permit

(c) Mining/reclamation Plan and Mine Plot Plan

City/County Department Health Services/Health Department

(a) Business Plan for hazardous materials

(b) Hazardous Materials Handler Permit and Hazardous Waste Generator Permit

(c) Risk Management Prevention Program

(d) Acutey Hazardous Materials Registration form

County Air Pollution Control District/Regional Air Quality Management District

(a) Authority to Construct Permit (New Source Review document circulated for public comment)

(b) Permits to Operate (issued weeks or months after equipment has been placed in service and compliance testing is

completed)

(c) Air Toxics Emission Inventory Plan (required once facility becomes operational, California)

**The following other permits, approvals and notifications may also be necessary for the construction and operation of a mine project:**

**Federal**

U.S. Department of Justice: Bureau of Alcohol, Tobacco and Firearms

(a) Purchase and Storage of Explosives Permit

(b) BATF Forms required for inventory and use

U.S. Department of Labor: Mine Safety and Health Administration

(a) Notice of Start of Operations

(b) Emergency; Fire, Evacuation and Rescue Plans

(c) Legal Identity Report

(d) Record of Inspection of Self-Propelled Equipment (inspections scheduled after equipment is on site)

(e) Record of Testing the Resistance of Electrical Ground System (Record must be available on site)

(f) Miner Training Plan

(g) MSHA Identification Number

**State**

State Lands Commissions (for school lands, e.g., Sections 16 and 36)

(a) Mine Lease of Permits (as applicable)

(b) Water Well Lease

State Occupational Safety and Health Administration

(a) Notification of opening a mine

(b) Injury and Illness Prevention Program

(c) Hazardous Materials Communication Standard

**County and City**

County Department of Environmental Services
(a) Domestic Water System Permit (potable water)
(b) Sewage Disposal System Permit (leach line)
(c) Water Well Permits and Inspection

County Department of Building and Safety
(a) Building permits
(b) Land Use Compliance Review

County Sheriff
(a) Purchase and use of explosives

County Fire Warden/Department
(a) Fire Protection Plan

(Most larger and complex mine projects require one to three years to obtain all of the necessary permits to operate. During that interval, there can often be impacting regulatory changes. They may include the listing of an endangered plant of animal species, additional air quality or water quality controls, new hazardous waste laws, or new mine reclamation requirements. As a contingency, it is always best to plan some additional space in the mine permitting time frame for such unpredictable changes. Furthermore, staff turnover at many local, state and federal agencies is high due to attrition, layoffs or transfer of key personnel to other areas by federal organizations. Frequently, mine company employees must deal with different agency personnel during the period required to permit a mine. This agency personnel turnover frequently results in additional delays as the newly responsible government employee si schooled about the project's circumstances.

An important strategic aspect to consider while planning for permitting a mine is that environmental groups often use the procedural requirements of various laws to delay a project. Examples include permit hearings in front of Air Quality Management. Districts and land use approval hearings before local, state and federal agencies. An appeal can drag the process on for several months, even if not successful and if successful, over one year. Commonly, projects cannot afford the delay. Taking advantage of this situation, some environmentalists may use the delay procedure in order to force additional environmental mitigation measures or other desired benefits from the applicant. Therefore, the prudent mine operator should also allow for appeal delays in the original permitting time estimate.)

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a regulation or a statute often is operating with only a partial perspective of the legal parameters affecting that particular issue. These are the types of reasons why an attorney can be helpful in assisting a mine operation through the regulatory gauntlet one must travel in obtaining mine permits.

### 7.4.1.3 Land Use Permit Applications

Another important legal aspect to be aware of are the local city and county ordinances and planning/development codes which will impact the permitting of the particular mine site. In many cases, even with mines otherwise wholly on federal jurisdictional lands, such as BLM or Forest Service lands, there will be a patented mining claim which is, thus, private property/fee land and outside the immediate jurisdiction of the federal agency. In such cases, the state or local government agency having jurisdiction over mine operations in the given state has concurrent jurisdiction with the federal agencies. In some states, either the BLM or the Forest Service, or both, will have entered into a Memorandum of Understanding (MOU) or similar agreement, whereby the federal, state and local agencies agree to work together in permitting the mine operations. In many cases, although the agencies do work together under the MOU, the cooperation and dual use of documents is still somewhat strained, even if effectuated.

An important case regarding environmental requirements for mining projects is California Coastal Commission v. Granite Rock (1987) 480 U.S. 572. In Granite Rock, the United States Supreme Court held that state agencies could enforce environmental laws on a mine operation located on federal land, in that case, National Forest land. The court held that although the state or local governmental agencies did not have the right to make any land use decisions regarding what use of the land would be made on the federal lands, they did have the right to impose environmental requirements on the land use permitted by the federal agency. However, the state regulations must not so interfere with the federal permitted land use as to negate the federal land use approval. As implemented, even in the case of a mine entirely on Forest Service or BLM land (i.e., unpatented mining claims), the state or county (e.g., California) has the right to review and require approval of the mine reclamation plan, as contrasted with decisions on the mine permit which remain with the federal agency, depending on whether the state or a local agency has mine reclamation authority in a given state. [For example, in California, under the Surface Mining and Reclamation Act (SMARA), a county, city or Indian Reservation will be the lead agency on reclamation issues.]

In some states, in addition to the local agency such as the city or county reviewing the mine, the state agency

also reviews the reclamation plan. In California, for example, the California Department of Conservation, Division of Mines and Geology, also reviews reclamation plans and comments to the local agencies on deficiencies in the reclamation plans.

### 7.4.1.4 Endangered Species

The Endangered Species permits may legally precede or postdate the land use approval; however, it is best to have such permits precede the land use decision for two reasons: 1) the data necessary for the ESA approvals can be used to assist preparation of the NEPA/CEQA document and 2) environmental organizations have been taking the position, for the last few years, that an adequate NEPA/CEQA requires a completed ESA review. Although this latter position is probably legally incorrect, compliance using that approach will eliminate one of the complaints received from environmental organizations.

Joint documents should be prepared where possible, for example, a combination of baseline studies can be prepared to meet both the State and Federal Endangered Species Act requirements.[1]

Under the Endangered Species Act (ESA), for projects involving a federally-listed plant or wildlife species, applicants must obtain either a Section 7 or 10a permit.[2] Typically, the easier permit to obtain is a Section 7 permit after going through the biological assessment/biological opinion process. However, to trigger the Section 7 process requires some type of federal nexus, e.g., the mine is on BLM or Forest Service property. If only private land is involved, and you need a federal ESA permit, then a mine company must comply with the Section 10a consultation which involves preparation of the Habitat Conservation Plan. The Section 10a process generally takes substantially longer (two years to complete, versus one year or less for the Section 7 process). That is one reason that if you have a private land mine project entirely on nonfederal lands, you may want to establish some type of federal nexus if you have a federal ESA issue.

Plants which are listed under ESA are *not* protected on private property unless destruction of the plant on private property would constitute a trespass or violation of a state law.[3] Thus, federally-listed plants on private property, if such plants are not protected by the state, can be destroyed by the land owner without liability under ESA.

In the area of endangered species, be aware that the BLM biologists often have more knowledge of the particular species or plants since they are actually in the field, as compared to a Fish and Wildlife Service biologist whose offices are frequently much further away from the actual site.

### 7.4.1.5 NEPA and Equivalent State Laws

The National Environmental Policy Act (NEPA) and California Environmental Quality Act (and equivalent Acts in other states) documents should usually be combined, including any related public hearings. The environmental documents prepared under the NEPA and its state counterparts are usually prepared, if an EIS, by environmental consulting firms either under contract directly to the mine applicant or to the government agency. This is an area of some concern because if is often easier to gain input into the documents if there is a direct contract and direct payment from the mine company to the third party environmental contractor. In such cases, there is more accountability by the third party contractor to the mining company.

Under some state environmental NEPA-like processes, such as California, detailed findings are required to prove that the final Environmental Impact Report (EIR) complies with the law and to discuss whether there remains significant environmental impacts after mitigation. These types of findings should typically be prepared by an attorney to protect the company in the event that an appeal is filed by any party.

In the EIR/EIS context, an attorney should usually review the EIS early on for legal adequacy and attempt to fortify the document against any later legal challenges. The use of an attorney in this context can be extremely critical because technical consultants review EIS documents in a different way in many respects. For example, an attorney's comments on the EIR are best directed initially to the client and therefore can be covered by the attorney-client confidence privilege. Therefore, if the client does not wish certain items to be raised in the EIS, those differences can be screened out in the process. In contrast, a letter directly to the consultant would not be privileged and could be discovered by an opponent of the project at a later stage. In addition, an attorney's review of an EIS focuses more on potential legal challenges than on the scientific adequacy of an EIS which latter point is the focus of technical consultants.

[1] 16 U.S.C., Sections 1531-1544; Cal. Fish and Game Code Sections 2050-2098; Alaska Stat. Section 16.20.180 *et seq.*; Colorado Rev. Stat. Section 33-2-101 *et seq.*; Idaho Fish & Game Code Section 36-201(f); Mont. Code Ann. Section 87-5-101 *et seq.*; Nev. Rev. Stat. 503.584 *et seq.*; New Mexico Stat. Section 17-2-37 *et seq.*; Or. Rev. Stat. Section 496.172 *et seq.* (state land only); Texas Parks & Wildlife Code Ann. Section 68.002 *et seq.*

[2] Section 7 is found at 16 U.S.C. Section 1536(a); Section 10(a) at 16 U.S.C. Section 1539(a).

[3] 16 U.S.C. Section 1538(a)(2).

#### 7.4.1.6 Air Quality

Given the requirement of increasingly more detail in NEPA/CEQA documents, the air and water quality permitting processes should also be started as early as possible to provide additional data for the NEPA/CEQA documents. For example, one year of air quality baseline monitoring data if often necessary for impact modeling, in which case it should be obtained for the project area early on. Other major environmental permits such as air quality and Regional Water Quality Control Board permits usually occur after approval of the land use permit.

For air quality permits, it is important to write into the time frames the public comment period for a new source review document, if applicable. An attorney knowledgeable on air quality issues should assist in complying with air quality requirements.

#### 7.4.1.7 Water Quality

The water quality permits required by state and federal Clean Water Acts are typically processed during the ongoing NEPA review. The earlier gathering of detailed water quality data is useful as it helps strengthen the NEPA document. Under water quality review, the Federal Spill Prevention Control and Counter-Measures Plan is very similar to the California requirement for a Business Plan. Both of those plans deal with what to do in a situation involving an emergency spill or exposure of a hazardous material. These documents are typically prepared after the project receives its land use approval, but before the commencement of project operations. Again, attorney review of these documents is advisable to ensure compliance with regulatory criteria. The Army Corps of Engineers 404 permit review can often be combined, or at least dovetailed, with stream alteration permits required by many states, including California, Alaska, Colorado, Montana, Oregon, Utah and Washington[4], giving the overlapping factual issues.

#### 7.4.1.8 Wilderness Study Areas

Areas designed as Wilderness Study Areas, pending a Congressional determination, are generally managed under a non-impairment standard. As applied by BLM Area offices, this standard is subject to some latitude, especially regarding drill programs. Meetings with the Wilderness specialists of the appropriate BLM Area office are recommended in this case.

[4] Alaska Stat. Section 46.40.010 *et seq.*; Colo. Rev. Stat. Section 33-5-102 *et seq.*; Mont. Code Ann. Section 87-5-501; Or. Rev. Stat. Section 196.600; Utah Code Ann. Section 23-15-3 *et seq.*; Wash. Rev. Code Ann. Section 90.58.010 *et seq.*

## 7.5 DEVELOPING A PERMITTING STRATEGY

**by D. W. Struhsacker**

### 7.5.1 INTRODUCTION

A permitting strategy is by nature highly project specific, and there is no generic environmental permitting strategy which is applicable to any given mining project. This section describes the key issues and major factors which need to be considered in developing a permitting strategy. The project manager, along with other key project team members, must identify the key project issues at an early stage in developing a permit strategy. For companies new to a project area, this may necessitate retaining local expertise to provide information on regulatory, legal, social, and political conditions which may influence project issues.

### 7.5.2 PROJECT-SPECIFIC ISSUES

The first step in developing a permitting strategy involves identifying and understanding the following key issues which influence project permitting:

*Environmental Issues* - What are the site specific environmental factors (real and perceived) which will be key issues during permitting? Examples of potential environmental issues include wetlands, threatened and endangered species, and potential contamination of ground water and surface water due to heavy metals leaching, acid mine drainage, or cyanide.

*Technical Issues* - What are the main technical issues which will have to be addressed during project design and permitting? Examples of potential technical issues include mine dewatering requirements and dewatering impacts, assessing the long-term geochemical behavior of mine and process wastes deposited on the site, and establishing reclamation plans and objectives.

*Regulatory Issues* - What is the regulatory framework for the project and how will site specific environmental factors influence the regulatory requirements? Examples of regulatory issues to be considered include defining the lead agency and all other federal, state, and local agencies; coordinating the involvement of regulatory agencies with overlapping jurisdiction; and when to initiate the permitting process.

*Political Issues* - Are there local, state, or national political issues which may be a factor for the project, and if so, what are those issues? Examples of political issues include responding to elected officials who oppose mining, or responding to legislative and rulemaking

proposals affecting mining.

*Social Issues* - Is there a nearby community which will be affected by the project, and if so how will this community react to the project? Examples of social issues include concerns regarding a boom and bust scenario, or upgrading housing and infrastructure to accommodate in-migration of a project work force.

The relative importance of each of these issues varies with each project. For complex and/or controversial projects, all of these issues may be important, and the success of the permitting effort will depend upon the degree to which each issue is effectively addressed during project permitting. For simpler and/or non controversial projects, not all of these issues are likely to be important.

### 7.5.3 THE KEY PLAYERS

Once the key issues are defined, identifying the key players and building a working relationship with them is the next step in developing a permitting strategy. In addition to the project proponent, the key players in a mine permitting effort include the regulatory agencies and corresponding regulatory personnel, key community leaders (i.e., non-elected public opinion leaders), key state and local elected officials, area residents, and third-party participants.

Developing good working relationships and channels of communication with all of the key players is crucial. The methods used to cultivate these working relationships must vary depending upon the entity in question. For example, a good working relationship with a regulatory agency typically requires frequent meetings, and a willingness on the part of the applicant to be forthcoming with sound, accurate information about the project. However, it may also require that an applicant demonstrate its commitment to permitting and developing the project and clearly communicate this commitment along with any related economic and scheduling constraints to the agency.

In contrast, building a relationship with a state or local elected official may initially have to be done through channels, and may require an introduction from an established influential contact within the community. Establishing a rapport with the local community requires being visible and active in the community, and supplying area residents with regular project updates. Developing an understanding of the objectives and political strategies of any project opponents is also critical at this stage. Although establishing a working rapport with these groups or individuals may not always be achievable, it is nonetheless important to consider their perspective in developing a permitting strategy.

### 7.5.4 THE REGULATORY ATMOSPHERE

The nature of the regulatory and political atmosphere with respect to mining is the most influential factor in determining whether permitting a project will be relatively straightforward and easy, or complex and difficult. States like California, Oregon, and Wisconsin are renown for being difficult places in which to permit a mining project. However, opposition to a project in any state or community may be triggered by any number of real, perceived, or manufactured issues. Moreover, in today's political climate of anti-mining activism, it is not uncommon for seasoned activists to infiltrate a community with the goal of developing anti-mining sentiment in order to thwart a mining project. The permitting strategy for a project facing known or suspected opposition will likely be much more complex and involve managing many more issues than that required for a non controversial project.

In assessing the regulatory climate an important factor to be considered is whether the key regulatory agencies responsible for the project have experience with mining. The mining experience factor is highly variable from state to state and within the federal land management agencies (i.e., the Bureau of Land Management, BLM, and the U.S. Forest Service, USFS). Some BLM and USFS personnel have considerable experience in evaluating mining projects, in assessing impacts due to mining, and in working with the state and federal regulations governing mining. However, some offices of the BLM and the USFS do not have much or any mining expertise. Working in districts with little or no experience with mining projects requires that an applicant devote considerable time and effort in developing the key regulator's technical awareness and understanding so that they can make sound decisions about the project.

The attitudes of individual regulatory personnel regarding mining can also influence the way in which a project proponent is treated during the permitting process. The management structure, style, and strength of the regulatory agency will play a key factor in determining whether overt pro- or anti-mining attitudes are tolerated within the agency. Regulatory personnel who approach a mining project with a readily apparent bias, either pro- or anti-mining, can present a significant problem for the project proponent. A discernible pro-mining bias on the part of a regulatory agency can elicit public concerns about whether the agency is sufficiently objective, and whether they are doing an adequate job of enforcing environmental protection regulations for mining projects. The other side of the issue, an overtly anti-mining atmosphere at a regulatory agency, also raises questions about objectivity and presents obvious problems for a project applicant.

The history surrounding permitting efforts for

existing mining projects in the area should be researched to provide information on the track record of the agency in making mining project decisions. Reviewing recent mine permit decisions and any mining-related permit violations and enforcement actions may give an applicant insight into the agency's decision-making process and key decision makers' attitudes about mining. This review may also reveal useful or problematic precedents set at other projects. Recent violations or environmental problems due to existing or old mining projects may also point to issues about which the regulatory community and the public are likely to be sensitive.

### 7.5.5 SELECTING A PROJECT TEAM

Once the project issues have been identified and the political and regulatory climates have been assessed, the next step is to pull together a project team custom tailored to work in this setting and to address these issues. The identified project issues should dictate the composition of the project team. As described in Section 7.1, the environmental project team should be a multidisciplinary group of professionals. Depending upon the specific needs of the project, the environmental permitting team should be comprised of some or all of the following:

*Technical experts* - the engineers, hydrologists, geologists, and resource specialists who address the site-specific environmental issues.

*Legal experts* - legal counsel with significant mining regulatory experience who can identify applicable laws and regulations, develop compliance strategies, and who have good contacts with the regulatory agencies.

*Government relations experts* - lobbyists or other professionals to provide a strategy for addressing legislative proposals or other political issues affecting mining in general or specific aspects of the project.

*Community relations experts* - a communications and public relations specialist who can develop a media management strategy and help prepare and disseminate information about the project.

The efforts of all of these experts must be coordinated in order to be most effective. In some cases, one group or individual may perform more than one function. For example, the community relations expert may have adequate political contacts to provide political strategy advice. Similarly the law firm retained to provide legal advice on environmental permitting requirements may also have senior partners with useful political contacts.

The team can be comprised of any combination of in-house staff and consultants, and the consultants may all work for one company or may be a consortia comprised of independent consultants or several consulting companies. Managing a single contract with one full-service consulting firm may be simpler than developing numerous smaller contracts with individual specialists or smaller firms. However, this approach may not provide adequate expertise for some specialized, site-specific issues. For projects which are anticipated to be controversial or require specialized technical expertise, it is usually better to hand pick a group of experts on the basis of their qualifications, rather than to select one consulting firm with the hopes of streamlining consultant management requirements.

Whenever possible, local consultants should be used in preference to importing consultants. Local consultants can provide an understanding of state and local regulations as well as established contacts with key regulators. However, in areas with few or no mining projects, local consultants may not have sufficient experience with mining to be qualified to perform the work required. In this case it may be prudent to augment the local team of consultants with senior-level consultants from outside the area who are experts in mining issues.

In some cases it may be necessary to retain a "big gun" consultant (i.e., a well known professional with impeccable credentials and extensive experience with the issue at hand) to provide expert testimony or a similar level of advice. The need to hire such an individual can be triggered by either technical or political issues. In order to have the greatest impact, a big gun consultant should be reserved for venues at which the appropriate decision-making regulatory and/or political authorities will be present and at which key decisions will be made.

### 7.5.6 WHEN TO INITIATE PERMITTING

One of the most fundamental questions to be asked in developing a project permitting strategy is when to initiate the permitting process. The permit process is a legal procedure which follows steps proscribed by statutes and regulations. Typically this process is started by filing a permit application or a project proposal with a specified regulatory agency. Any technical or environmental studies performed prior to taking this step are not part of the legally defined permitting process. For projects on federal land, submittal of a Plan of Operations is the action which initiates the permitting process described under the Federal Land Policy Management Act (FLPMA). As described in Section 7.6, this process involves preparing an environmental document, either an Environmental Assessment or and Environmental Impact Statement as outlined by the National Environmental Policy Act (NEPA) to assess the effects of the project. On the state level, submitting a

state permit application typically starts the legally defined permit process.

In an age of increasingly protracted permitting schedules, there is a growing tendency to initiate permitting activities and environmental studies prematurely. Initiating the permitting process and performing extensive environmental baseline studies too early can be an expensive mistake. Environmental baseline data need to be collected in the context of a proposed project, and successful discussions with project opponents and the media regarding the potential impacts of a project can only be achieved by presenting technical evidence that project impacts can be controlled and mitigated. Prematurely initiating permitting activities only serves to subject a project to public scrutiny and criticism prior to having adequate information about the engineering, monitoring, and reclamation measures which will be used to address environmental concerns. Therefore developing sufficient economic and feasibility data and determining the best mining, processing, and reclamation options is advisable prior to commencing the permit process.

Although starting the permitting process too early can create problems, it must be emphasized that for controversial projects there is an early need for community relations, information dissemination, media management, and government relations programs. These programs should develop community, media, and political contacts and nurture public support and trust so that the technical information about project design and environmental controls can be a principal public and media focus during project permitting efforts. Community, political, and media communications programs implemented early during a project can pay important dividends in later project permitting efforts.

### 7.5.7 DEFINING PROJECT SCOPE

Defining the scope of a project is an important element in developing a permitting strategy. The project scope determines the size and duration of the project and influences the nature of some project impacts. Traditionally mining projects have been permitted and developed in stages, starting with a core development and expanding incrementally. The permit applications for each expansion phase deal principally with the expansion and reference previous permit submittals and environmental studies.

In the past, permitting a project in phases was a way in which to expedite the permitting process because permitting a smaller project generally required less time and effort than permitting a larger project. However, the regulatory community and the public have recently become less accepting of a piecemeal or phased approach to project permitting. Many agencies are encouraging and even requiring applicants to submit applications for some or all probable future project phases in conjunction with a permit application for a project proposed for the immediate future.

Project applicants are now faced with the important decision of whether to permit a project in phases versus permitting all foreseeable activities as one large project in an omnibus-type permit application. An omnibus permit application typically presents detailed designs for the project elements proposed for the immediate future and provides conceptual plans for envisioned expansion phases. This approach requires considerably more up-front planning than permitting a project in phases.

In some settings, the size of the project *per se* does not determine the type of intensity of public concerns or regulatory requirements for a project, and small projects may be subjected to the same level of public and regulatory scrutiny as larger projects. For example, there is little permitting advantage today in developing a pilot-scale project because a pilot-scale project triggers all or most of the regulatory requirements as a full-scale project. Unless there is a compelling technical reason to develop a pilot-scale effort, there is typically little to be gained from a permitting perspective because permitting the pilot-scale project will be time consuming and expensive.

On a per ton basis, permitting costs for smaller projects are typically higher than for larger projects (Bailey, 1992). With the exception of socioeconomic impacts, most of the environmental and permitting issues facing a proposed project are not particularly sensitive to project size. For instance, public concerns about cyanide use and the potential for water quality impacts may be similar for a 3 million ton or a 30 million ton heap leach operation. Similarly, assuming the same permitting requirements, the length of time required to permit the 3 million ton project will not be significantly shorter than that required for the 30 million ton effort.

Given these considerations, coupled with the likelihood of more stringent future regulations, there can be future dividends associated with the omnibus approach and permitting as much of a project as possible in one effort. If a future expansion is included as part of an original permit application, some agency rules allow a streamlined process to review the detailed designs for the expansion, and approval of the expansion as a minor modification of the existing permit. Conversely, if the future expansion is not included as part of the original permit application, it may be necessary to start the entire permitting process again to obtain permits for the expansion. If that process is controversial, time consuming, or expensive, it is probably prudent to permit as large a project as possible in one effort rather than to submit to numerous protracted permitting efforts for each expansion phase.

Determining the scope of the project thus becomes a

very important component in the overall permitting strategy. Defining the scope of the project involves evaluating all foreseeable mine development, and weighing the pros and cons of preparing an omnibus permit application to include future development versus permitting the project in phases is an important exercise. This evaluation should assess corporate, exploration, engineering, environmental, regulatory, and political factors in reaching a conclusion.

### 7.5.8 THE PERMITTING SCHEDULE

Environmental permitting professionals are often asked to make estimates of the amount of time required to permit a project. Depending upon the circumstances, developing schedule estimates can either be fairly straightforward or highly conjectural. For most projects, estimates of the length of time required to permit a project should be regarded as a forecast rather than a plan based on a set of known parameters. Like any forecast, a permit schedule estimate needs to be constantly updated to reflect changing circumstances. The many factors which can prolong the permitting process include both external and internal considerations, and controllable and uncontrollable circumstances.

Most regulations establish specific time limits for various stages of the permit review process. These established time periods should usually be construed as the minimum length of time required to secure a permit. Except for unique circumstances, the concept of fast tracking a mining project through the permitting process is largely a thing of the past. In today's regulatory climate, very few agencies are capable of processing a permit application in less than the time allotted to them by statute or regulation due to manpower and budgetary constraints and the increased level of third-party scrutiny to which mining projects are now subjected.

Projects which are potentially controversial have a high probability of having prolonged and unpredictable permitting schedules. The prolonged and unpredictable nature of permitting schedules for controversial projects can be minimized to an extent by the amount of effort expended in addressing and controlling controversial issues. As discussed in Section 7.5.10, effective public, government, and media relations programs can facilitate permit acquisition, and may be a crucial element of an environmental permitting strategy for a controversial project.

A frequently overlooked factor controlling permitting schedules is the level of commitment and effort devoted by the applicant towards permit acquisition. Assigning sufficient budget and personnel to a project permitting effort is critical to maintaining permit schedule objectives. Inadequate or fluctuating staffing and funding levels for permitting efforts can contribute significantly to the length of time and ultimately the cost of permit acquisition.

### 7.5.9 IDENTIFYING FATAL FLAWS

An effort should be made to identify any permitting risks or legal or environmental fatal flaws associated with the project during the early stages of developing a permitting strategy. A fatal flaw analysis should evaluate the suitability of the site for mining and should focus on factors which could preclude or severely restrict mining. Contacting local wildlife officials to assess the potential for endangered species in the project area is one of the most important components of a fatal flaw analysis because unmitigated adverse impacts to species on the Federal Threatened and Endangered list can stop a project. A site suitability analysis should also determine whether any mandated unsuitability criteria or land withdrawals apply to the site. Unsuitability criteria vary from state to state; examples include wetlands, water bodies protected by restrictive anti degradation water classification status, wildlife preserves, cultural sites, and certain types of public land.

### 7.5.10 AUTHORITY FOR PERMIT DENIAL

From a legal perspective, most regulatory agencies do not have the discretionary authority to deny a permit application for a mining project if the applicant can demonstrate that the proposed project will comply with all environmental protection requirements. Traditionally, many project applicants have assumed that permits for a project will eventually be granted and any uncertainty in the permitting process has rested with the amount of time and money required to secure the necessary permits.

In the future, however, the question may not be *when* a project is permitted, but *if* a project is permitted. Given the current political climate towards mining in many areas of the U.S., there is potential for regulatory agencies to be given more discretionary authority in the future to deny mining permits. Many anti-mining activists are lobbying on the state and federal levels to rescind or greatly restrict a mining applicant's right to a permit even though a project may meet all regulatory requirements. Those opposed to mining would like to give the regulatory community and the public a greater opportunity to regulate and restrict mining operations on the basis of subjective and discretionary factors. In this setting, the risk associated with how long it may take to obtain permits needs to be reevaluated in terms of the risks associated with being denied a permit.

### 7.5.11 CONTROVERSIAL PROJECTS

In areas where mining is controversial, persistent political and legislative assaults upon the mining industry are predictable. Effective community

involvement, government relations, and media management programs are critical to the success of permitting efforts in this environment. Mining project proponents working in this regulatory and political setting must be prepared to participate in lobbying, communication, and information dissemination efforts to support their project, to educate the community about the project and the importance of mining, and to refute the misinformation typically spread by anti-mining activists.

Regulatory decisions in this setting may be influenced by political factors and public opinion rather than being based solely on science and technology. Thus a project proponent must make a concerted effort to influence political decisions and to manage public opinion with the objective of minimizing the political aspects of regulatory decisions on mining projects. In a controversial setting, it is necessary to create a political and public opinion environment which allows elected officials to feel comfortable in supporting (or at least not actively opposing) a project, and which allows regulators to base their decisions solely on technical rather than political factors.

An environmental permitting strategy for a controversial project must thus address issues which are a complex mixture of legal, political, technical and regulatory concerns. Although some of these considerations are not traditionally viewed as being part of "environmental permitting" by the mining industry, they are critical to the success of mine permitting efforts for controversial projects. The task facing the mining industry in these settings is how to fight smarter - *not* how to fight harder, and integrating community involvement, government relations, and media management into the permitting strategy sets the foundation for a fight smarter strategy.

### 7.5.12 UPDATING PERMITTING STRATEGY

Developing a permitting strategy must be an iterative effort which is responsive to changing circumstances. A permitting strategy needs to be constantly reviewed to determine if modifications are warranted to accommodate new events. Circumstances which may require modifications to the permitting strategy include external changes in the political or regulatory arena, newly identified features or concerns at the project site, or internal changes in corporate plans, objectives, or structure. Modifying the permitting strategy can encompass changes in schedule, personnel, or even approach. For example, proposed anti-mining legislation or development of new regulations may necessitate devoting more effort towards government relations and lobbying, which in turn can affect the schedule and budget for other permitting efforts. Similarly, shifts in corporate objectives for a project can either enhance or diminish the importance of the project to the company and this change would need to be incorporated into the permitting strategy.

### 7.5.13 SUMMARY AND CONCLUSIONS

A well conceived permitting strategy is critical to the success of permitting efforts for a mining project. Developing a permitting strategy involves identifying key issues and players, developing working relationships with key players, nurturing useful contacts with important elected officials, gathering a team of experts to address project issues, and planning and preparing to respond to key issues.

The task of developing a permitting strategy is largely the responsibility of the project manager and/or/the environmental coordinator. However, a coherent strategy requires input from a number of the professionals on the project permitting team. Implementing a permitting strategy involves integrating the advice and perspective of key project players and balancing the many complex issues affecting the project. This task typically requires the ability to work on numerous issues simultaneously and to understand how these issues are interrelated. Conditions affecting permitting efforts for a mining project can be complex and mercurial. The volatile nature of these conditions requires frequent review of the permitting strategy to determine whether the strategy is still appropriate.

## 7.6 THE ENVIRONMENTAL IMPACT STATEMENT PROCESS

### 7.6.1 EIS PROCEDURES, CONTENT, AND SCHEDULE
**by R. Larkin**

#### 7.6.1.1 Steps in the EIS Process

Step 1. Notice of Intent (NOI) [40 CFR 1501.7]

Major Objective: Notification to affected publics that an agency has made a decision to prepare an Environmental Impact Statement.

Step 2. Scoping [40 CFR 1501.7]

Major Objective: Early identification of significant issues related to the proposed action.

Step 3. Environmental Analysis [40 CFR 1502.16]

Major Objective: Display relationships between Direct/Indirect, Long Term/Short Term and conflicts

or tradeoffs.

Step 4. Draft EIS [40 CFR 1502.9(a)]

Major Objective: Provide information that the agency is considering for public comment.

Step 5. Final EIS [40 CFR 1502.9(b)]

Major Objective: Provide final information that the agency is considering plus responses to public comment during draft.

Step 6. Record of Decision [40 CFR 1505.2]

Major Objective: Public notification of what alternative the agency selected and why that alternative was selected.

Step 7. Appeals and Litigation

Major Objective: Provides publics aggrieved with the agency's decision to have either a higher administrative review or have a court of law review agency's decision.

### 7.6.1.2 EIS Format, Content, Schedule

#### *7.6.1.2.1 Recommended EIS Format [40 CFR 1502.10]*

(a) Cover Sheet
(b) Summary
(c) Table of Contents
(d) Purpose of and need for action
(e) Alternatives including Proposed Action
(f) Affected environment
(g) Environmental consequences
(h) List of Preparers
(i) List of Agencies, Organizations and persons to whom copies of the statement were sent
(j) Index
(k) Appendices

#### *7.6.1.2.2 EIS Content [40 CFR 1502.18]*

(a) Cover sheet (1 page)

This is to provide a list of the responsible agencies, title of the proposed action, location of where the action is located, name, address, telephone number for additional information, designation of the document as draft, final or supplement, one paragraph abstract and date by which comments must be received.

(b) Summary (1-15 pages)

This is a separate statement from the abstract and accurately summarizes the statement to include major conclusions, areas of controversy, issues to be resolved and choice among alternatives.

(c) Table of Contents (1-5 pages)

Provides a list of chapters, appendices and corresponding page numbers.

(d) Purpose and need (1-5 pages)

A brief statement specifying the underlying purpose and need that the agency is responding to including alternatives.

(e) Alternatives including the proposed action (5-25 pages)

This is the heart of the EIS, providing the results of the information and analysis presented in the Affected Environment and Environmental Consequences and presenting the environmental impacts of the proposal, the alternatives in a comparative form designed to sharply define the issues and providing a clear basis for a choice among options.

(f) Affected environment (5-25 pages)

A description of the affected environment shall be no longer than is necessary to understand the effects of the alternatives, including the proposed to the existing environment.

(g) Environmental Consequences (5-25 pages)

This is the scientific and analytic basis for the comparisons under the alternatives section and shall include any environmental effects which cannot be avoided, the relationship between short-term uses and long-term productivity, irreversible or irretrievable commitments of resources, direct and indirect effects and their significance, conflicts, energy requirements and conservation potential, and means to mitigate adverse environmental effects.

(h) List of Preparers (1-2 pages)

Listing of names, qualifications of the persons who were primarily responsible for preparing the document as well as significant background papers.

**EIS Schedule**

| Action Item | Typical Timeline | Influences on Timeline | Pit Falls |
|---|---|---|---|
| Scoping | 1 to 3 months | Agreements between parties on what issues are important and what public involvement is needed | Making sure that the NOI is filed before starting public involvement |
| Data Collection/Analysis | 3 months to 2 years | Availability of some types of data (e.g., seasonal nature of plants, archeology), costs and availability of specialist | Agency disagreements on data standards, analysis |
| Drafting Review Document | 3 to 6 months | Availability of qualified personnel to complete the writing | Critical Contractor understands Agency requirements or rewrites become very expensive |
| Review Document Circulation | 45 days to 1 year | Adequate review time depending on significance of issues and scope of who needs to be involved | Peter Principle reigns supreme on this one–if it will go wrong here is where all the hard work breaks down. Don't despair–just keep going. |
| Final Decision | 1 month to 1 year | Agency procedures, politics, local economics, regional, national issues | All bets are off here: if you think you had an agreement, you really didn't. Time to play hardball–pull out all stops. |
| Appeals and Litigation | 3 months to ? | Internal Agency process, Court rulings and procedures; what you thought was a nice simple project just turned ugly. If you want a friend here, buy a puppy. | |
| Total Time Average | 8 months to 4 years | | |

(i) List of Agencies, Organizations and persons to whom copies of the statement are sent.

Listing of who received the document.

(j) Index

Cross reference of important words, concepts, names, objects or subjects.

(k) Appendix

Material that is not suited for the main text, but important as background or additional information to help the reader understand the scope, context, magnitude and relationship to other material.

## 7.6.2 MEMORANDUMS OF UNDERSTANDING
**by T. Leshendok**

### 7.6.2.1 Introduction

The federal agency that makes the "federal action" decision is responsible for preparing the NEPA document. To meet agency goals, the agency has found that formal agreements have been beneficial in two major areas: agreements with the cooperating or participating agencies in the same specific project and NEPA document, and agreements for preparing third-party NEPA documents, with the three parties being the federal agency, the proponent and, usually a contractor or consulting company or individuals.

### 7.6.2.2 Cooperating Agencies and MOUs

As analysis of federal actions become more complex, many agencies have found that preparing NEPA documents jointly with one or more federal, state or local agency partners fosters a unified, more consistent analysis of a project. For example, the Bureau of Land Management (BLM) in 1992 in Nevada, for a prepared NEPA document on a copper mine application in the Ely District, formally added the State of Nevada, Division of Environmental Protection; White Pine County; and the City of Ely as full participating agencies that are listed on the NEPA document. These agencies then assisted the BLM in providing data and analyzing the proposal. The NEPA document was also sent to other interested state and local agencies as part of the specific public participation process.

Primary reasons for joint preparation, such as reducing delay and eliminating duplication, are formally identified in the Council on Environmental Quality (CEQ) regulations, 40 CFR 1500.5 h. CEQ also lists in 40 CFR 1506.2 that such cooperation shall, to the fullest extent possible, include joint planning processes, joint environmental studies, joint public hearings and joint environmental assessments. Practically, such participation usually does save time and effort for all parties since many disputes and issues are resolved and agreed to internally within the participating agencies before public disclosure is made.

Agencies may or may not develop formal Memoranda of Understanding (MOUs) between or among participating parties. A typical MOU among participants will be a concise document which identifies who is the lead agency, defines schedules for completing each task, defines the responsibilities of the cooperating agency(ies), and lists administrative procedures of the MOU itself. Several agencies require the cooperating agencies be identified in a *Federal Register* notice.

### 7.6.2.3 Third-Party NEPA Documents and MOUs

Many agencies have used contracting of all or parts of NEPA documents as a management tool for the following reasons: heavy permitting workload, lack of environmental or technical specialists in an agency, scheduling concerns, and saving taxpayer funds. The CEQ allows this practice but provides no detailed requirements. The primary requirements in 40 CFR 1506.5 focus on having the responsible federal agency furnish guidance and participate in preparation.

The key factors in the regulations are that the federal agency shall independently evaluate the statement prior to approval and take responsibility for scope and contents. Several agencies have been criticized by some interest groups due to perceptions that third-party contractors or the operator/applicant have taken control of the process from the agency. Many federal agencies will strongly emphasize that the third-party EA or EIS is their document, and assume full "ownership" of all statements and decisions. So far, no third-party EA or EIS has been challenged successfully in court with respect to lack of ownership or control by the responsible federal agency.

One concern that has been raised intermittently is the variability of the EA or EIS process and policies. Such variability has been noted and discussed on several levels: significance, regional or state differences, length of documents, conflict of interest, document organization, MOU, etc. One example, noted in a recent Rocky Mountain Mineral Law Foundation meeting, identified an apparent variability in BLM state office decision making especially as to whether an EA or EIS was necessary. The author concluded that such was "not necessarily inappropriate if content and intensity are taken into account."

The issue of variability raises an extremely important point: even with CEQ and agency regulations, many aspects of the NEPA process vary by agency and locations. It is important that anyone who is participating identify the agency or local concerns and variations early in the permitting/NEPA process. Early up-front coordination with the lead agency becomes paramount for any operator or contractor with a short timetable. Almost all the principal guidelines of an agency may vary, and the MOUs for third-party contracts may also vary in many ways. Figure 4 shows a composite MOU taken from BLM and U.S. Forest Service MOUs for development of a third-party EA or EIS documents for gold mining prospects in the Great Basin, in the early 1990s.

In developing an MOU the key components to keep in mind are:

- Agency variations for that project.
- Special needs, e.g., enhanced cumulative impacts.
- Clear roles and points of coordination.
- Clear understanding of agency data and studies requirements, if any.
- Timetable and clear scheduling of EIS/EA steps.
- Who will the actual contract selector be?

Formal coordination through agency MOUs can be an important factor in developing a sound NEPA document and ensuring a proposed project receives proper analysis and review.

### 7.6.2.4 Conflict of Interest Issues

The federal land managing agencies can take third-party conflict of interest concerns seriously regarding preparation of NEPA documents. Possible

preparers or "third parties" need to ensure they are aware of the particular agencies' policies.

For example, the BLM has formally indicated in at least one western state in 1992 that an environmental firm would not be eligible for award of a third-party EIS if they had participated in the preparation of the Request for Proposal (RFP) and/or prepared the Plan of Operation for the proposal. Review with Department of the Interior solicitors indicated that this would be a conflict of interest pursuant to 40 CFR 1506.5(c). This applies to the EIS process; not the EA selection process. MOUs, developed early, can offset future "conflict" problems.

Most agencies use two different processes for EAs and for EISs. Again, variability in policy and process mandate early identification of these issues at a particular location. In several agencies, an applicant may bring a consultant in on the initial scoping for an EA and have the consultant prepare the EA. This may not be acceptable for EISs in the same agency. The composite MOU in Figure 4 follows EIS preparation processes and policies.

**Figure 4** Composite/Model Memorandum of Understanding Between a Federal Agency (and other agencies as necessary) and a Mining Company

I. Introduction/Purpose

II. Authority. Identified agency law and regulatory authority. May refer to agency formal manual or handbook.

III. General Provisions

A. Establish roles and responsibilities. Identify lead agency.
B. Identifies interdisciplinary team and any special needs, (e.g., cumulative impacts policies).
C. Identifies EIS procedures outline, e.g., scoping, public participation, etc. Should include preparation of "Preparation Plan."
D. Needed environmental studies; data standards, provisions, if needed.
E. Confidentiality. Identifies confidentiality provisions; Freedom of Information requirements.
F. Monitoring and coordination schedules.
G. Responsibility. Affirms agency responsibility for document; gives any special instructions as to preparation.

IV. Procedures for Selecting a Contractor

A. Establishes contracting rules and payment provisions.
B. Selection procedures:
   1. Joint preparation of RFP and schedule.
   2. Technical Proposal Evaluation Committee or joint process committee for hiring contractor. Identifies agency selectors.
   3. Selection standards; experience, education, and any licensing criteria, e.g., PE.
   4. Selecting - Agencies select. Applicant/proponent pays.
C. Contractor Provisions
   1. Points of contact and coordination.
   2. Contractor schedule of action.
   3. Record keeping and data requirements.
   4. Special provisions, e.g., special design of visual aids, special ADP applications, etc.
D. Agency Provisions to Contractor

V. Terminations and Modification

VI. Signature Blocks

## 7.6.3 SELECTING AN EIS CONTRACTOR by L. Russell

### 7.6.3.1 Introduction

The Council on Environmental Quality (CEQ) regulations (40 CFR 1500) encourage integrating NEPA with other planning and environmental permitting procedures so that all such procedures can run concurrently rather than consecutively. The wise selection of a third-party consultant to develop an EIS or an EA can greatly assist the efficient and cost effective procurement of all required NEPA and permitting information. This can save the proponent significant expenditures of money and time in developing a proposed project; and at the same time, result in a better EIS/EA from which agencies can base decisions and actions on a proposed project.

### 7.6.3.2 Approaches to EIS/EA Preparation

There are three general approaches to developing an Environmental Impact Statement (EIS), or an Environmental Assessment (EA): the Proponent Directed, the Agency Directed and Third Party Contract.

Under the Proponent Directed approach the project proponent retains a contractor to design and perform baseline studies, prepare environmental documents and an operating plan which is then submitted to the lead agency involved. The proponent generally discusses environmental data collection and potential project components with the agency prior to initiating the NEPA process. The submittal of the Plan of Operations generally triggers the preparation of an EIS/EA by the lead agency using the data supplied by the proponent. The CEQ regulations, however, require the lead agency

to evaluate and take responsibility for the accuracy of the information submitted.

The disadvantages of this approach are that the lead agency may disagree with the project scope, the baseline studies conducted, or the alternatives analysis performed by the proponent. This would require additional data collection and reassessment of the project scope and environmental consequences. Not only would this delay the preparation of the EIS/EA, the proponent may also pay twice as much for the development of the EIS/EA. On the other hand, if the agency accepts the proponent's information without sufficient verification, the EIS/EA is exposed to subsequent litigation on its adequacy due to the failure of the agency to conduct an independent evaluation of the data.

This approach may also require a second learning period for the agencies to become familiar with the project purpose and need, the affected environment, the potential alternatives to the proposed action, and the potential consequences of the action alternatives. The persons preparing the baseline work may be different than those writing the EIS/EA which may lead to delays and misinterpretations of data.

The second approach is the Agency Directed EIS/EA. Under this approach, the lead agency, after coordination meetings with the proponent and other cooperating agencies, designs the baseline program, collects and/or manages baseline data collection, develops alternatives to the proposed action, and writes the EIS/EA. The disadvantage of this approach is the complexity in management. This approach relies heavily on personnel within the lead agency and cooperating agencies. The quality and continuity of the EIS/EA effort is dependent upon the internal agency priorities and funding. This approach may hinder agency responsibilities in other regulatory, land management and resource programs. In addition, the agency must manage consultant's efforts and involvement by the proponent. The potential for delay in completing the EIS/EA is high under the Agency Directed approach.

The third approach is the Third-Party Contract. Under the contract approach the lead agency and proponent enter into a "third-party contract" termed a Memorandum of Understanding (MOU). The MOU provides for the lead agency selection of a private contractor to be paid by the proponent. The CEQ regulations (40 CFR 1506.5(c)) require the consultant to be selected solely by the lead agency "to avoid conflict of interest". As discussed in Section 7.6.2, the MOU should clearly define agency, contractor and proponent roles, responsibilities, restrictions, and authorities; as well as procedures or processes, time frames and the basis for modifying and terminating the contract.

Under the third-party contract a consultant collects baseline data pursuant to the scope of work developed by the agency and proponent, prepares an impact assessment, preliminary, draft, and final EIS/EA. The lead agency provides guidance in the baseline collection effort (potentially including technical oversight during the baseline studies), participates in preparing the document, independently evaluates the statement prior to its approval, and is responsible for the scope and content of the document. The proponent provides data to the lead agency and contractor for incorporation into the NEPA document.

The advantages of this approach to EIS/EA development include efficiency, reduced potential for delay, and a high quality EIS/EA, depending upon the contractor selected. Some parts of the EIS/EA may be developed simultaneously with the baseline data collection which expedites the overall EIS/EA time frame. A contractor generally has the manpower necessary to meet established deadlines.

A disadvantage of this approach, especially from the proponent's perspective, is the loss of control in the process. This is due to the CEQ requirements that the contractor be under the control of the lead agency. The agencies and/or the contractor may not be sensitive to the proponent's financial expectations and development schedules. This issue can be reduced somewhat by developing a well thought out MOU. In addition, the loss of control in the process may be offset by a reduction in the risks of delay in project development by either agency disapproval of the fundamental elements of the scope and baseline studies, or a successful appeal of the EIS/EA. The third-party approach may also require use of a full-service environmental consultant with considerable project management skill to successfully coordinate the effort and meet established deadlines. This may be especially true for preparing an EIS.

The selected approach to preparation of an EIS or EA will depend on the proposed project, the resources available to the proponent and the regulatory agencies, and whether an EIS or EA is being prepared.

#### 7.6.3.3 Selection of Consultants

Although the contractor must be selected solely by the lead agency, the proponent participates in the process leading up to the selection of the contractor by first helping draft the MOU which describes the authority, roles, responsibilities, and coordination requirements for the proponent, agency and the contractor. Second, by providing input into the scope of work developed for the project. This document describes in general terms the project definition, permit process and the significant environmental issues to be addressed in the analysis. A good scope of work will help ensure that the contractor proposals focus on the important project and environmental issues. Third, by providing input into the request for proposal (RFP) including the contractors to be contacted and the criteria to be used for selection of

the contractor. The request for proposal will also include the MOU and scope of work.

The criteria by which a contractor and/or contractor team is selected will vary from project to project based on the site and mining proposal. However, the following general criteria should be evaluated:

NEPA Experience
Credibility (Agency Relationships and References)
Data Analysis and Interpretation
Methodology
Project Manager
Mining Regulation Knowledge
Mining and Processing Operations Knowledge
Schedule of Work/Commitment
Costs
Public Communication Skills
Geographic Location

In selecting a consultant it is important to assemble a team of professionals in the fields of wildlife, fisheries, vegetation, water quality, geology, archeology, etc, as well as mining and process engineers, to assess the affected environment and evaluate impacts from a proposed action or action alternatives. The experience, technical qualifications and methodology (including quality control and quality assurance) of those collecting the data are important in obtaining reliable and defensible data. The contractor must be competent and have credibility with other regulatory agencies and the public. A contractor should also be able to provide references to the quality and timeliness of past NEPA work.

A critical aspect of selecting a consultant is designating the contractor's Project Manager who directs, supervises and coordinates the EIS/EA effort. A well selected project manager will work diligently to achieve the project schedules, remain within the anticipated project budget, and minimize conflict between parties involved in the process. In addition to NEPA experience and personal credibility, good project management, communication skills, and a commitment to the project are essential.

The contractor must also have a working knowledge of mining regulations and operations. Consideration should be given to the contractor's sensitivity to the Plan of Operations and engineering feasibility studies prepared by the project proponent. This involves understanding the logistical, engineering, mineral processing, and economic constraints of the project, and the ability to balance these criteria with the regulatory requirements of NEPA. Developing a clear project definition in the scope of work, including preliminary engineering criteria, at the onset of developing the EIS/EA, will help focus the contractor's efforts and expedite the process.

Another consideration in selecting the contractor is geographic location. A local contractor should know the local conditions, have established credibility with local decision makers, and preferably, have contract experience with the local agency.

As the proponent has financial responsibility under the third-party contract approach, it is common for the proponent to focus on costs when evaluating or suggesting contractors for performing an EIS/EA. While a particular contractor may be expensive, good NEPA experience and an understanding of mineral development will expedite the process, thereby potentially saving time and money in the long run.

Agencies, on the other hand, may tend to focus more on the regulatory process, looking for NEPA experience, expertise in baseline data collection and analysis, as well as the contractors methods and approach toward the EIS/EA. However, the proponent should also be concerned with a consultant's understanding of the process. The proponent's financial interest in the project requires the consultant to have a complete understanding of NEPA and state, local and other federal regulatory requirements governing the project. It is important that the NEPA process be followed correctly to minimize the chances for a costly challenge to the EIS/EA. A successful challenge could make a project unprofitable due to extended delays and changing market economies.

The resources available to the contractor should also be considered in the selection process. Small or independent contractors can bring a solid commitment to the effort as they may focus on this single project. A larger firm may try to "work this one in" as they attempt to maintain billable hours of large work staffs. For the smaller firm the project manager will require exceptional coordination skills as they will most likely be directing subcontractors to complete baseline studies and special investigations. Smaller firms, however, may be less expensive than larger firms.

Larger firms can bring a "turn-key" approach to an EIS/EA project. Studies and analysis can frequently be completed by personnel on staff which can improve project coordination and expedite the process. Larger firms may have a better base of available data and may survive difficult economic times better than a smaller firm. The disadvantages of a larger firm may be a lack of commitment to the project (one of many) and costs are usually higher.

Once consultant proposals have been submitted in response to the request for proposal, they should be evaluated against the selection criteria and how well they address the scope of work. This can be done by weighting each criteria according to its relative importance and rating each proposal based on how well it satisfies each criteria. This provides an objective basis for comparing the proposals.

Although the agency is ultimately responsible for contractor selection, both the agency and proponent should independently rate the proposals and discuss the

results. Often there will be several contractors who are highly qualified and satisfactory to both the agency and proponent.

#### 7.6.3.4 Summary

The prime consideration in selecting an EIS/EA contractor should be competence, reputation and credibility. The more qualified the contractor, the less chance the EIS or EA will be successfully challenged.

Agencies may tend to focus on a contractor's understanding of the NEPA process, data collection and methodology in an effort to comply with both the letter and spirit of the statue and implementing regulations. The proponent may put more weight on costs, schedule, and look for a consultant who understands the owner's financial expectations and the project development schedule. These differing priorities may cause conflict (whether actual or merely perceived) in the contractor selection process. Because of this, it is important to have a well developed scope of work which includes a good project definition, preliminary engineering criteria, permitting process, defined roles, and expected time frames when using a third-party contractor.

### 7.6.4 ASSESSMENTS VERSUS IMPACT STATEMENTS
**by D. W. Struhsacker**

#### 7.6.4.1 The Difference Between an EA and an EIS

The federal land management agencies (i.e., the U.S. Forest Service, USFS, or the U.S. Bureau of Land Management, BLM) must decide between preparing an Environmental Assessment (EA) or an Environmental Impact Statement (EIS) for proposed mining projects. In some situations, the project proponent may be able to influence this situation by requesting preparation of either an EA or an EIS. This choice may also exist for projects in states with a state EA/EIS process. In requesting either an EA or an EIS, the project applicant is making an important commitment to a permitting strategy. Prior to deciding between an EA and EIS, the project proponent needs to understand clearly the distinction between an EA and an EIS, and to evaluate carefully any potential political issues affecting the project, land use decisions on federal land, and the likelihood of third-party opposition.

Both an EA and an EIS are disclosure documents which describe project-related impacts. Contrary to the common misconception that an EIS is a more intensive review of environmental conditions than an EA, the real difference between the two documents is procedural; there are many complex legal requirements for public scoping and review that do not apply to an EA. Another fundamental difference is the limited range of decision options associated with an EA. Projects approved by an EA can cause no significant impacts. In reaching a decision for a project analyzed by an EA, the responsible official from either the BLM or the USFS can either conclude that there are no significant impacts associated with the project and issue a "Finding of No Significant Impact" (a FONSI), or can conclude that there may be significant impacts and that an EIS will be required to evaluate those impacts. In contrast, if an EIS is prepared for a project, the responsible agency may approve the project even if there are potentially significant impacts, if it can be shown that these impacts have been mitigated to the greatest extent possible. The EIS must disclose the type, magnitude, and duration of the significant (and non-significant) impacts.

As discussed in Section 7.6.1, both the EA and the EIS processes include an appeal process in which a third-party can protest the decision of the land management agency. In the case of appeals to an EA, the appeals typically contend that the project may cause significant impacts to the environment, and petition that an EIS be prepared.

#### 7.6.4.2 EA versus EIS

Generally speaking, an EIS has been required for most mining projects on USFS land. The situation has been different, however, for projects on BLM land. A number of mines developed during the 1970s and 1980s on BLM land were approved by the BLM with an EA. This was particularly true in Nevada and California.

In 1989, the BLM made a nationwide decision to enforce a requirement to prepare an EIS for all future mining projects proposing more than 640 acres of cumulative surface disturbance. Other factors including anticipated significant impacts to a specific resource or the presence of a sensitive resource would also be sufficient to require an EIS. Following this decision, the BLM started preparing EIS documents for most major mining projects. In mid-1993 the Sierra Club and the Mineral Policy Center filed the first appeal of an EA for a mining project in Nevada. The appeal included the demand for an EIS, contended that NEPA requirements had not been met by preparing an EA, and also raised a couple of environmental issues. The appeal was sustained, the FONSI for the project was retracted, and the BLM was required to prepare an EIS.

It appears that in the future the use of EA documents for approving mining projects, regardless of size, will become more and more limited. It may still be possible to secure approval for mine expansion projects with an EA, particularly if an EIS has already been prepared for the project. However, as discussed below, there will be business risks in attempting to permit mining projects with an EA.

#### 7.6.4.3 Political Considerations

There are inherent risks in trying to permit a mining project with an EA given the current regulatory climate and political atmosphere affecting mining in the U.S. In order for a FONSI to remain unchallenged by third-party intervention or to be upheld on appeal, the responsible agency must be able to convince the public and elected officials that the project will cause no significant impact to the environment. The current political atmosphere is not particularly supportive of this conclusion; most elected officials, anti-mining preservationist groups, and the general public feel that projects involving open-pit mines, waste rock or tailings disposal facilities, or the use of cyanide processing facilities do involve a potentially significant impact.

#### 7.6.4.4 Business Risk - EA vs. EIS

In attempting to permit a mining project with an EA, the project proponent must realize that projects with potentially significant impacts or controversial projects may incur unnecessary costs and delays by going through the EA process only to be subsequently required to prepare an EIS. The decision to prepare an EA rather than an EIS must also carefully evaluate any political considerations affecting the project, and whether political factors might precipitate an appeal of an EA. Permitting strategies for mining projects on federal land should thus carefully weigh the pros and cons of preparing an EA versus an EIS. In many regards the decision to attempt to permit a project with an EA is a business decision which must evaluate the risks associated with an EA and the financial impacts of delaying the project to prepare an EIS should the EA route prove unsuccessful.

## 7.7 DEFINING PROJECT IMPACTS AND PLANNING RECLAMATION

**by A. C. Baldrige and A. Czarnowsky**

Defining project impacts, developing mitigation and planning for reclamation are important components of the permitting process. The Environmental Assessment/Environmental Impact Statement (EA/EIS) and permitting processes integrate these activities and allow regulators to review the operations under the framework of existing environmental standards and regulations, and provide the operator with a mechanism for monitoring the environmental performance and compliance of the mining operation.

Although the critical evaluation of project impacts, mitigation and reclamation occurs during the permitting process, these aspects of the project must be routinely assessed throughout the life of an operation to ensure continued integration with changing project conditions and needs, updated environmental standards and new technology. The final plan should be detailed enough to allow evaluation against environmental standards, but flexible enough to adjust for on-site operating conditions.

The evaluation of the impacts, mitigation and reclamation for a project should involve a variety of technical and regulatory experts. The team of specialists should include scientists, regulators, engineers, operators, and manufacturers' representatives, as appropriate. In defining project impacts, developing mitigation, and planning for reclamation, the team of specialists must recognize that every mine is different and presents a unique opportunity for integration of environmental baseline data, mineral system characteristics, project design, and engineering controls into a comprehensive environmental plan.

### 7.7.1 INTEGRATING ENVIRONMENTAL DATA

Previous sections of this chapter have discussed collecting baseline and mineral system characteristics data and developing project design and engineering controls. All of this information must be integrated into the permit documents to allow evaluation of project alternatives, assessment of project environmental impacts, and development of project mitigation measures.

By necessity, to minimize the potential for environmental impacts, the data collection cannot be performed separately from the project design and development of engineering controls. The engineering design must be developed in conjunction with the evaluation of information received from the environmental baseline studies. Nor can mitigation in the true sense of the definition be separated from the ongoing data evaluation and development of the project design. Engineering design work, environmental data collection, impact assessment, and mitigation measure development cannot exist in a vacuum; all of the project components must be integrated together during the process to develop a comprehensive operational, reclamation, and environmental control plan.

Baseline environmental data will allow an operator to develop a project that is protective of the environment. For instance, information on the location of prime wetlands or significant archaeological sites within the project vicinity should be used to evaluate the location and design of project facilities. Information on baseline ground water and surface water quality should be used to develop engineering controls for the project. Information on vegetation and soils should be used to develop reclamation plans for the facility.

Throughout the process, the team of involved

specialists should be striving to refine both the baseline studies and the initial operating proposal in light of the environmental characteristics delineated during the data collection period. In this respect, the integration of the baseline environmental studies, mineral system characteristics and engineering design and controls is a process which is ongoing throughout project permitting. This process requires coordination and teamwork from all specialists involved in the permitting. The team needs to be able to decide when to reevaluate an issue or study and when there is enough data to satisfy the informational needs.

Throughout the process, there is a tendency to believe that more is better in terms of data collection, but at some point in the process, the data collection must be judged adequate to allow for assessment of impacts, selection of project alternatives, and development of mitigation. The process requires a strong project manager as well as a detailed schedule and budget which is agreed upon by the team of specialists.

Once the baseline environmental conditions of the site have been determined, the mineral system characteristics defined, and the preliminary project designs and controls optimized, the next important step in the process is integrating these factors into the permit document to develop alternatives and to predict the issues and impacts that will result for the proposed project and alternatives under study. Some preliminary impact assessment must occur at this time in order to select project alternatives; however, the detailed impact assessment occurs after the alternatives are selected.

### 7.7.2 EVALUATING PROJECT ALTERNATIVES

A mining project is made up of a number of components. Components are separate elements which when joined together form the complete project. Components include the method of mining, waste rock disposal techniques, ore processing, wastewater treatment, tailings disposal, surface facilities, and access and transportation options. Alternatives are changes to the location, design, operation or reclamation of the project components, separately or as a whole project, which could feasibly attain the project's objectives but at a lower environmental cost or a decreased level of environmental degradation. Although project alternatives may reduce environmental impacts, they may also increase capital and operating costs. Alternatives analysis must carefully consider both the environmental and the economic consequences of each alternative.

The EIS process requires that a number of reasonable alternatives to the operations as proposed by the operator be examined. Depending on the other regulatory requirements, other permits may also require a review of alternatives. For example, most water quality permits require an evaluation of best available control technology (BACT) or all known available and reasonable technology (AKART). The following discussion centers on the EIS process since alternatives evaluation is critical to an EIS; however, the discussion could be easily applied to other permits as well.

Selecting project alternatives focuses the evaluation of changes to the proposed plan which might have fewer environmental impacts than the proposed operations. Although not specifically required in the EA process, increasingly regulators are including analysis of a number of alternatives in an EA to protect against decision appeals due to a lack of discussion of potentially less environmentally damaging alternatives.

Each project has technical, environmental and economical location criteria which must be met. In any given location, there may be a number of feasible designs for facilities. Typically, an operator and the regulatory authorities will review a broad range of alternatives during the project development. This examination is essential in optimizing the ultimate project proposal. However, the examination can be cursory or in depth depending on a determination of whether an alternative is reasonable or feasible.

The concept of reasonable or feasible as applied to the selection of alternatives has been the subject of much debate. In general, NEPA requires review of a range of reasonable alternatives which meet the purpose and objective of the operator's proposal, and alternatives which are not technically or economically feasible do not warrant further evaluation. For example, alternatives which are economically infeasible or significantly reduce the project returns could be considered as not achieving one of the objectives of the proposal; to provide a reasonable rate of return to project investors. Alternatives which are technically infeasible such as experimental mining or processing techniques should also be eliminated from further study. Although there is no specific prohibition against studying infeasible alternatives, it can be argued that such a study is unnecessary and does not fulfill the NEPA requirements since infeasible alternatives can also be argued to be unreasonable.

The discussion of alternatives is a critical component of the EIS process. There must be a reasonable array of alternatives to achieve the purpose for which an EIS is prepared. The alternatives analysis always includes evaluation of the project as proposed by the operator, as well as evaluation of a no action alternative. The no action alternative evaluates positive and negative impacts if the full-scale operations do not proceed. It should be noted that evaluation of infeasible alternatives essentially results in the evaluation of a no action alternative, thus another reason that infeasible alternatives do not deserve further evaluation in the EIS document.

### 7.7.3 IMPACT ASSESSMENT

Once the alternative selection is complete, the detailed impact assessment can begin. The first step is to define the critical aspects of the project or proposed alternatives as they relate to baseline environmental, mineral system characteristics, project design and engineering controls. Critical aspects of the project are those aspects which could create political, environmental, or technical issues. It is important to keep in mind that an issue can and should be either positive or negative in nature.

Once the critical aspects of the project are defined, then the impacts associated with these aspects can be developed. Impacts can be defined as changes in the environment caused by critical project aspects or affecting those items defined as critical aspects. For instance, the use of cyanide for processing could be considered a critical aspect, and impacts of the use of cyanide on the environment should be evaluated. Similarly, maintaining down gradient water quality could be a critical project aspect and the potential for water quality impacts should be evaluated. It is important to remember that impacts can be either short term, long term or permanent and that impacts can be both positive and negative.

The team of specialists should reach a consensus on what defines critical aspects and impacts before proceeding. This is crucial to the completion of the permit process. A strong project manager and knowledgeable regulators will help to reach this consensus. An operator may also be asked to provide additional information for use in this process.

Impacts must be assessed for both the proposed project and any alternatives under study. The proposed project may have differing critical aspects from the alternatives resulting in separate impact assessments for each alternative being evaluated. Keep in mind that even a no action alternative can have impacts, particularly in the area of socioeconomics.

The impacts should be evaluated individually and as cumulative impacts. Individual impacts are those impacts which result only from the alternative being evaluated and do not take into consideration any other action: past, present or future. The Council on Environmental Quality has defined cumulative impacts as impacts on the environment which result from the incremental impact of the proposed action when added to other past, present and reasonably foreseeable future actions regardless of what agency or person undertakes such other actions. These actions can be mining or non-mining related actions. The Council goes on to say that cumulative impacts result from individually minor, but collectively significant actions taking place over a period of time.

Although for a number of years proposed coal mining projects have been required to evaluate cumulative impacts, in recent years the cumulative impact analysis has taken on a great degree of importance in the permitting of other types of mines, particularly in areas of concentrated mining activities such as in certain parts of Nevada. Cumulative impacts have been analyzed in several different forms. Typically in the development of the document, each baseline resource study is separately evaluated for cumulative impacts.

In evaluating cumulative impacts, the use of reasonably foreseeable future actions has been difficult to interpret. In most cases, an agency has interpreted an action to be in the reasonably foreseeable future if the economic feasibility has been fully evaluated, engineering work implemented, and the action is forthcoming (e.g., permit applications have been submitted). Actions which are not expected to occur in the reasonably foreseeable future can be discussed in the document, but do not need to be evaluated as part of the cumulative impact assessment.

The assessment of worst case impacts is sometimes used in impact assessment to determine the impacts of catastrophic accidents. This assessment is completed in the case of potential transportation accidents for hazardous materials and possible catastrophic failures of project components. Caution should be used when assessing worst case scenarios, as they can be quite alarming and unrealistic in nature. Risk assessment or a probability analysis type arguments can and should be used to dissuade the evaluation of worst case impacts as unrealistic and unreasonable.

Impacts typically evaluated for a project are defined as direct impacts. However, there can also be indirect impacts as a result of the mining project. Indirect impacts are those that are associated with a project but generally occur off-site. For example, an indirect impact to a mining project might be the impact of a new trailer park that might be developing as a result of the proposed mine. Another example would be an increase in secondary employment in the communities surrounding the proposed mine. Generally, there is not a definite distinction where direct impacts end and indirect impacts begin. However, typically, indirect impacts would be associated with indirect population increases resulting from the development and operation of a mine.

Once the project impacts and those of any identified alternatives have been identified, then an evaluation of the potential mitigation of the impacts can occur. For every impact identified there is a mitigation measure which can be implemented to minimize or eliminate the impact. The next section discusses the evaluation of mitigation measures for project impacts.

### 7.7.4 MITIGATION

Mitigation measures are those measures which can be implemented for a given impact which lessen or eliminate the effects of the impact. Before determining

individual mitigation measures, the team of specialists must define the goals and objectives that they hope to achieve by implementing mitigation measures for each impact. These goals and objectives for mitigation must be reasonable and achievable. For instance, in defining a goal for the impact of cyanide spills, it may be unreasonable to state that the mitigation is to eliminate the use of cyanide, but is more reasonable to state a goal of development of a comprehensive emergency response plan to minimize the potential effects to the environment in the event of a spill.

In developing the mitigation goals and objectives, the team also needs to consider the existing regulatory requirements which will impact both the need for mitigation and the way that the mitigation must be implemented. Regulatory requirements can and will dictate both the goals and objectives and the way that the mitigation must be performed. Regulatory authorities should play a key role in the mitigation discussions.

Once the mitigation goals and objectives are defined, the project impacts can be evaluated for individual or collective mitigation measures. The simplest way to complete this evaluation, particularly if the evaluation involves a number of alternatives, is to first determine impacts which may have common mitigation measures. For example, impacts to vegetation and wildlife may have a common measure in the requirement for reclamation. In addition, in the case of evaluating a number of alternatives, those impacts and mitigation measures common to the different alternatives can be evaluated together. By eliminating those mitigation measures common to different alternatives, one is left with those that are unique to the individual alternative.

The development of mitigation measures should be viewed as a problem which presents an opportunity for solution. The solutions or mitigation measures can be environmentally based or engineering based. Engineering controls such as spill containment, processing control or changes in the engineering design can be used to minimize some impacts. Other may require environmental control such as dust suppression, reclamation, and wetlands replacement.

Mitigation measures can also be immediate or long term, temporary or permanent. Immediate measures are those which must be implemented prior to or ongoing with the project development. These measures can include engineering controls or design changes. Long-term mitigation measures are implemented later in the life of the project. Reclamation is an example of a long-term mitigation measure. Temporary mitigation measures are those which are implemented during the period in which a short-term impact is occurring. For example, during the period of cyanide use in mineral processing, a mitigation measure which involves implementing a spill prevention and emergency response plan could be required. However, once the use of cyanide stops at the site, the plan is no longer necessary. Permanent mitigation measures could include site reclamation or, in some cases, include a permanent water treatment system to mitigate water quality impacts.

As discussed for the determination of mitigation goals and objectives, mitigation measures themselves must be reasonable and feasible. If a required mitigation is unreasonable or unfeasible, then the result is to essentially stop the project and create a no action alternative.

Mitigation planning must be integrated into the permitting process to assess the true project impacts. Most impacts can be mitigated to some extent. Impacts for which there is no reasonable or feasible mitigation, or for which the mitigation measures will not eliminate the impact, will form the basis for project decision making. Whether the proposed project or an alternative is approved by the regulatory agencies will depend almost exclusively on the impacts and mitigation planning for those impacts.

One of the key mitigation measures required for mining projects, is the development and implementation of a "cleanup" or reclamation plan for the project once activities are completed. Reclamation planning is discussed in detail in the next section of this chapter.

## 7.7.5 RECLAMATION PLANNING
**by J. K. McAdoo**

### 7.7.5.1 Introduction

The differences in environmental impacts between historic and current mine operations are largely a function of comparative acreage disturbed. Modern day ore processing has made the recovery of gold from low-grade ore economical; in turn, relatively larger volumes of waste rock and ore have been removed. In response to this, coupled with an increasing public mandate for environmental responsibility, reclamation technology has likewise improved. Many reclamation techniques applied today have been borrowed (and often modified) from coal, oil-shale, and phosphate mine reclamation technology, as well as from the discipline of range science. However, reclamation technology for modern hard-rock mines is dynamic, with new or improved methodologies being developed rapidly (McAdoo and Acordagoitia 1989).

Legal requirements for reclamation and reclamation planning are much more stringent for modern mining companies than for yesterday's operations. Many mines in the Intermountain West, for example, operate primarily on public lands and must comply with reclamation requirements of the managing agencies, the Bureau of Land Management (BLM) or U.S. Forest Service (USFS). Reclamation of mining-disturbed lands has been required on USFS lands since 1974, and on

BLM lands since 1981. Most states also have regulations requiring reclamation plans for mine operations. Recently, the bonding requirements of both state and federal agencies have been tightened. Thus, there is an obvious legal and logical need for sound reclamation planning. The recent changes in environmental regulations require mine operators to conduct reclamation planning in more detail, with greater emphasis on early reclamation planning and concurrent reclamation of mining disturbed areas (Buck and Botts 1990).

### 7.7.5.2 Defining Reclamation

Although it has been variously defined in the literature, reclamation as discussed herein denotes a return of land productivity, typically in terms of vegetation and related natural resources. The productivity goal(s) for site-specific reclamation would in most cases be a function of pre-mining land use or combination of uses (e.g., wildlife habitat, livestock forage, watershed, recreation, etc.). Planned exceptions might include alternate post-mining land uses which deviate from pre-mining uses (e.g., converting pits to reservoirs). Such alternate land uses may come about as the result of economic and/or practicality constraints which make conventional reclamation unachievable.

Thus, reclamation, as defined broadly here, would include both the creation of sites that will support plant and wildlife communities similar to that which was present before mining *and/or* returning the land to a stable form and productivity level, according to a predetermined land-use plan. Brown and Hallman (1984), term the latter part of this definition as "rehabilitation."

"Restoration," on the other hand, implies that the land will be returned to precisely the state it was before mining. This is nearly impossible to achieve because it requires rebuilding the soil, precise placement of trees and rocks, and use of only native plants and animals to repopulate the site (Brown and Hallman 1984).

However, reclamation is a process, not an event (Albrechtsen 1992), and in some cases restoration may be a long-term goal of reclamation. Similarly, reclamation planning should be a process, beginning with an initial plan before the advent of mining. As mining and reclamation proceed, reclamation plans should be modified appropriately in order to fine-tune additional plans for the shaping, seedbed preparation, and revegetation according to site-specific situations.

Reclamation is an integral part of the entire mining process. Some reclamation-oriented tasks must be completed before mining starts in order to meet legal requirements. Other reclamation tasks are accomplished throughout the mining process to reduce site disturbance. If reclamation is considered throughout mining activity, revegetation will be of higher quality, more quickly achieved, and cheaper than if reclamation is strictly a post-mining effort (Hallman 1984).

Reclamation may be classified into three categories:

*Interim reclamation* - reclamation actions implemented to accomplish only interim/short term goals during mining (e.g., revegetation of haul road cut and fill slopes to reduce sedimentation, revegetation of growth medium stockpiles for soil stabilization, etc.).

*Concurrent reclamation* - sequential reclamation actions implemented during active mining that lead to final reclamation of mine components (pits, dumps, etc.) in areas where mining activity has ceased.

*Final reclamation* - reclamation actions conducted on disturbed areas with minimal potential for future re-disturbance and typically completed after cessation of all mining activity. Emphasis in this section will be on concurrent and final reclamation, since they require more sophisticated and detailed planning. Interim reclamation may be thought of as an ongoing impact reduction measure.

Like beauty, good reclamation may indeed be "in the eye of the beholder." For example, good reclamation as perceived by a rancher may or may not be so perceived by a wildlife manager in the same area, or by a recreationist. Because of differences in climate, soils, and other environmental factors, the definition of good or even reasonable reclamation must of necessity be flexible enough to allow for site-specific characteristics. The fruit of a reclamationist's labor can easily be criticized on the basis of an individual's perspective and preconceived notions of "good reclamation." "Good reclamation" can best be defined as that which has accomplished the pre-established goals of a sound reclamation plan (McAdoo and Acordagoitia 1989).

### 7.7.5.3 Reclamation Planning Rationale

Reclamation planning is a legal necessity, a sound business approach, and an environmental responsibility. Perhaps just as important, reclamation planning and implementation must be viewed as an integral component of mining. Just as mineral exploration and mining are not conducted haphazardly and without detailed planning, so it should be with reclamation. According to Wade (1988), mining and reclamation should be viewed as ecosystem construction. Wade maintains that, "if planned properly, the energy expended in mining and moving materials can be directed towards placing and shaping the overburden into the physical base of planned and engineered ecosystems." Viewed in this context, mining is one of a series of "land use generations."

Buck and Botts (1989) discuss the merits of generic

reclamation plans versus detailed plans. They recommend an intermediate approach to reclamation involving specific reclamation goals and designs for major cost centers such as topsoil management, regrading designs, runoff control, etc., so that realistic surety estimates can be prepared. However, flexibility would be provided for such components as seed mix composition, topsoil application, seedbed preparation, and soil amendments. These items would be evaluated during the mine life using test-plots and/or concurrent reclamation, with the results used to prepare final reclamation specifications.

### 7.7.5.4 Reclamation Planning Considerations

According to Albrechtsen and Farmer (1987), the following considerations should guide development of the reclamation plan:

- The reclamation plan should guide both the operator and the administrator toward a future expected condition of the disturbed area.
- Reclamation plans should be an integral part of the operating plan, either incorporated or as a separate document.
- The reclamation plan should be developed by the operator with input from the surface administrator, and must be approved by the appropriate land management and regulatory agencies.
- The plan should describe in detail what is expected to happen to the disturbed site, both during and after mineral extraction, to reduce impacts on other resources and return the land to a productive state consistent with the long-term management direction.

Albrechtsen and Farmer (1987) also say that reclamation plans should include the mitigation requirements discussed in the National Environmental Policy Act (NEPA) document (i.e., the Environmental Assessment or the Environmental Impact Statement), if any was involved in the permitting process, as well as mandatory information required by regulatory agencies.

Finally, during development of the reclamation plan, the 10 basic steps of scientific reclamation should always be kept in mind (Albrechtsen and Farmer 1987):

- Insure that reclamation objectives agree with the long-term land management objectives.
- Use an interdisciplinary approach to analyze the physical, chemical, and climatic site characteristics and make recommendations for reclamation plan.
- Conserve all topsoil and material that is suitable for a growing medium on areas to be disturbed. Reapply it during reclamation.
- Reclaim disturbed areas as soon as practical to minimize exposed surface and soil loss during operations (concurrent reclamation).
- Control toxic substances that may contaminate water, air, or prohibit plant growth.
- After mineral extraction, shape the land so it is consistent with sound watershed principles and will accommodate the desired long-term land use.
- When the final landform is achieved, immediately stabilize the surface to hold the soil in place and guard against soil loss from major storms or spring runoff.
- Select equipment that is well suited to the site and prepare a good seedbed before attempting revegetation.
- Plant selected species that will hold the soil in place, provide vegetation diversity and, through succession, contribute to a stable ecosystem.
- Protect young plants until fully established.

### 7.7.5.5 Reclamation Plan Contents

A reclamation plan should contain five major categories to be discussed in detail: (1) general site conditions and situation; (2) land uses and land-use goals; (3) reclamation objectives, standards, and criteria; (4) reclamation procedures; and (5) monitoring specifications, particularly for vegetation sampling (McAdoo et al. 1990). These are discussed briefly in the following paragraphs.

#### *7.7.5.5.1 General Site Conditions*

The "general site conditions and situation" portion of the plan introduces the type and scope of proposed mining, describes the project area (location, climate, soils, vegetation, wildlife, etc.), and details current site disturbances due to existing mining or exploration activities (Thiel 1988). This portion of the plan also describes environmental priority concerns which were raised during the NEPA review process.

Depending on the land management and regulatory agencies to whom the reclamation plan must be submitted, details on acreages of proposed and existing disturbances, along with maps and other descriptive information may also be required.

#### *7.7.5.5.2 Land Use Goals*

Under the "land uses" heading, pre-mining land values and uses, land uses expected to be concurrent with mining, and post-mining land use goals are discussed. Typical pre-mining values and uses in the project areas include seasonal livestock grazing, watershed, wildlife habitat, outdoor recreation (e.g., hunting and fishing), and aesthetic values. Many prior resource uses can occur concurrently with mining, although typically at lower levels due to the surface disturbance and increased human activity (Thiel 1988). Typically, the post-mine land use goals are a function of pre-mining land use (McAdoo et

al. 1991), and are derived from concerns and goals addressed in the NEPA document for the particular project area.

In the past, some reclamation has undoubtedly occurred without formal written goals, but simply with the hope to "make some grass grow." Most current reclamation efforts have prioritized holding soil in place (minimizing erosion) and minimizing invasion by noxious alien weeds as short-range objectives. Beyond this, long-range objectives are typically related to pre-mining land use. Reclamation goals for wildlife habitat and visual quality are long-term goals in many cases. Other long-range goals may include establishing livestock forage or watershed enhancement. In most situations, and particularly on steep slopes subject to erosion, holding the soil has to be the initial reclamation priority. If the soil cannot be stabilized, other goals cannot be met (McAdoo et al. 1991). In addition to these site-specific goals, general reclamation goals for mass stability, final configuration, drainage, and public safety should always receive consideration (McAdoo and Acordagoitia 1989). In some situations, "restoration," as defined earlier, may be an ultimate long-range goal.

Alternate land use goals may supplant goals related to pre-mine land uses at some mine sites or portions of mine sites. According to Wade (1988), surface mining is a force in landscape modification that differs from glaciation, volcanism, or local tectonic forces in that its results can be controlled. By taking opportunistic advantage of changes in topography, soil parent material selection, water tables, etc., mining itself can be viewed as a resource to effect a beneficial change in land use. Certainly this land-use planning strategy has been successfully used at selected sites in Europe, and in eastern and mid western coal mining regions in the U. S. (Ashby et al. 1978, Wade 1988).

Specifically, mined lands have been targeted for such uses as crop production, forestry, recreation, and wildlife habitat. In hard-rock mining areas of the west, there are some relatively recent examples of alternate use for mined lands. These include development of wetlands and reservoirs (Proctor et al. 1983), environmental studies research stations (Krauss 1990), wildlife habitat creation or enhancement (Steele and Grant 1981, Parrish 1989, McAdoo et al. 1991, and Ricciuti 1991), and others. When mining is seen as transitional land use, mining and reclamation become the capital and means of producing future renewable resources (Wade 1988).

The post-mining land use goals, whether related to pre-mine uses or opportunistic alternative uses, become the key elements in "driving" the remainder of the reclamation planning process.

#### *7.7.5.5.3 Objectives/Standards/Criteria*

The real meat of a reclamation plan is contained in the reclamation "objectives, standards, and criteria" portion. According to Albrechtsen and Farmer (1987), the criteria to be discussed in this portion of a reclamation plan include the following: 1) mass stability objectives; 2) final configuration of the disturbed areas; 3) topsoil/growth medium management; 4) acceptable plant species for revegetation, 5) standards for air, water, and esthetics; 6) concurrent reclamation requirements 7) standards for seasonal closures, long-term shutdowns, and final reclamation; 8) fence management; and 9) surety calculations and conditions for surety release:

*Mass Stability Objectives* - Mass stability objectives should be addressed by providing for the use of sound engineering principles in the design of the pits, dumps, and roads so that long term stability, erosion, and drainage concerns are met (Thiel 1988). According to Bauer (1990), construction management is the key to successful reclamation, and begins at the time of the initial project proposal. A good seeding effort will be rendered worthless by faulty construction techniques which produce mass instability of a reclaimed site.

*Final Configuration of the Disturbed Area* - Objectives for final configuration of the disturbed area can be divided into at least nine distinct types: single lane or exploration roads, mine haul roads, pits, waste-rock dumps, low-grade ore stockpiles, ancillary facilities, sediment ponds, heap leach pads, and tailings ponds. Determining the final configuration objectives is perhaps the most difficult and time-consuming part of the reclamation planning process.

Final configuration planning for pits, waste-rock dumps, and haul roads present possibly the greatest challenge, particularly in the steep topography of the Intermountain West. Some pit reclamation alternatives include back-filling (the exception rather than the rule due to economical, geological, logistical, and sometimes even environmental constraints), partial back-filling and reclamation of pit bottoms (McAdoo et al. 1991), sculpting pit benches and high walls by blasting (Parrish 1989), and alternate uses such as reservoirs (Proctor et al. 1983).

Final configuration options for waste-rock dumps include flat-topped dumps with angle-of-repose slopes, reshaped dumps with approximately 3:1 slopes, and terraced sequential dumps, all designed to ensure stability and sufficient drainage of peak water flows (McAdoo and Acordagoitia 1991). Final configuration planning options for haul roads may include such options as: (1) constructing proper drainage, pulling in fill slopes and/or ripping the road bed, then applying topsoil; (2) "plug dumping" with waste rock placed against cut slopes to facilitate recontouring and eventual placement of topsoil; and (3) recontouring with large backhoes (McAdoo et al. 1990).

In general, final configuration planning for various mine disturbances will vary based on engineering design, steepness of terrain, environmental constraints (e.g., proximity of disturbance to streams and other sensitive areas), and site-specific goals. Through innovative and flexible planning, resulting topographic diversity of a reclaimed mine-site, particularly if undisturbed "islands" are left, can benefit wildlife and even result in a cost savings (Steele and Grant 1989, Grant and Monarch 1989).

*Topsoil/Growth Medium Management* - The reclamation planning process should detail the necessity for topsoil recovery and stockpiling, commensurate with requirements for site-specific post-mining land use(s). Topsoil is generally considered to be the "A horizon" of the soil profile. However, from a reclamation view, topsoil is material that can serve as a plant growth medium without continued additions of soil amendments (such as fertilizer). Thus, "B" and "C" horizons may be included in the topsoil category (Brown and Hallman 1984). According to May (1975) spoil or overburden material in some cases may be as good or better growth medium than native topsoil. For the purposes of this discussion, the terms topsoil and growth medium will be used interchangeably.

Topsoil should be salvaged from all areas of disturbance wherever practical and economically feasible. Typically, soil materials can be salvaged on slopes less than 30% to 40%. The maximum slope within this range from which topsoil can be stripped will depend upon the site-specific situation, ground conditions, and safety factors for standard earth moving equipment. The reclamation plan should also specify that topsoil stockpiles be surveyed annually to track storage volume. Proper advanced planning for reclamation involves soil surveys to show quantity and quality of available growth medium.

Much research has been conducted on replacement depths of topsoil needed for reclamation which indicates that more is not necessarily better. For example, optimum topsoil depth for maximum forage production, total plant cover, and species diversity may be as low as 10 to 20 cm in some areas of the west (Crofts et al. 1987). In fact, shrub and forb biomass, critical for those areas where plant diversity and/or wildlife habitat are reclamation goals, have been found inversely related to soil depth in some areas (Crofts et al. 1987). However, in cases where spoils are phytotoxic (e.g., very low or high pH), greater topsoil depths may be necessary for revegetation (Albrechtsen and Farmer 1991). If in doubt, reclamation plans should call for study plots established early on to test the adequacy of various topsoil replacement depths.

*Acceptable Plant Species for Revegetation* - Seed mixes being used for reclamation must be based on reclamation goals and site-specific characteristics (soil type, vegetation community, precipitation, aspect, etc.). Mixtures should be developed with rationale to include the following: 1) adapted species, 2) diversity of species (typically grasses, forbs, and shrubs), and 3) species which enhance natural succession (Booth 1985, Ogle and Redente 1988).

In areas with vegetation diversity goals for wildlife habitat or aesthetics, emphasis should be placed on rapidly establishing species which hold the soil and compete minimally with native species that may naturally invade the site. Heavy seeding of introduced grasses should be avoided where wildlife goals are a priority, because these grasses are often highly competitive with native shrubs and forbs which may either be in the mix or expected as "volunteer" species. Useful references on appropriate plant species for revegetation include Plummer et al. (1968), Monsen and Christensen (1975), Thornburg (1982), Wasser (1982), Albrechtsen and Farmer 1987), and Horton (1989).

*Standards for Air, Water, and Aesthetics* - Typically, air and water quality objectives are to meet state and federal air quality standards. Achieving water quality and ground cover objectives will minimize fugitive dust. Appropriate emissions controls (as designated in the operating plan) should be specified for crushing, screening, and conveying of waste rock and ore within the mining areas. These operations must be conducted in accordance with state air quality regulations.

Similarly, water quality and post-mining hydrology objectives specified within the reclamation plan must adhere to state and federal regulations. Other specific objectives typically include the following: (1) provide for surface and groundwater flows to be self-maintaining after mine abandonment, (2) minimize erosion to meet watershed goals, and (3) reduce sedimentation by retaining disturbance-generated sediments on site with sediment control structures, interim reclamation, and sound engineering design.

Visual (aesthetic) quality objectives, if any, will be highly site-specific, and should reflect concerns and goals that were mentioned in the NEPA permitting documents. Emphasis on aesthetics in reclamation, although sometimes mentioned in NEPA documents and subsequent operating plans, is often a secondary consideration in reclamation planning (McAdoo at al. 1991). Although, a few states have passed visual impact laws, regulations that address visual impacts are rare and subject to considerable controversy (Heifner 1990). Visual quality reclamation is largely a function of shaping and revegetation efforts. Obviously, open pits

and waste-rock dumps left with angle-of-repose slopes cause long-term visual modifications.

*Concurrent Reclamation Requirements* - Concurrent reclamation is defined as reclamation that occurs during the life of the mine rather than at its conclusion. Active mine areas cannot be reclaimed, but there are times and places where concurrent reclamation can be accomplished. Concurrent reclamation should proceed wherever and whenever practicable during the active mining operation. Areas in which mining activity has not occurred for over one year should be considered for partial or complete reclamation, unless there is a potential for future mining and/or the area contains ore stockpiles. Typically, a concurrent reclamation plan should be completed annually. Concurrent reclamation should follow the same objectives, standards, and procedures as the end of mine reclamation. The reclamation plan should emphasize final reclamation, with most objectives, standards, and criteria applying to both final reclamation and those concurrent reclamation activities that can and should occur as mine life proceeds.

*Seasonal Closures, Long-term Shutdowns, and Final Reclamation* - Most states have regulations outlining steps to be taken during seasonal closures and/or long-term (more than one year) shutdowns. Language similar to the following may be incorporated into the reclamation plan:

> In the event of interim or partial shut down of the mine operation, an interim shut down plan will be submitted to the appropriate agencies for approval. The interim reclamation objectives for these plans will be to ensure mass stability and minimize erosion. Partial reclamation to meet these interim objectives may be required. However, this procedure will not apply to short weather-induced seasonal shutdowns.

Some reclamation plans include requirements for seasonal shutdowns of at least some components which may include specifications for interim seeding, water bars, sediment control structures, and other such temporary impact reduction measures.

*Fence Management* - For safety reasons and because most mines are surrounded by range land, reclamation plans should include plans to fence mine operations to exclude the general public and livestock. The mine operation is typically responsible for fence purchase and installation, as well as maintenance of these fences during the life of the mine. Mine fences should remain in place, effectively excluding livestock, until acceptable vegetation cover objectives have been met. At the time of final mine reclamation, all fences constructed by the mine operation and no longer needed for public safety and/or for protection of revegetated sites from livestock should be removed by the mine.

*Surety Calculations and Conditions for Surety Release* - As discussed in Section 7.9.2, financial surety (bonding, etc.) is required of most mine operations by both state and federal agencies. Surety calculations are typically included in reclamation plans and in some cases are required by agency regulation.

Conditions for surety release will be specific to each mine project. Ideally, surety should be set up such that commensurate portions may be released sequentially as various stages of reclamation work are completed and objectives are met. Typically, the largest portion of surety (60 percent or more) is released upon satisfactory completion of earthwork (shaping/final configuration). Additional surety is released after revegetation work is completed and revegetation objectives are achieved. The remaining surety is released after all requirements of an approved reclamation plan, including detoxification of leachates (if applicable), removal of ancillary facilities, etc., have been satisfied.

### 7.7.5.6 Reclamation Procedures

Although the exact techniques, methods, and materials will vary according to disturbance type, the following summary outlines typical reclamation procedures. Successful reclamation planning and implementation demand proper choice and use of equipment and proper timing of treatment. Flexibility within a reclamation plan is vital; the ability to handle situational changes is necessary (Brown and Hallman 1984). Changes in such things as soil types, slope gradients, or aspect may indicate that different equipment or techniques will provide better results. As sites become available for reclamation, they should be field reviewed to evaluate site-specific characteristics so that suitable equipment and procedural choices can be made.

Brown and Hallman (1984) provide a detailed account of standard reclamation procedures, and much of the information discussed herein is based on their publication. Albrechtsen and Farmer (1987) have also compiled useful information on this topic in a compact field guide which is very useful to both novice and experienced reclamation planners.

#### *7.7.5.6.1 Final Configuration of the Disturbed Area*

A variety of earth-moving methods and equipment can be used to facilitate economical and ecologically sound shaping of the disturbed area for final configuration. Equipment to be used may include standard dozers, angle

dozers, large conventional and track-mounted backhoes, gradalls, drag-lines, scrapers, etc. Specific equipment to be used for each job (e.g., recontouring, grading, etc.) should be chosen according to practicality and availability.

Typically, overburden spoils should be ripped (to at least 60 cm, where possible), and scarified prior to growth medium application. This procedure will improve water infiltration potential, allow deeper plant root penetration, and eliminate smoother surfaces between spoils and growth medium. Ripping and scarification can be done by dozers, and grading (as needed) using dozers, scrapers, or other suitable equipment. In areas where ripping will create more harm than good (e.g., unearthing of large boulders), it should be avoided. In some areas, soil compaction may be worsened through extensive shaping (Ashby 1988), and this must be taken into account in the reclamation plan.

#### *7.7.5.6.2 Topsoil/Growth Medium Salvaging, Stockpiling, and Application*

The procedures section of a reclamation plan should detail the salvaging, stockpiling, and application procedures for growth medium (Brown and Hallman 1984, Albrechtsen and Farmer 1987, McAdoo and Acordagoitia 1991). Proper planning and growth medium handling is a vital component for reclamation success.

Direct placement of topsoil onto reclamation sites, when possible, has an obvious economic advantage over the double-handling associated with stockpiling. This procedure may also enhance vegetation establishment through the presence of viable native seeds in fresh topsoil.

There are many logistical problems involved with keeping true topsoil separate from subsoil horizons. Reapplying segregated horizons has not been shown to be effective in increasing total plant cover, plant biomass, and species diversity after approximately 10 years (Crofts et al. 1987). Therefore, attempts to separate the soil horizons during "topsoil" removal may not be warranted.

However, subject to logistics and available space for growth medium stockpiles, an attempt should be made to store relatively "high-quality" topsoil from specific areas separately from lower quality growth medium removed from other areas. This high quality topsoil can then be used as a shallow "veneer" on areas there quality topsoil is deemed to be a requisite for revegetation. Allen (1984) suggested that respreading approximately 2.5 cm of fresh topsoil onto regraded spoil or poor quality topsoil might be more advantageous than reapplication of a thick layer of biologically inert stored topsoil. Glass (1989) emphasized the value of fresh topsoil as a source of viable native seeds.

Growth medium stockpiles which are to remain in place through and/or beyond one growing season (inactive stockpiles) should be left at low profile with moderate slopes if possible. The surface of the stockpiles should be left in a roughened condition following grading to retard erosion and provide a suitable seedbed. The disturbed areas can then be seeded with an appropriate mixture.

Growth medium can be redistributed in lifts using conventional earth moving equipment. A dozer equipped with a ripper shank or scarifier may partially mix the growth medium and underlying materials to minimize the interface between the materials. The dozer should be operated on the contour and growth medium placed only during dry conditions in order to minimize clodding and compaction.

The reclamation plan should also specify the need and procedures for testing growth medium quality before placement on reclaimed sites in order to determine whether soil supplements are necessary.

#### *7.7.5.6.3 Seedbed Conditioning*

Seedbed conditioning is a vital element to reclamation success. Seedbed preparation can loosen compacted soils, provide water catchments (for plants), and create good "safe-sites" for seed germination and seedling survival. Equipment for seedbed conditioning includes rippers, disk plows, specialized side hill pitters, dozer blades, etc. Methods can be combined to provide desired reclamation results. The most practical and available equipment should be used for seedbed preparation.

Growth medium materials should be conditioned to a depth of approximately 15 cm. Tillage operations should be conducted on the contour to minimize erosion. The final seedbed will consist of a furrow-like configuration to help minimize erosion and increase available soil moisture. Seedbed preparation should be accomplished immediately prior to seeding to minimize the time the growth medium is subject to wind or water erosion without benefit of vegetation protection.

#### *7.7.5.6.4 Soil Supplements*

The reclamation plan should contain a discussion in the "procedures" section on the potential need for mulch and/or fertilizer on reclaimed sites. This discussion should include when, where, and how these supplements will be used, if at all. For fertilizer in particular, there are both advantages (Brown and Hallman 1984) and disadvantages (McKell 1974, Holechek 1981) of use, depending on site-specific situations. For more information on the necessity and procedures for mulching and fertilizing reclaimed sites, refer to Brown and Hallman (1984), Albrechtsen and Farmer (1987), and McAdoo and Acordagoitia (1991).

#### *7.7.5.6.5 Revegetation Procedures*

Planning for appropriate revegetation equipment and procedures should take into account site-specific variables such as access, slope, area size, and ruggedness of terrain. A wide variety of seeding equipment/procedures are available, including range land drills, brillion seeders, seed dribblers (mounted above dozer tracks), broadcast seeders and drags mounted on ATV's or tractors, hand-held broadcast seeders, and hydroseeders. These and other methods have been used successfully in various mine and mineral exploration road reclamation projects (Brown and Hallman 1984, Buck and Botts 1989, McAdoo et al. 1990) The reclamation plan should also specify seeding rates and proper timing for seeding reclaimed areas. Fall seeding is typically most successful in the Intermountain West, because planting at this time often meets cold-dormancy requirements of seeds and stimulates seedlings to grow rapidly.

Well planned seeding strategies can also contribute to the success of vegetation establishment. Interseeding of shrubs with grasses can result in a constant ratio of shrubs to grasses over time, but care must be taken not to over-seed grasses (Richardson and Trussell 1980). Seeding of shrub species alone is not recommended on steep slopes and/or in areas of extremely low precipitation. The seeding of shrubs in strips alternatively with grasses has been successful in some areas. This strategy reduces competition between slow-developing shrubs and fast-growing grasses.

Many other strategies for achieving vegetation diversity have been reported. The seeding or direct planting of shrubs in favorable sites can be supplemented by water harvesting (e.g., snow fences) to enhance establishment. Dense grass stands established by prior reclamation and needing diversity can be "scalped" for direct planting of shrubs on appropriate sites (Monsen 1989). Sometimes the direct planting of just a few shrubs will provide a seed source sufficient for eventually establishing stands of shrubs.

Supplementing commercial seed mixes with seed collected on-site can improve species diversity as well. Although collecting many species is labor-intensive, the effort can augment natural succession. Diversity in a seed mix provides different species to correspond with the various micro-niches within a site (Mahler 1990). Several types and sizes of commercial seed harvesters are available, ranging from hand-held harvesters to attachments for trucks and tractors.

Revegetation of virtually any disturbed site can be enhanced by direct planting of shrubs and, in some cases, trees. Western reclamationists would do well to learn conceptually from the tree reclamation successes of eastern reclamation projects (Ashby et al. 1978), keeping in mind the vast differences in environmental variables between the regions. Establishing trees in arid climates may be difficult without irrigation. However, the use of xeric-site adapted native species such as Utah juniper (*Juniperus osteosperma*), pinyon pine (*Pinus monophylla*), and mountain mahogany (*Cercocarpus ledifolius*) should be considered for use where growing requirements can be met.

In the Great Basin, the direct planting of adapted shrubs is probably more appropriate than planting trees in many situations, and several species have been successfully established in arid regions without irrigation (Monsen and Christensen 1975, Everett 1980). Species for direct planting include big sagebrush (*Artemisia tridentata*), antelope bitterbrush (*Purshia tridentata*), rubber rabbitbrush (*Chrysothamnus nauseosus*), winterfat (*Eurotia lanata*), fourwing saltbush (*Atriplex canescens*), shadscale (*A.confertifolia*), and others. Shrubs that are adapted to infertile soils, lithic outcrops, and shallow soils are especially useful for mine reclamation. Monsen (1989) summarized the adaptability attributes of several shrub species for use in the Great Basin. Techniques for transplanting have been reviewed by Plummer et al. (1968) and Everett (1980).

### 7.7.5.7 Monitoring Specifications

Reclamation monitoring requirements are vital to a reclamation plan. Particularly in those reclaimed areas where revegetation is deemed necessary and appropriate to achieve post-mining land-use goals, an objective monitoring plan is needed to track progress, evaluate success, and serve as the mechanism for bond release. Ensuring success can only be accomplished by closely monitoring the reclamation results, and taking prompt and effective remedial action when the situation warrants. Monitoring plans vary greatly, but typically contain descriptions of monitoring intervals, methodologies, and statistical reliability.

Monitoring requirements vary site-specifically and with various agency regulations. However, some basics should be considered when establishing a monitoring plan. Namely, a monitoring plan must be timely and reliable. Regarding timeliness, interim monitoring on an annual basis is wise from the standpoint of detecting potential problems (e.g., noxious weed invasion) early on so that correctional measures can be planned and implemented. Most importantly, site evaluation for bond release should be scheduled appropriately to allow sufficient time for vegetation establishment. In the arid Intermountain West, this may be after at least three full growing seasons. Ideally, an evaluation of revegetation success should be made during a normal to optimal climatic year, with measurements taken during the season of peak phenological development specific to the elevation of the site. The operator's desire for release of the remaining bond not withstanding, it is to the

advantage of all parties involved, as well as the resource, to allow a sufficient length of time for vegetation establishment. This is well-documented in the literature. Premature evaluation will likely result in pressure to re-seed, when re-seeding may be not only unnecessary, but both economically and ecologically costly (i.e., additional site disturbance, potential for weed invasion, etc.).

With regard to reliability, the monitoring plan methodologies, as with other components of the reclamation plan, must be mutually acceptable to both the mine operator and the regulatory agencies.

#### 7.7.5.8 Conclusions

Good reclamation planning is a painstaking process requiring cooperation and communication between the mine operator and regulatory agencies. Advanced planning allows an early opportunity to analyze objectively the quantity and quality of reclamation that can be achieved over time; this process should minimize the surprises to all parties at the end of mine life concerning unknown requirements and/or unexpected limitations (Thiel 1988).

Reclamation planning should be a dynamic process, and be flexible enough to adapt to site-specific situations as they arise (Brown and Hallman 1984, McAdoo et al.1991). Ashby (1988) warns reclamationists about the pitfalls of narrow-minded reclamation requirements which can result in counterproductive results, and advises that some areas may respond best to low-level enhancement of natural recovery processes.

According to Wade (1988), miner-reclaimers are in the business of ecosystem construction whether they want to be or not, with their only options being the quality and utility of the ecosystems they build. Modern surface mining-reclamation is a powerful force in landscape modification. This power should not be used myopically with one eye on what has been "good enough" and the other on the profit margin, although the latter is necessary. Rather, future resource needs should be considered as post-mining land-uses are planned, with reclamation results becoming a "monument to our generation and a source of comfort and utility to our descendants" (Wade 1988).

Concurrent reclamation in hard-rock mines is accelerating out of environmental, social, and legal necessity. Properly planned reclamation can be both economically feasible and effective in restoring land productivity. Continuing development of reclamation "success stories" will require the close cooperation of land managers, mine managers, engineers, renewable resource specialists, and equipment operators, all with a far-sighted understanding of post-mining land-use goals (McAdoo et al. 1990).

## 7.8 ENGINEERING FOR PERMITTING

**by M. Hames**

### 7.8.1 THE ROLE OF THE ENGINEER

This section discusses the role, timing and amount of engineering required to define a proposed mining project and to support the permitting process. It also emphasizes the benefits of coordinating the efforts of engineers and other specialists, rather than segregating their activities.

Engineers are specifically qualified to design, supervise, the construction and maintenance of, and report on industrial works, machinery, roads, bridges, river improvements, docks, drainage, and hydraulic works, sewage disposal facilities, and the transmission and application of power, light and heat. For mine development, the relevant disciplines include mining, metallurgical, civil, structural, mechanical, electrical, instrumentation, and marine engineering. Historically, some of these disciplines have been omitted from the early mine planning phase, a time when engineers should be collaborating with the geoscientists and environmental resource specialists to define the project, to identify potential project impacts, and to determine the scope of the data collection programs.

Engineering serves four main functions: defining the design requirements; communicating these requirements; ensuring that the requirements are adhered to or adjusted to meet the expected performance; and planning how to deal with emergencies such as accidental releases of contaminants. The details are developed through a process of study, review and final design which needs to be coordinated and dovetailed with the permitting activities. This coordination should start with preparing the project plan and the permit applications, in order to provide a comprehensive approach to project development.

During permitting, project engineers and engineering consultants define the design requirements and develop a proposed project facilities arrangement and design to satisfy those requirements. During this process alternative configurations for project facilities are also evaluated. In response, the regulatory agencies review the proposal and the alternatives and assess the impacts. The project proponent is then responsible for translating the decisions and conditions stipulated in the permits into design details, purchase orders, and contract documents that communicate the commitments to suppliers and construction contractors. Both the project proponent and the regulatory agencies subsequently share an interest in ensuring that the work is performed according to plan.

Because mines are commercial ventures, the proponent's engineering team tends to concentrate on providing functional, cost-effective facilities which comply with environmental protection requirements. The

regulatory agencies main focus is on minimizing environmental impacts, ensuring compliance with prescribed standards, and addressing public concerns. The difference in emphasis results from their distinct mandates; one team defines what needs to be built and how, while the other is concerned with what needs to be protected and how. However, both groups should strive to consider the complete picture from the beginning to avoid costly iterations while trying to reach the best combination of economic, physical and biological benefits.

### 7.8.2 CO-ORDINATING ENGINEERING AND PERMITTING

Efficiency argues in favor of co-ordinating the design engineering and permitting activities so that the project can be correctly defined and important issues properly addressed from the beginning. Increased communication leads to better understanding and assists in making wise, informed decisions without unnecessary expense or delays. Separating permitting and engineering design activities, on the other hand, can lead to confusion. This confusion can delay resolution of competing or conflicting goals, making it difficult to formulate effective plans acceptable to all interested parties (i.e., the proponent, the agencies and the public). It may even make a profitable mine impossible to achieve because of a lost window of opportunity for development.

At the conceptual and permitting stages, project definition tends to be iterative, with actions being proposed and analyzed, and amendments being recommended. The process runs more smoothly when the issues are correctly anticipated and addressed in the first place. For best results, the various engineering disciplines that will ultimately be involved should participate in the strategic planning so they can gain a better appreciation of the issues they will need to consider during project design.

The strategic planning exercise should identify design options and preferences and evaluate the cost and environmental impact implications associated with each option. This is a good opportunity for planning coordinated data acquisition programs to provide both the project engineers and the environmental scientists with useful information. Specific data gathered during exploration activities and baseline studies can assist the project engineers in making better engineering decisions early during project planning.

The early planning exercise should also identify any areas of special environmental concern in order to avoid impacting these areas if possible, or to develop mitigation measures if impacts to these areas cannot be avoided. The information flow and decisions that link the design and permitting activities should be identified at this stage to assess the extent and scheduling requirements for engineering input into the permit applications.

Table 21 shows a sequence of activities that allows the appropriate information flow and response to decisions that can be adapted to suit particular circumstances. It illustrates engineering and permitting activities following parallel paths linked by planning, or "brainstorming" sessions that control the evolution of the project.

Brainstorming requires a multidisciplinary team with decision-making skills and expertise on all aspects that can influence the project, including engineers representing the various disciplines involved. This core group should be established at the earliest point that meaningful discussion and planning can take place, and should steer the project by meeting at strategic intervals to provide continuity.

Brainstorming sessions help co-ordinate the engineering and permitting efforts by providing a forum for risks, opportunities and consequences to be openly discussed, thereby reducing subsequent surprises. Participants gain direct exposure to the issues they must jointly address which also promotes creative problem-solving and helps avoid biases that can distort or dominate the project.

In particular, work on the Plan of Operation and the feasibility studies should be co-ordinated because they both deal with basic project concepts and criteria. Although they serve different audiences, these are key documents for decision-making and need to be consistent if regulators, owners and investors are to be deliberating the same courses of action. Consequences to the environment and associated costs also need to be related. For example, the feasibility studies should address the costs of mitigation options and provide sensitivities based on best and worst case scenarios, including potential delays.

There are a number of disadvantages associated with omitting design engineers from planning teams. Some of the problems which may be precipitated by the lack of adequate coordination with the project engineers include the following: the need to rework design concepts that may prove over-conservative, or unworkable; over or under estimation of potential impacts or problems, before they have been properly assessed; locating facilities in sensitive, or impractical areas prior to adequate sizing and consultation; premature publication of details that have not been agreed upon by the appropriate experts; and misdirected effort on details that do not affect the permits, while overlooking issues that do.

In terms of the sunk costs and interest on loans that accumulate during the development phase, "time is money", and the timing of engineering to support permitting activities is crucial to avoid unnecessary expense. For example, premature permit applications

**Table 21** Engineering for Project Definition and Permitting

(POO = Plan of Operations, FS = Feasibility Study, Per = Permit Applications)

| Component or Activity Definition<br>( ) = non-engineering<br>* = selective detailed design | Level of Effort<br>c = conceptual<br>d = detailed<br>f = final<br>POO | FS | Per | Engineering Disciplines Involved |
|---|---|---|---|---|
| **Area Characteristics** | | | | |
| location, topography, climate, seismicity, (ownership & history) | f | f | f | civil |
| geology: (general, regional, local & ore body mineralization) | d? | f | f | |
| **Project Description** | | | | |
| (geologic resource) & mineral reserve | d | f | d | mining |
| mining operations: access & haul roads, underground &/or open pit development, mining methods, equipment, services | c | d | d | mining, civil , electrical |
| *waste rock disposal: dumps, backfill, landfill | c | c | d | mining, civil |
| mine plan & production schedule | ? | d | c | mining |
| metallurgy & metallurgical test work review | c | d | d | metallurgy |
| process options | c | c | c | metallurgy |
| process design criteria | | d | c | metallurgy |
| process flow sheet | c | d | c | metallurgy |
| process equipment sizing | | c | | metallurgy |
| *equipment specification: select items affecting or protecting environment | | | d | metallurgy, mechanical |
| processing: methods, plant layout & operation | c | c | c | metallurgy, mechanical |
| *reagents: usage, handling & storage | c | c | d | metallurgy |
| *cyanide: usage, handling, destruction, neutralization or degradation | c | c | d | metallurgy, civil |
| process control & instrumentation | | c | | metallurgy, instrument |
| *leach pad, solution ponds & ditches: earthworks, liners, drains, leak detection, & wildfowl protection covers, netting or wires | c | c | f? | civil, structural |
| *solution application, piping & pumping | c | c | d | civil |
| tailings disposal & reclaim options | c | c | c | civil, metallurgy |
| tailings disposal: method, containment, seepage control, reclaim & leak detection | c | c | c | civil, metallurgy |
| *dam design, seepage control & leak detection | c | c | f? | civil |
| site layout: component location options, including avoidance or minimization of: disturbance to wetlands, wildlife habitat & migration routes, historic sites | c | c | c | civil, structural, mechanical, electrical |
| site preparation & development | c | c | c | civil |
| *logging, clearing & stripping plans | | | d | civil |
| *grading plans | | | d | civil |
| *reclamation recontouring | | | d | civil |
| topsoil storage | c | c | c | civil |
| *fencing: wildlife, range, safety & security | c | c | d | civil |
| infrastructure & services: access & haul roads, airstrips, docks, water supply, storm & wastewater management, power supply, fuel & oil storage, sanitary & solid waste disposal, snow removal & avalanche protection, security, camps & new housing or townsites | c | c | d | civil, marine, electrical |
| fire protection & communication systems | | c | c | mech., electrical |
| *new access roads, bridges, docks & other works affecting navigable waterways | c | c | d | civil, structural |

| | | | | |
|---|---|---|---|---|
| water & power distribution | | c | c | civil, electrical |
| *water balance | c | c | d | civil |
| *wells | | c | d | civil |
| *powerline ROWs | c | c | d | |
| ancillary facilities: offices, change houses, first aid, ambulance, mine rescue, repairs & maintenance, warehousing & laboratory | c | c | c | mining, metallurgy, mechanical |
| **Environmental Protection Measures** | | | | |
| stated intentions to minimize impacts where feasible | c | c | d | |
| pollution control measures & equipment including: dust suppression, retention basins & diversions to control sediment & surface runoff, revegetation for erosion control, noise suppression devices for equipment, filters & collectors to control air emissions, treatment of process water | c | c | d | civil, mechanical, metallurgy |
| air quality: revegetating stockpiles, road surfacing & spraying with chemical stabilizer &/or water, speed & travel restrictions, dust collection on drills or wet drilling, baghouses on crushing, screening & conveying | c | c | d | mining, civil, mechanical, metallurgy |
| *point source identification, emissions estimate & controls | | | d | mechanical, metallurgy |
| *specifications for dust & fume control equipment: baghouses, scrubbers, retorts, fans, gas detectors & sprays | | | d | mechanical |
| *dust & fume containment: enclosures, room finishes & seals, conveyor covers & discharge chutes, dust tubes & wind fences | | | d | structural, mechanical |
| *erosion & sediment controls: grading, revegetation, diversion ditches, runoff collection, silt fences, sediment ponds & dams | c | c | d | civil |
| water quality monitoring: surface & groundwater | c | | d | civil |
| *effluent treatment & sewage disposal | | c | d | civil |
| *landfills | c | c | d | civil |
| *spill prevention, containment & contingency plans for handling, storage & use of: fuel, oil-filled equipment, hazardous materials & process solutions; this includes discharge response strategy & SPCC plan | c | c | f? | civil, structural, mechanical |
| *spill containment details: double-walled tanks, tank covers, welded pipe joints, concentric pipes, curbed or diked materials transfer & mixing areas, liners & leak detection beneath certain process areas | | | d | civil, structural, mechanical, electrical |
| employee environmental education program covering laws, concerns & safety | c | | d | |
| cultural resources: avoidance, fencing, controlled access | c | | d | |
| visual resources: isolation in low-visibility area, painting structures to blend with background, dust suppression | c | | c | civil, structural |
| livestock, wildlife & wildfowl: fencing & cattle guards, shielded lighting, pond & ditch covers, garbage management, minimized traffic, wildlife education program | c | | d | civil, electrical |
| *powerline raptor protection | | | d | electrical |
| wetlands protection: agreement to meet agency requirements | c | | c | |
| *wetland mitigation plan | | c | d | civil |
| recreation: reroute trails, add signs, fences & other safety measures | c | c | d | civil |
| **Reclamation** | | | | |
| goals & commitments: stated intent | c | c | d | |
| scheduling interim & final reclamation | c | c | d | |
| procedures: reclaim abandoned roads & stream diversions no longer required, stabilize surface, recontouring, control erosion, reapplication of topsoil, revegetation, removal &/or fencing of | c | | d | |

| | | | | |
|---|---|---|---|---|
| potentially hazardous structures & landforms, plug wells | | | | |
| **Workforce and Schedule** | | | | |
| construction & operating workforce numbers & availability | c | c | d | mining, metallurgy |
| schedule of principal predevelopment, construction, operation & reclamation activities | c | c | c | mining, civil |
| **Drawings** | | | | |
| location map, site plan, seismic events, snowcourse data, geologic map, underground or pit & waste dump cross sections, leach pad plan & details, haul & access road cross sections, surface water quality sampling sites, monitoring well detail, diversion ditch cross section, controlled solution routing diagram, post reclamation contours | c | c | d | mining, civil |
| mine plans & sections, mine services, process flow sheets, site layout, plant & ancillary facility GAs, water distribution diagram, electrical single line diagram | | c | c | mining, civil, metallurgy, mechanical, electrical |
| *plans, sections & details of works affecting watercourses & navigable waterways: new access roads, bridges, docks & dams | | | f? | civil, marine |
| **Costs and Economics** | | | | |
| capital & operating cost estimates: base case & alternatives | | d | c | mining, metallurgy, civil, mechanical, structural, electrical |
| economic analysis | | d | | mining, metallurgy |
| risks & opportunities | | c | | all |
| | | | 15% | |
| **Procurement** | | | | |
| *specifications, POs, evaluations, expediting | | | f | mechanical |
| | | | 30% | |
| **Contracts Preparation and Administration** | | | | |
| *scope, detailed drawings, specifications, general & special conditions & commercial terms | | | f | civil, mechanical, structural |
| | | | 5% | |
| **Construction Management** | | | | |
| *supervision & QA inspection & testing | | | f | civil, mechanical |

with insufficient engineering can lead to the abortive collection of baseline data, drilling, test work, hydrology, analysis and design, if the facilities have been improperly sized or located, or if the basic design criteria have been inadequately defined. Delays can be equally damaging, burdening a project with additional interest, escalation, carrying charges on ordered long delivery items, and possibly cancellation charges.

A lost window for construction can also prove expensive if it causes winter work that entails snow clearing, additional downtime because of inclement weather, difficult earth moving conditions and the need for temporary protection and heating. Alternatively, construction may have to be interrupted for the winter which increases the mobilization/demobilization costs, or it may have to be completely postponed until the next season, thereby delaying any possible return on investment and perhaps "killing" a marginal project.

The above-mentioned concerns can be minimized if the engineering is dovetailed with the permitting activities to provide the correct information flow and prompt response to decisions. Again, this argues in favor of coordinating and integrating these activities rather than segregating them.

### 7.8.3 COORDINATING DESIGN, PROCUREMENT, AND PERMITTING

The scope and steps associated with the various stages of engineering include the following:

- Conceptual: feasibility and trade-off studies.
- Detailed: preparing drawings and specifications describing what is to be constructed, and how.
- Procurement: obtaining suitable quality equipment and materials that perform the necessary functions.
- Construction management and inspection: insuring the design is correctly interpreted and followed.
- Commissioning and start-up: verifying that the facility performs according to needs and expectations.

Historically, for "fast track" projects, a preliminary engineering stage was inserted between the feasibility studies and the final detailed design, procurement and construction phases. Sometimes the preliminary engineering phase overlapped the feasibility studies, and frequently preceded final corporate, or agency approval for the project. This allowed the early ordering of long-delivery items critical to an accelerated schedule to start initial site grading as soon as regulatory approvals were obtained.

The increasing demands for information to satisfy the permit applications, and agency requirements for better definition and more detailed answers to critical questions, has extended the scope of preliminary engineering. To compensate for the lengthening permitting process and to make best use of the time, one tactic has been to commission and even complete final detailed design and strategic procurement before receiving agency approval for the project. However, this approach risks the added costs of abortive work if the assumed scheme is not approved by the agency, which may result in extra carrying charges and interest payments in the event of delay, or lost investment if permits ultimately fail to be obtained for an economically viable alternative. An unplanned hiatus in the development schedule can also entail having to repeat certain engineering and procurement tasks because of lost continuity or elapsed orders, and can mean missing the best construction conditions causing even further delay and cost to the project.

The danger of over-investing in engineering and early procurement needs to be balanced with providing sufficient detail to complete the permitting process and generating adequate definition to be able to describe the project and to proceed with construction at the earliest opportunity. This confirms the importance of ongoing planning using the best information and guidance available in all fields that will ultimately be engaged in the project.

### 7.8.4 ENGINEERING DESIGN REQUIREMENTS

A viable project design will provide technically sound facilities and operations which perform the necessary functions at acceptable costs. Project designs must also satisfy regulatory requirements and important public concerns to minimize and control short and long-term project impacts through appropriate choices, mitigation and monitoring.

The engineering design requirements are developed by the following steps:

- Reviewing the ore reserve data, metallurgical test work and site characteristics.
- Deciding the mining and processing rates, based on technical and economic considerations, including company policies, or hurdle criteria such as the minimum mine life.
- Selecting the mining and processing methods after comparing the options.
- Establishing the design criteria including the mine plan, flow sheets and GAs, and sizing the facilities to suit.
- Identifying the necessary infrastructure, services and ancillary facilities.
- Developing alternative configurations for the site development, including component options and ranking the alternatives according to technical acceptability, constructability, costs, potential issues and concerns, risks and opportunities.
- Selecting the best alternative through successive screenings, including trade-off studies or more detailed examination if necessary.
- Developing the proposed project plans for use in permit applications.
- Modifying the plan as required to answer agency or public concerns or to comply with agency decisions and approval conditions.

Much of the work described above is normally performed while preparing feasibility studies used by the proponent to decide whether to proceed with the project, and/or to obtain funding. Greater detail is reached through further engineering.

Table 21 lists items that are normally addressed in the Plan of Operations and/or the feasibility studies, together with subjects that demand further definition, or selective detailed design to satisfy permitting requirements. The tasks and levels of input indicated are based on recent gold projects and represent between 15% and 25% of the detailed engineering, besides completion of the feasibility studies. Depending on the scope for the work listed, the approximate range of final design completed by

discipline is typically: mining 30% to 50%; metallurgy 30% to 50%; layout 60% to 80%; civil 60 to 80%; structural 10% to 30% mechanical, piping and building services 5% to 15%; and electrical and instrumentation 5% to 10%.

## 7.9 CLOSURE AND POST-CLOSURE PLANNING

### 7.9.1 CLOSURE AND POST-CLOSURE REQUIREMENTS
**by B. Licari**

#### 7.9.1.1 Closure

For purposes of this section, closure is defined as the activity of a mining company related to the shut down and reclamation of mining projects in a cost effective and environmentally responsible manner. Because what is or is not acceptable as environmentally responsible will ultimately be determined by outside parties and not by the mining company itself, a proactive approach to developing and implementing a detailed closure plan will benefit the company by providing evidence to the regulatory agencies that a responsible closure can be achieved. Additional cost savings can usually be realized by reducing hidden or untimely costs caused by poor planning in the early stages of a project or during operations.

#### 7.9.1.2 Preliminary Closure Plan

A preliminary closure plan is usually required very early on in the project and is normally included as a requirement of one or more permit applications. For example, most states require submittal of a preliminary closure plan in conjunction with the water pollution control permit application for heap leach operations and waste rock and tailings disposal facilities. This plan is usually filed within six months of the issuance of the permit, and is normally updated annually to reflect any changes in overall closure strategy and estimated mine life. Also included would be any process changes, solution analysis, and any new characterization of tailings or overburden material which would affect the final disposition of the facility. On federal land, a closure plan will be required before the issuance of a permit to operate, and significant changes in process are required to be submitted as amendments to the plan as they are implemented and incorporated into the Plan of Operations.

#### 7.9.1.3 Ongoing Monitoring

The ongoing monitoring program produces data that is essential to verify assumptions used in the preliminary closure plan and to develop the final closure plan. Costs involved in the preparation of the final closure plan are significantly reduced if the ongoing monitoring effort has been diligent and accurate, particularly with regard to ground water quality. Data which will provide input to the mass balance and chemistry of water impoundments to be left on the property should be included early in the project, as the success of the ground water model used for closure will be dependent upon the quantity and accuracy of this information.

#### 7.9.1.4 Final Closure Plan

The final closure plan is usually submitted six months or more before shut down of operations. For regulatory purposes the plan will be required to include a timetable and a detailed outline of activities necessary to complete reclamation and prevent future environmental degradation as a result of mining-related activities. Normally mining companies compile a much more comprehensive closure plan for internal use, and selected parts of the plan are submitted to regulatory agencies as necessary.

The main areas of concern by regulatory agencies will include the following: tailings pond closure; hydrology of water impoundments; pit slope stability or subsidence concerns; and reclamation of overburden stockpiles and waste rock dumps. Discussion of the dismantling of equipment and structures as part of closure is dependent upon the circumstances of ownership and ultimate use of the property; and may not be requirement for a closure plan on private land. On federal land, dismantling and removal of all equipment and structures will normally be required within a reasonable time period, and need to be included as a key element of the closure plan.

#### 7.9.1.5 Post-Closure Maintenance and Release

Legal requirements for post-closure maintenance vary from state to state, but generally monitoring will be required with a progressive reduction in frequency for a period of at least three years. Many projects have water impoundments that have the potential to impact surrounding water quality, and additional time may be required to verify the accuracy of the water quality model used to predict steady state conditions.

In most cases, acceptance by the lead regulatory agency of completion of various stages of reclamation activity is sufficient for a corresponding reduction in the amount of required financial assurance, and this reduction can be staged to reflect the overall closure timetable.

## 7.9.2 REDUCING FINANCIAL OBLIGATIONS
**by J. Bokich**

### 7.9.2.1 Introduction

Bonding as it applies to reclamation in mining operations is a vehicle whereby a government entity, through promulgated regulations, requires a financial assurance that reclamation of lands that have been affected by exploration or mining activities will be completed in a manner that is consistent with those regulations and a permit issued by that agency. Bonds are allowed in different forms by different agencies or states. There is a great deal of variation in the types of bonds, but they are all consistent in that they are a form of insurance to ensure reclamation after a project regardless of the financial standing of the company holding the permit.

The main types of activities covered by reclamation bonds include removal of facilities; regrading and reshaping of roads, dumps, pits, and other disturbed sites; replacement of growth medium, seeding, fertilizing, mulching, etc., where needed; and other stabilization measures. There is generally a revegetation success criteria as part of the regulations or part of the permit which says that when vegetation meets a certain density, productivity, etc. that the bond will be released. The mining industry is also starting to see bonding applied to such things as ground water monitoring around tailings or heap leach facilities, closure of heap leach facilities or other facilities which contain toxic substances. As discussed below, there are also many ways of implementing and releasing bonds through phased implementation and phased release.

Bond amounts typically assume reclamation costs based on the costs for an agency to manage the reclamation using third-party contractors to complete the work. This often includes an overhead cost for management of the reclamation by the agency, and costs for third-party contractors including their profit and overhead. In some cases, standardized rates such as the Bacon-Davis Law are required, which are generally extremely conservative and overestimate bonding costs. An agency may allow utilization of costs provided by the company for operation of their own equipment or submittal of a cost statement from third-party contractors working for the company to establish an hourly or per acre rate to determine bonding costs.

### 7.9.2.2 Reclamation Bond Types

There are five types of reclamation bonds typically used by the mining industry. These five bond types are discussed below:

#### *7.9.2.2.1 Reclamation Surety*

The reclamation surety or bond is the most common type of bond and is usually issued by an insurance or bonding company. The basis of the bond is the permit issued to the company which spells out the total cost to reclaim a site after mining or exploration activities are complete. This cost is based on general removal of facilities, regrading of roads and other disturbed sites, reapplication of growth medium, seeding, and some kind of reclamation success standard for revegetation, where applicable. A reclamation surety is one of the simplest forms of bonding. A premium is paid by the company to the insuring institution to guarantee that if reclamation is not completed to the standards of the permit and the applicable regulations, that funds are available to the agency to complete the reclamation. Often the insurance company will require a Letter of Credit to back up the bond, which makes it more expensive. A demand letter is also generally attached which requires the company to repay the insurance company in case the surety is drawn by the regulatory agency.

#### *7.9.2.2.2 Letter of Credit*

A Letter of Credit is similar to a surety bond in that a financial institution will guarantee that the money is available to complete reclamation if the company should not complete it as required and does not have the financial resources to complete it. A Letter of Credit is issued by a bank and is usually for a larger sum of money to be covered by the reclamation liability and generally has a lower premium cost to hold it. This, of course, requires that the company be in good financial standing. There is a demand letter attached to the Letter of Credit which says the company owes the bank the amount of the surety if it is drawn by the regulatory agency.

#### *7.9.2.2.3 Trust Fund*

A trust fund is a less used vehicle to provide for bonds that generally costs the company little or no money and allows them to collect interest on the trust fund as long as they meet the reclamation requirements of their permit. Essentially, the trust fund is set up with the state as a beneficiary until reclamation is approved and released by that agency. Interest on the fund can either come back to the individual or the company, or can be allowed to accrue within the account towards further reclamation liability for ongoing activities. An unattractive aspect of a trust fund is that those funds are tied up until bond release.

#### *7.9.2.2.4 Insurance*

Insurance is an infrequently used type of bond which is

generally less attractive to the agencies. This form of bonding involves the signing over of an insurance policy with the state as a beneficiary for the funds if reclamation is not completed or the company prematurely goes out of business prior to reaching the reclamation goals.

#### *7.9.2.2.5 Corporate Guarantee*

Corporate guarantee is becoming a more common vehicle being used by companies because it reduces the amount of premium required to little or none. In general, a corporate guarantee is based on an evaluation of the assets and liabilities of the company and its ability to pay the cost of reclamation as determined by the permit should the agency not be satisfied that the reclamation has been completed to the requirements of the permit or the regulations. Corporate guarantees frequently require regular submittals of financial statements by the corporation to the agency, and a specified ratio of assets to liabilities to demonstrate ability to pay.

### 7.9.2.3 Bonding Mechanisms

There are three main bonding mechanisms whereby bonds can be applied to a project.

#### *7.9.2.3.1 Life of Project Bond*

A life of project is an up front, lump sum bond amount to cover all exploration and mining operations that are planned at the time of the issuance of the bond. This allows maximum flexibility for expansion without reevaluating the bond or needing to increase coverage of the bond at a later date. This is generally undesirable from a company standpoint, because the operation can be significantly over bonded in the early phases, requiring payment of high premiums for activities not yet undertaken. In addition, should a company become insolvent for one reason or another and the bond be attached by the agency, there will be a tendency to try to obtain more of the bond funds than are actually needed to complete the reclamation required at that point in time.

#### *7.9.2.3.2 Statewide and Blanket Bonds*

A statewide or blanket bond is a vehicle generally used for exploration where a company posts a certain lump sum bond amount to apply to all of its operations, generally confined to one state. As projects are submitted for permit approval, the reclamation costs that are applicable to that ongoing permitting will be attached from the statewide bond to a specific permit. For example, a company may post a $50,000 reclamation statewide bond and during that year obtain permits for five exploration projects with a total of $10,000 per project reclamation bond requirement. As each permit is approved, $10,000 out of the statewide bond is earmarked towards a specific project. Because the funds are already in place, this bonding mechanism accelerates the permitting process and allows the operator to initiate exploration activities sooner. This can also be applied to mining operations but is less frequently done, as it is seldom that mining activities are permitted at such a rapid pace or rate during a given period of time.

#### *7.9.2.3.3 Phased Bonding*

Phased bonding is becoming more and more common and popular. It allows a company, particularly mining operations, to allow either for expansion of their operations or on an annual basis to increase the bond to cover the next proposed activities. For example, a mine might be bonded to disturb 300 acres and an expansion is proposed which will disturb another 100 acres. The company would increase their bond to cover that 100 acres prior to initiating those new activities. This allows the company to maximize their coverage while minimizing their liability exposure and cost of premiums.

### 7.9.2.4 Bond Release Mechanisms

Bond release can be done in basically two different ways: a lump sum release or a phased release.

#### *7.9.2.4.1 Project Bond Release*

The project or lump sum bond release mechanism is for all bonds to be held until all final reclamation is completed and revegetation criteria met, and the entire sum of the bond released at one time. This is the less favorable mechanism because the company assets or insurance premiums must be paid in full until final bond release for the entire project. A much more attractive mechanism is phased bond release.

#### *7.9.2.4.2 Phased Bond Release*

There are two basic methods of phased bond release. The first method is used when phases of work are completed and the bond is released for that phase. The second phased method is done on the basis of reclamation for specific area being completed and releasing the bond for that area. Generally, a combination of the two is the most attractive as it allows for the earliest release of bond liability. Bond release by phase of work type completed releases part of the bond upon completion of different activities in the reclamation plan.

It is well recognized that the major cost of reclamation is the dirt work required for backfilling, reshaping, and regrading. Today, most agencies will allow between 65 percent and 90 percent of the bond

amount to be released for a specific area when the dirt work has been completed to the satisfaction of the permit requirements and the agency. This cost generally includes replacement of growth medium where it is required. The next phase is the actual seeding and other activities required by the permit such as mulching, fertilizing, rip-rapping, etc. for revegetation and stabilization of an area. Generally, another 5 percent to 25 percent of the bond amount is release upon completion of the seeding and other stabilization methods required for revegetation. The last increment of 5 percent to 15 percent of a bond amount is generally held for a period following final reclamation. This money is held in the event that revegetation does not succeed as defined by the revegetation success criteria specified in the permit, and additional seeding must be done.

The other method of phasing would be phasing by area. For example, as a certain waste rock dump within a multi-dump mine is completed, regraded and reseeded, the bond money allocated to that specific area can be released either in a lump sum fashion or phased by the different phases of work as previously described. This again is a good vehicle to utilize because it frees up assets or premium requirements at an earlier date instead of waiting until the entire project is complete.

### 7.9.2.5 Bond Release Criteria

Probably the most important aspect of bonding, and probably the least well defined at this point in time is bond release criteria. In general the criteria which allows for the total release of bond is based on a revegetation standard where revegetation is to be required. All criteria however, reflect back to the prescribed post-mining land use. The post-mining land use is decided either by the agency that is responsible for managing the land on public land, or in the case of public lands by the private land owner. In many of the lands in the west where mining activities take place, the areas are remote and are primarily used for grazing and wildlife prior to mining activities, and these are the most commonly designated post-mining land use.

On private lands in many states, the regulations provide that the land owner can designate the ultimate post-mining land use. For example, a land owner has the right to change the land use from a pre-mining livestock or wildlife to a post-mining use of a golf course. There may be some opportunity for challenge to changes of post-mining land use on private lands through the permitting process and public comment. However, as long as the selected post-mining land uses do not interfere with the rights or use of adjoining lands, then the land owner's wishes generally prevail. In addition, private lands will still have to meet requirements of the Clean Air Act, Clean Water Act, and other applicable federal laws that recognize no property boundary lines.

Another important concept for bond release criteria and determining a post-mining land use on public land is compatibility of the post-mining land use designation with the resource management plan goals. Most public lands managed by a federal agency have resource management plans for a specific area such as a specific Forest or BLM District or Resource Area. Wherever possible, the company should work with the land management agency to ensure that the designated post-mining land use and the stipulated revegetation goals, meet the resource management objectives as closely as possible. It will be possible in many areas to enhance conditions for wildlife or other values through proper planning and implementation of reclamation. If the post-mining land use and reclamation plan meet the goals of the resource management plan, then meeting these goals should be factored into the bond release. Once those goals are met, the bond should be released back to the company.

A commonly used method for evaluating bond release is actual revegetation success as a measurement of vegetative establishment over a certain period of time after seeding. Numbers such as two, three, or ten years after seeding are used and vegetative measurements such as productivity, density, etc. are determined. If they meet the pre-established criteria, the bond is completely released. Another factor which has not been as widely utilized but is important is stability. In some areas revegetation may not be the final goal and some measurement of stability and erosion off of a site may be utilized for the final bond release criteria.

### 7.9.2.6 Reducing Financial (Bonding) Obligations

As indicated above, bonding mechanisms and process are sometimes expensive, confusing and difficult to administer and obtain release. There is no given recipe to ensure reduction of long-term financial obligation through the permitting process. It is imperative, however, that personnel spend sufficient time planning operations to minimize impacts, and to limit disturbance to areas where it is absolutely unavoidable. Proper planning will reduce the overall liability and reclamation burden on an operation. In addition, and when feasible, things such as backfilling of pits in a sequential pit mining operation, shaping of dumps or placing dumps in lifts, are all functions of planning that can lead to reduced reclamation costs and bonding obligation.

Much planning needs to go into how a permit application is structured and worded. It is very important to select carefully every word that goes into an application, to ensure that the implications of the commitments being made are well understood. Care also needs to be taken to ensure that the application addresses applicable regulations, and that no commitments are

made to overly restrictive requirements which are not mandated by regulations.

Another mechanism for reducing the amount and duration of bonding obligations is to conduct concurrent reclamation during operation of the mine. As soon as roads are no longer needed, waste dumps are completed, pits completed, etc. those areas should be reclaimed. This will lessen the overall bonding requirement, reduce premium costs or withholding of assets and is well received by the regulatory agencies and the public. And lastly, a specific plan must be made for determining bond release. It is up to the company to determine when an area has met bond release criteria, and to pursue the release of the bond with the appropriate agencies.

In general, bonding requirements and the mechanisms for application and bond release are relatively new in the hard rock mining industry in the west. Bonding requirements and release mechanisms have been evolving in the coal industry since 1976. The hard rock mining industry should try to learn from the coal experience which clearly demonstrates that the most critical item in the whole formula is the bond release criteria. This is the most argued over and misunderstood piece of the puzzle, and as of today there is still has no clear cut resolution for either the coal or the hard rock mining industries. Because of the very serious nature of the financial resources that are tied up through bonding, it is imperative that companies take a proactive approach in developing new ideas and mechanisms for bonding through their permit applications, and through the development of reasonable regulations with the local land management agencies or state agencies that enforce reclamation programs for mining.

## 7.9.3 REDUCING CLAIM POTENTIAL
**by L. Orser**

### 7.9.3.1 Introduction

Enforcement actions for violations of environmental laws have been steadily increasing since the U.S. Environmental Protection Agency (EPA) issued its Resource Conservation and Recovery Act (RCRA) Civil Penalty Policy (RCPP) in October of 1990. With the current political climate of environmentalism, it seems likely that this trend will continue.

The EPA can take enforcement action under the provisions of several laws, including the RCRA, the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA, also referred to as Superfund), the Superfund Amendment and Reauthorization Act (SARA), the Clean Water Act, and others. These laws empower the EPA to force violators to study the impacts of contamination, evaluate corrective action alternatives, and undertake an appropriate action. In addition, civil and sometimes criminal penalties, including fines and imprisonment, may be imposed.

Beyond the costs of cleanup and corresponding penalties, CERCLA also contains provisions for violators to be held liable for damages to natural resources. These damages may take several forms. They include injury to resources from residual contamination left after cleanup, the failure to restore resources to their pre-contamination condition, and damages for lost use of an injured resource until it is restored.

In addition to federal laws, there are numerous state and local laws under which environmental damage claims may be pursued.

While the costs of damaging the environment can be crippling, with proper planning, operation and maintenance, and with a proactive approach to environmental compliance, it is possible to reduce environmental damage claims or even avoid them altogether.

### 7.9.3.2 Basis for Damage Claims

Environmental damage claims at mines, at or following closure, are most likely to be based on CERCLA, although the provisions of other laws mentioned above may also be applicable. CERCLA defines the potentially responsible parties as the present owner or operator of a facility, the past owner or operator at the time of a release or disposal of a hazardous substance, a generator of a hazardous waste or hazardous substance, or a transporter of a hazardous substance. Owners or operators will be found liable if a release of a hazardous substance from a facility has occurred.[1]

CERCLA defines a release broadly as "any spilling, leaking, pumping, pouring, emitting, emptying, discharging, injecting, escaping, leaching, dumping, or disposing into the environment."[2] The environment includes groundwater, surface water, soil, and air. Liability may be imposed regardless of the amount of a hazardous substance released; even a trace amount can trigger a CERCLA action.

A hazardous substance under CERCLA is any substance designated hazardous by EPA or any substance designated and regulated under other federal environmental statutes.[3] There are currently several hundred such substances, and they include both primary products and waste products.

A facility is also broadly defined under CERCLA, and may be "any building, structure, installation, equipment, pipe or pipeline..., well, pit, pond, lagoon, impoundment, ditch, landfill, storage container, motor vehicle, rolling stock, or aircraft."[4] Thus any and every mine component is a potential facility.

Finally, the term "natural resource" is defined by CERCLA to include land, air, water, fish, wildlife, biota, and other resources belonging to, managed by,

held in trust by, pertaining to, or otherwise controlled by the United States, any state or local government, any foreign government, or any Indian tribe.[5]

Regulatory agencies will generally require soil and water sampling at the time of mine closure. If contamination is found during the course of this sampling, and there is indication that the contamination is the result of releases from the mine facility, or from any facility on the property, action under CERCLA may be brought against the owner and/or operator as discussed below.

Similarly, post-closure monitoring of soil and of groundwater and/or surface water is typically required. Evidence of contamination occurring as a result of improper or ineffective closure of mine system components will be grounds for action under CERCLA.

#### 7.9.3.3 Process of Filing Claims

The first step in an environmental damage action is typically a Notice of Violation (NOV) from the EPA or an authorized state agency. If the violation is serious enough, or if the operator has a history of noncompliance, the EPA will issue an Administrative Order. Such an order may be unilateral, that is, prepared and imposed by the EPA, or it may be consensual, where the operator and the EPA work jointly to define the order's provisions. This administrative order will force the operator to take one or all of the following actions: study the impacts of contamination, evaluate corrective action alternatives, or undertake a specified corrective action. In addition, a penalty component may be imposed, generally in the form of a fine. Finally, if an operator is suspected of criminal activity, such as endangering the public health or the environment through willful negligence, the EPA is authorized to pursue criminal prosecution, which may result in additional fines or imprisonment. Should an operator be unwilling to undertake the provisions of an administrative order, the EPA is authorized to refer the case to the Department of Justice.

Under the provisions of CERCLA, claims for natural resource damages can only be brought by the United States, individual states, or Indian tribes, acting as trustees for the resource(s) in question.[6] CERCLA authorized the President to designate officials to act as public trustees for the resources under federal trusteeship. These officials include the secretaries of Commerce and Interior. EPA is not a designated trustee but is required to give notice to trustees of potential damages from releases it is investigating. State governors are also required to designate trustees for resources under state trusteeship; typically, these officials include directors of state health, environment, or natural resource departments.

Currently there are no provisions for individual citizens to file suit for natural resource damage claims under CERCLA. However, with the growing trend towards public involvement in the regulatory process, typified by "bounty" provisions in recent environmental legislation, this may change in upcoming reauthorizations of RCRA and CERCLA.

#### 7.9.3.4 Avoidance of Claims

Because there are few, if any, successful defenses against environmental or natural resource damage claims once a release has occurred, the prudent operator will design a mine, from exploration to closure, to minimize or avoid entirely the possibility of a release that could lead to a claim. Because an operator or owner can be held liable for releases or damages that occurred prior to obtaining the property, the most important first step is the collection of baseline data and the evaluation of any preexisting liability.

Section 7.3 discusses baseline evaluation and the collection of baseline data in detail. If a property has pre-existing contamination, the costs of cleanup will most likely become the responsibility of the new owner. This cost must be evaluated against the potential profit from the proposed mining operation. Natural resource damage claims, however, can only be filed for damages occurring after December 11, 1980, the effective date of CERCLA.

On the other hand, baseline studies may show naturally-occurring phenomena, such as high levels of metals in the local groundwater. Baseline data such as this will prove invaluable at mine closure to demonstrate that such elevated levels are not the result of releases or mining-related contamination.

All baseline data should be kept throughout the life of the mine and following closure until final bond release. Ideally, all information should be kept in a computer database, and supplemented with monitoring data collected during operation and following closure of the mine. This will enable the operator to observe any trends that may develop over time or in a given area. This in turn allows an operator to take prompt action should a release be detected.

Section 7.2 discusses characterizing the mineralized system. This is an essential part of the avoidance of subsequent environmental damage claims. Adequate characterization of ore and waste, the project environment including geology and hydrology, and the processing system is necessary in order to design a facility to prevent any releases and to contain process fluids and waste.

A plan for closure should be developed as an integral part of the Plan of Operations. All mine components, including the open pit or underground workings, overburden piles, and ore stockpiles, as well as all parts of the mineral processing system, should be designed to prevent and/or contain contamination. It is particularly

important to design barriers, containment, or neutralizing capacity for heaps and overburden piles in those cases where characterization has indicated the potential for acid rock drainage or metals mobilization.

This closure planning should be a team effort, incorporating where feasible the input of regulatory agencies and reputable citizen groups. At this stage it may be possible to prevent future natural resource damage claims by negotiation. This may be critical in areas with recreational or aesthetic value, as natural resource damage claims may be based on an aesthetic injury or for the "existence value" of the resource, defined as the value that members of the public place on the continuing existence of the resource, whether or not that resource is ever used. It may be possible at this point to obtain an agreement wherein the operator commits to off-site mitigation or habitat enhancement as compensation for irrevocable damage or change to a resource, such as an open pit which is not backfilled. While this may be seen as a costly option, or as "giving in" to unreasonable demands of environmental groups, it may also prevent extremely expensive surprises at closure, and it allows for the expense of such a mitigative measure to be spread over the mine life.

It should be noted that there are two defenses to a natural resource damage claim, if the damage was the result of a permitted release. The first removes the liability for such damage if the responsible party can show that there was specific identification of an irreversible and irretrievable natural resource commitment made in an environmental impact statement or similar document, that this commitment was authorized in a permit or license, and the responsible party has acted in compliance with the terms of that permit or license.[7]

The second defense states that damages resulting from a federally permitted release (under RCRA, CERCLA, CWA, etc.) are recoverable under existing law instead of CERCLA.[8] This is a defense only for releases that are in compliance with permit terms. Damages can still be recovered for releases that were not specifically authorized, that exceeded permit limits, that occurred without a permit being in place, or that were accidental.[9]

Thus, by disclosing the unavoidable commitment of resources in an EA or EIS, and by incorporating permitted releases, an operator may be able to avoid a claim for subsequent natural resource damages from an operation. However, as previously mentioned, under CERCLA an operator or owner may still be liable for the cleanup of contamination resulting from such permitted releases.

Best available control techniques should be incorporated into the design, operation, and closure of all facilities, whether or not they are required by permit conditions. Unfortunately, if a control fails and a release occurs, the operator is liable for costs of cleanup and damages even if the control was agreed to and permitted by the regulatory agency. The solution to this dilemma may be to design controls beyond the minimum required, to the point that this is economically feasible. This includes double lining of process components, lined ditches for all piping, leak detection for process components, etc.

In summary, the best, if not the only, way to avoid claims for environmental damage is to ensure that no damage occurs. This process should begin with the initial evaluation of a potential mining property by avoiding any property with existing environmental liability, and continue through the design process, where every component should be designed with pollution prevention in mind and with a back-up prevention or containment system. Consideration should also be given during the planning phase to off-site mitigation for resources irrevocably committed. Mining operations should include constant monitoring so that should a release occur, it can be identified and contained before contamination or significant environmental damage can occur. Closure should be designed and implemented to prevent pollution or the migration of contaminants from all mine components.

#### 7.9.3.5 Resolution of Claims

If prevention has failed and a release with subsequent environmental damage occurs, an operator should move quickly to resolve the situation with the appropriate regulatory agency. In a drawn-out battle, the usual winners are the lawyers and the EPA.

It is critical that all releases be properly documented and promptly reported. Failure to report a release will most likely result in punitive civil penalties, and may result in criminal penalties. To the extent possible, the plan for cleanup and mitigation, where necessary, should be included with the release report.

A company is best positioned to survive an enforcement action if it has a history of compliance and amicable relations with environmental regulatory agencies. Such a company is most likely to be able to develop a consensual agreement for corrective action, and avoid a unilateral order. A history of compliance, including appropriate management of hazardous materials and wastes, a thorough monitoring program, and accurate and up-to-date record-keeping, will be likely to help a company avoid civil and criminal penalties.

When a release has occurred and it is evident that corrective action will be required, the operator should move quickly to establish communication with all affected parties, including the EPA, state and local authorities, and in some cases, citizen groups. A corrective action proceeding can be very complicated and will go much more smoothly if open communication can be maintained and input from all affected parties is included.

Generally the best and least costly solutions for a company can be found through a negotiated settlement rather than a court battle. Taking the EPA to court has the potential to take years and cost millions of dollars, and typically still results in the issuance of a corrective action order and claims for damages. An exception to this, of course, would be a case where a company had reason to believe that an action had been brought on the basis of invalid or improperly interpreted data.

Another key for claim survival is prompt action on the part of the operator. Releases should be stopped as soon as possible after detection, and steps should be taken to prevent contamination migration immediately, where feasible. It should go without saying that the smaller the release and the area of impact, the less costly and time-consuming the corrective actions will be. Further, evidence of prompt action by the operator may convince the authorities that punitive measures are unnecessary, or at least should be reduced.

Costs of corrective actions can be very high. Under CERCLA and SARA, any one potentially responsible party (PRP) may be held liable for the entire cost of a cleanup resulting from the actions of multiple parties, as in the case of contamination from a hazardous waste facility or the acquisition of a property with a history of environmental problems. With natural resource damage claims, a responsible party may be liable for the cost of returning an injured resource to its prerelease condition, even if this cost is greater than the value of the resource lost due to the injury. The lost value of the resource until it is restored is also recoverable.

Again, open communication with all affected parties may be able to reduce these costs. Each case is different, of course, but negotiation with regulatory agencies and concerned parties, where an operator has a history of compliance and good faith, may result in cleanup standards of less than prerelease conditions, or more affordable replacement of an injured resource in lieu of restoring the damaged resource.

The most important factor in resolving any environmental claim will be the company's record of compliance and overall environmental attitude. The company that takes an environmentally proactive stance from the inception of a project will always be able to resolve a claim or a corrective action more quickly and cost-effectively than a company that views environmental fines as just another cost of doing business.

### Notes

[1] 42 USC Sec. 9607(a)
[2] 42 USC Sec. 9601 (22)
[3] 42 USC Sec. 9601 (14)
[4] 42 USC Sec. 9601 (9)
[5] 42 USC Sec. 9601 (16); 33 USC Sec. 2701 (20)
[6] 42 USC Sec. 9607 (f) (1)
[7] 42 USC Sec. 9607 (f) (1)
[8] 42 USC Sec. 9607 (j)
[9] 42 USC Sec. 9601 (10)
[10] Ohio vs U.S. Dept. of the Interior, 880 F.2d at 438

## 7.10 PROJECT MONITORING

### 7.10.1 MONITORING REQUIREMENTS
**by W. Schafer**

#### 7.10.1.1 Project Monitoring

The objectives of an environmental monitoring program vary depending on the development stage of the facility. A comprehensive environmental monitoring program involves a multimedia approach. Groundwater, surface water, climate, air, soil, and biota may all be involved in such a program. Selection of appropriate media to be monitored, the frequency and kinds of measurements obtained, and the parameters to be measured should be decided on the basis of site and facility characteristics.

During baseline evaluation, the purpose of environmental monitoring is to establish a benchmark of pre-mining environmental conditions to which operational monitoring data will be compared. During start-up, the monitoring will focus primarily on environmental effects most often associated with facility construction. During the operating life of a facility, environmental monitoring will evaluate the effects of both the mining and processing operations. Monitoring the success of the reclamation program and other environmental mitigation programs is also an important objective during operational monitoring. Finally, routine environmental monitoring should also include cumulative disturbance, topsoil salvage quantity, and cumulative reclaimed acreage. During post-closure stages, environmental monitoring will be gradually phased out as the long-term effectiveness of the facility closure program is established. Post-closure monitoring must be of adequate duration to establish long-term reliability and should be tied to bond release criteria.

#### 7.10.1.2 Construction and Start-Up

Environmental impacts during facility construction are likely to be associated with large-scale earth-moving or land-clearing operations (Table 22). Pre-stripping operations in the pit, construction of heap or tailings areas will require stripping large areas during a short time period. In particular, deployment of large areas of geomembrane liner before placement of ore or tailings greatly increases the risk of excess water inventory and large run-off events. The timing of construction of

**Table 22** Potential Environmental Impacts Associated with Facility Construction and Start-up Phases

| Environmental Media | Potential Impacts | Constitutents Monitored |
|---|---|---|
| Groundwater | Increased recharge | Monitor TDS and major ions in groundwater, evaluate changes in static water levels. |
| | Disturbance of seeps and springs | Monitor spring/seep flows, report cumulative disturbance area. |
| Surface Water | Erosion and sedimentation, Stormwater management | Monitor TSS and turbidity is surface water, determine stream channel bed characteristics. Evaluate sediment pond design and performance. |
| | Increased peak flow | Continuous flow monitoring at selected stations |
| Air Quality | Fugitive dust | PM10 stations. |
| | Equipment emissions | |
| Soil Resources | Soil stripping | Report cumulative land disturbance and soil salvage inventory and compare to planned amounts. |
| Biota | Wildlife | Site specific inventory program. |
| Other | Noise. | Site dependent monitoring program dependent on proximity of residential areas and on wildlife present |

ponds, diversion structures, and sediment control features is crucial in determining potential water quality impacts during construction. If large rainstorm events occur during the construction season, significant increases in erosion and sediment loading may result. Removal of vegetation may also increase groundwater recharge, which may increase the flow and major ion concentrations in shallow groundwater systems.

Fugitive dust and equipment emissions are the most likely air quality impacts during construction phases. Wildlife displacement due to increased activity may be associated with facility construction, however many species also adapt to increased noise levels. Many mines experience an influx of wildlife due to a haven effect of hunting restrictions within the mine property boundary.

### 7.10.1.3 Operation and Reclamation

Operational environmental monitoring will include two components (Table 23). First, multimedia sampling will be used to detect potential environmental impacts of the mine operation. Second, evaluation of environmental programs within the facility boundary including routine inspections of containment systems and processing areas, review of reclamation success, geochemical verification programs, evaluation of wildlife impact mitigation programs, and other site-specific programs will be completed.

Changes in groundwater static water levels may result during mine operations as a result of dewatering efforts. Water levels in groundwater monitoring wells should be monitored at least quarterly to detect changes. More frequent monitoring or continuous stage measurement may be prudent on key wells.

The geochemical nature of mine waste may affect the quality of seepage through waste rock storage facilities. In wetter climates, waste rock seepage may affect groundwater or surface water quality. Although water quality measurements should include all major ions and several trace metals, water quality changes can best be identified by evaluating key "indicator parameters". Certain ions are likely to serve as a marker of waste rock seepage. Elevated nitrate levels are common in waste rock seepage due to residual explosives. In addition,

**Table 23** Potential Environmental Impacts During the Operating Life of a Mine and Monitoring Program Elements for Identifying Them

| Environmental Media | Potential Impacts | Constituents Monitored |
|---|---|---|
| Groundwater | Effect of mine dewatering program. | Monitor static water levels in vicinity of mine. Compare impacts to pre-mining predictions. Identify water quality in mine water and evaluate disposal options. |
| | Seepage through waste rock storage area or tailings embankment on water quality. | Identify presence of indicator parameters such as nitrate, and sulfate in downgradient wells. Establish geochemical sampling program if necessary to characterize waste rock. |
| | Localized disturbance of hydrologic balance. | Site-wide monitoring of static water levels should include off-site wells if impact is possible. |
| Surface Water | Runoff, erosion and sedimentation from disturbed areas. | Evaluate changes in TSS and turbidity from baseline stages. Regularly inspect diversion structures and sediment control structures and evaluate performance. |
| | Runoff from mine facilities and effects on water quality. | Perform comprehensive water quality analysis at regular intervals. Formalize statistical evaluation criteria. |
| Air Quality | Haul road impacts on air quality and effectiveness of dust abatement program. | Compare PM10 sampling results to ambient air quality. Develop operational mitigation as necessary. |
| | Blasting and mining impacts. | |
| Soil Resources | Soil salvage and replacement program. | Maintain inventory of soil salvage area and soil stockpiles. |
| | Success of reclamation. | Develop and maintain a revegetation monitoring program. Document impact of reclamation on air and water resources. |
| Biota | Wildlife | Implement a facility-specific wildlife mitigation program as needed. |
| Other | Mine waste characterization | Continue to sample ore and waste generated in pit to identify potential water quality issues. |
| | Noise | Implement monitoring program. |

elevated sulfate levels are also common. These constituents are "conservative" meaning they readily move in pore water within waste rock and are not geochemically attenuated as are many metal ions. Consequently, nitrate and sulfate are ideal indicators of waste rock seepage contribution to local groundwater. Groundwater quality measurements downgradient of a mine waste facility are shown in Figure 5. Elevated

**Table 24** Post-Closure Facility Monitoring Program

| Environmental Media | Potential Impacts | Constituents Monitored |
|---|---|---|
| Groundwater | Recovery of groundwater static water levels | Monitor water level recovery and compare to predictions. Revise model as required. |
| | Long-term water quality effects | Phase out water quality monitoring during post-closure period if compliance is certified. |
| Surface Water | Performance of long-term diversions and erosion control measures | Modify structures to minimize maintenance and inspection requirements. |
| | Long-term water quality effects | Phase out water quality monitoring during post-closure period if compliance is certified. |
| Air Quality | Return to ambient conditions | Phase out air quality monitoring during post-closure period if compliance is certified. |
| Soil Resources | Reclamation success | Complete reclamation of processing areas. Continue evaluation of reclamation success. |
| Biota | Utilization of reclaimed areas by wildlife | Facility-specific |
| Other | Bond release criteria | Develop bond release criteria with partial releases tied to completion of decommissioning schedule and to post-closure environmental compliance. |

nitrate and sulfate levels are due to seasonal seepage through waste rock.

Acid rock drainage (ARD) is an environmental concern where sulfide ore is mined. Waste rock storage areas commonly are the first facilities to provide an indication of acid-production. Elevated sulfate, decreased alkalinity, and elevated zinc and manganese levels in groundwater or springs downgradient of waste rock storage areas may be a precursor of subsequent ARD.

The source of a change in surface or groundwater quality must be identified before a mitigation plan can be developed. Natural systems exhibit seasonal variation in water quality, with the variability typically more pronounced in surface water. Data in Figure 6 illustrate the natural seasonal variation in sulfate concentration in surface water. In surface waters, major ion concentrations often decrease during high flows and increase at low flow. In addition to seasonal effects, annual drought may also trigger an "apparent" degradation of water quality. A useful method employed for detecting when an increase in a particular constituent has occurred is to compute the mass loads for each monitoring station. The degree of natural variation in water quality constituents should be characterized during baseline monitoring so that statistical criteria can be established which constitute a water quality impact.

#### 7.10.1.4 Post-Closure Phase

Post closure monitoring is employed for an acceptable duration after mining operations have ceased. In arid climates, migration of contaminants through mine waste facilities is often slow. Hence, water quality impacts are not always detected during life-of-mine operations.

The duration and scope of post-closure monitoring should be negotiated between regulatory agencies and

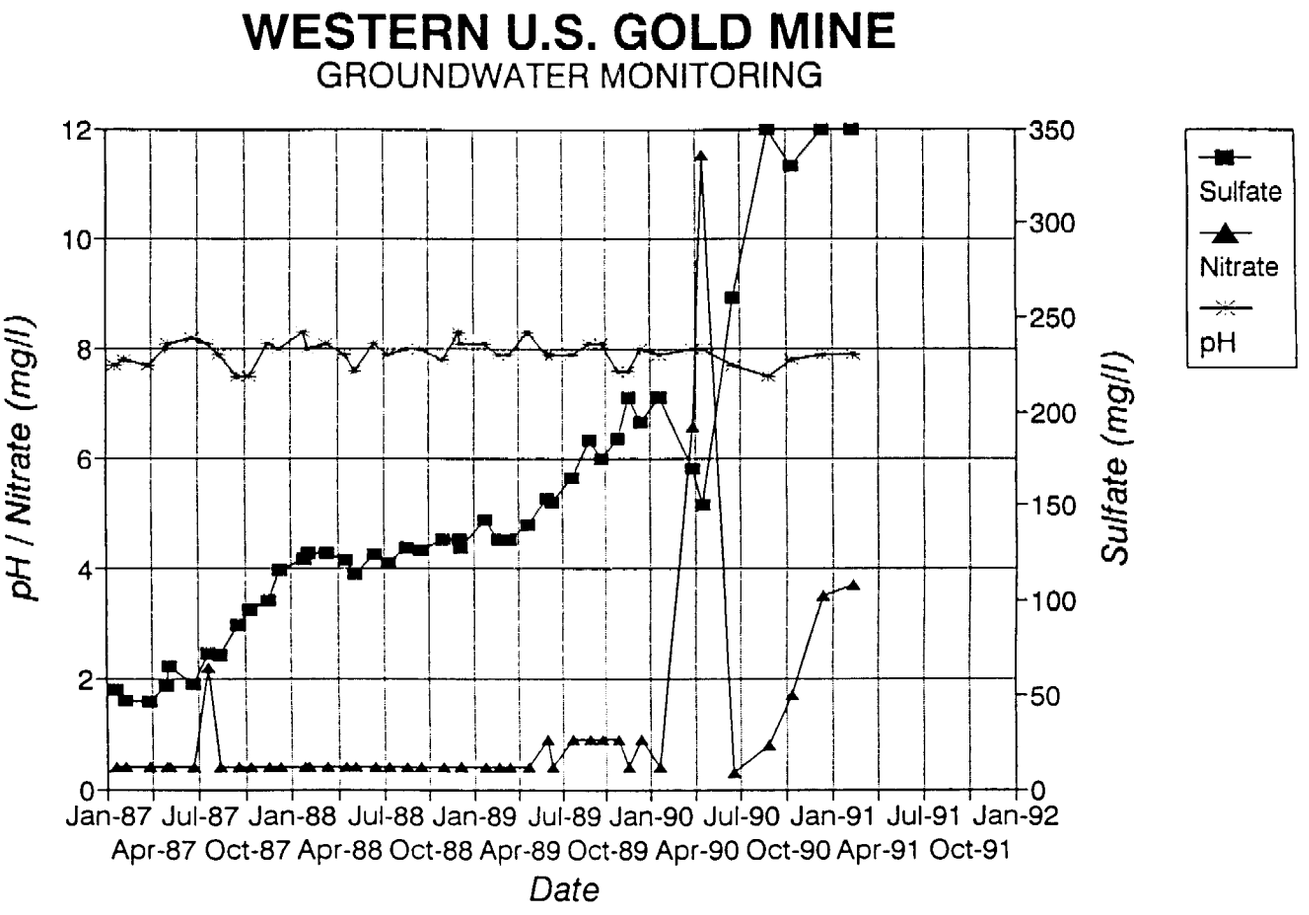



**Figure 5** Changes in nitrate and sulfate levels in groundwater downgradient of a mine waste facility.

mining companies in advance of closure (Table 24). Ideally, post closure monitoring should also be tied to bond release. Key components of post-closure monitoring should include reclamation success, decommissioning of process solution in heap leach and tailings systems, and surface and groundwater monitoring. Recovery of groundwater systems impacted by dewatering should also be monitored.

### 7.10.2 AIR QUALITY MONITORING
**by R. Steen**

#### 7.10.2.1 Introduction

It is expected that all emission limitations and monitoring systems agreed upon during permitting will be implemented during operation. In the case of Major Stationary Source (MSS) or Major Modification (MMD) sources, and sources with the potential to emit above the thresholds triggering MSS and MMD, there must be federally enforceable compliance conditions written into the air permit insuring that the controls are installed and operated properly and provide the expected control of emissions. These may be in the form of measurements of process rates and fuel rates, documentation of pressure drops and water flow rates through control devices such as scrubbers and baghouses, and in some cases continuous emission monitors (CEMs) on the exhaust stacks. In some situations post-construction ambient monitoring can also be required to insure the ambient standards are not violated.

#### 7.10.2.2 Ambient Monitoring

There are no requirements for post-construction ambient monitoring in the federal program, only an allowance for it on a case-by-case basis. Some of the state and local programs require it for mining operations where it is nearly impossible to measure directly fugitive dust emissions. Rather than disputing the degree of control needed in the permitting phase, the local agencies have resorted to requiring that absolute ambient standards be met at various locations beyond the boundary. If the operation cannot meet ambient standards, it is required to increase emission controls until the standards are met. Monitors are to be located at the points of anticipated

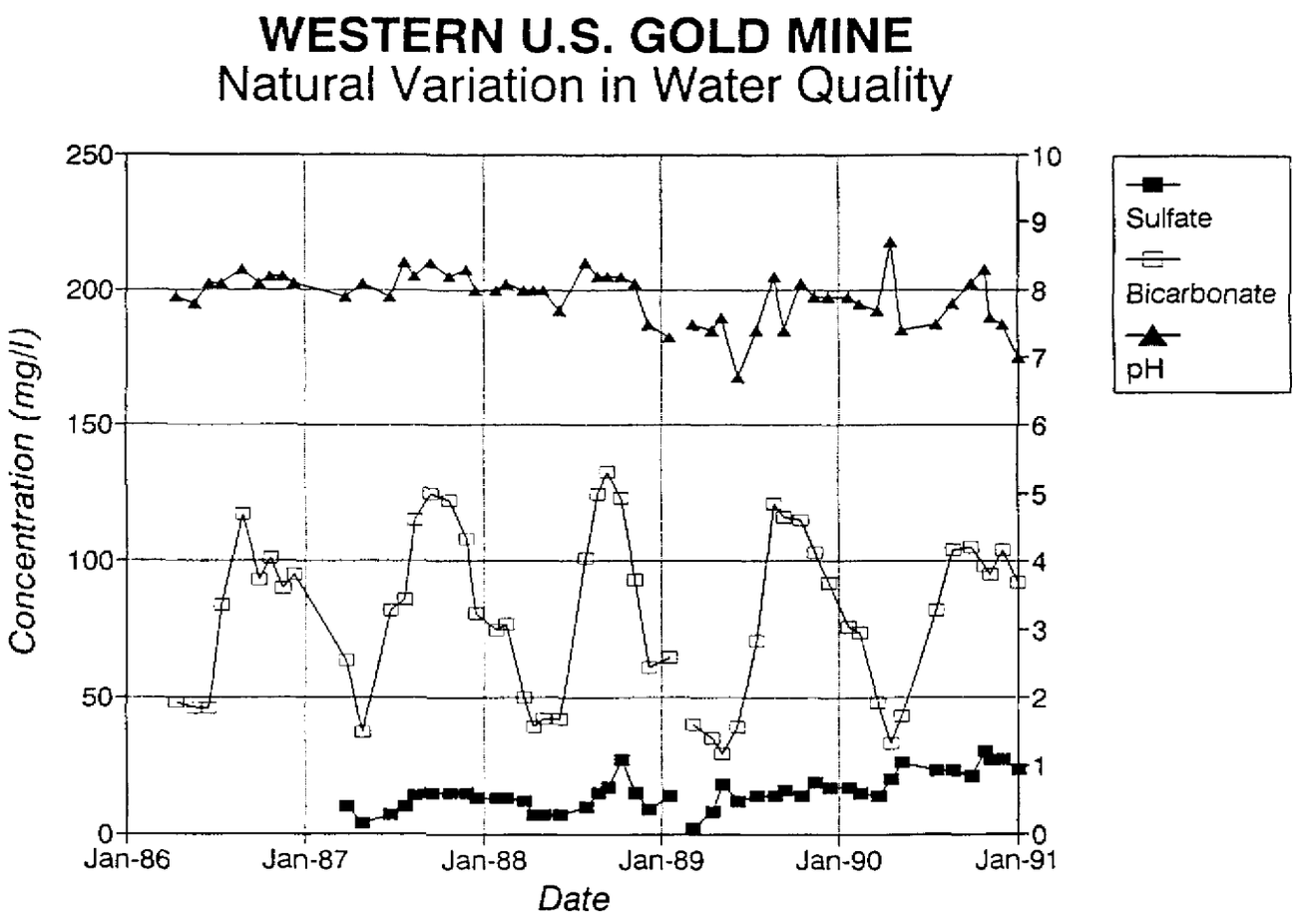



**Figure 6** Natural seasonal variation in sulfate concentration in surface water downgradient of a mining facility.

maximum impact, but are often selected near sensitive locations such as residents and schools where concern for compliance with the standard is greatest. This is especially true in cases where the agency relies on health risk assessment as an environmental management tool.

### 7.10.2.3 Emission and Control System Monitoring

The trend is to require monitoring of emission-related parameters during operation for the bigger sources. There are requirements for this as part of the NSPS, NESHAP, and MACT federal regulations. These requirements can take the form of source testing at project startup and annually thereafter, or of indirect continuous monitoring or direct continuous emission monitoring (CEM's). Indirect continuous monitoring is of emission surrogates that are easier to monitor than emissions themselves. For mining operations, the ore throughput is a surrogate for particulate emissions, for diesel power generation, fuel consumption or power production or generator on-time are used as surrogates of the various consumption pollutants emission rates. Oftentimes surrogates are used with source tests where the source test establishes the relationship between the surrogate and actual emissions.

Direct emission monitoring using CEMs, is required for the largest sources such as power plants, smelters and chemical production facilities. CEM's are instruments which monitor stack temperature, flow rate, opacity (particulates), sulfur oxides, nitrogen oxides, carbon monoxide and hydrocarbons. For combustion sources a diluent is also measured such as carbon dioxide or oxygen to normalize for stack gas dilution with ambient air. The CEM parameters to be measured depend on the nature of the process.

For mining operations the maximum processing and transfer rates are usually limited as a permit condition and there is a requirement to continually monitor (on a daily basis) the ore throughput. The NSPS for crushing and conveying systems (40CFR 60.380 for metallic minerals and 40CFR 60.670 for nonmetallic minerals) requires that the pressure drop across dust control devices and water flow through scrubbers be monitored. The NSPS for dryers and calciners (40CFR 60.730) requires continuous opacity monitoring. For wet scrubbers the

pressure drop and liquid flow rate are measured. Other monitoring requirements can include documenting the application of dust suppressants to the haul roads, documenting the moisture content of the ore being loaded to the primary crusher, and documenting the opacity of dust emissions at the crusher and behind haul trucks by certified visual observation. There is a wide variation of monitoring conditions applied to mining operations by local agencies. Reviewing previously issued permits is the best way to prepare for the conditions likely to be placed on a new permit.

There are NSPS standards and compliance monitoring requirements for incinerators and large petroleum storage tanks, both categories of which mines may, but normally do not trigger.

In the past, CEM systems were limited to large process facilities such as coal-fired steam generating plants, smelters, and cement plants. The CEM systems measured opacity within the stack (a measure of particulates), and concentrations of sulfur dioxide, and nitrogen oxides. These systems are now being required for large-sized gas-turbine power generation, and particulate generating facilities smaller than coal-fired units. CEMs are also being required for emitters of volatile organics and toxins. These CEM units are becoming more reliable and less expensive to operate, and they are becoming a part of "federally enforceable" compliance conditions for many facilities.

## 7.11 PUBLIC RELATIONS AND COMMUNICATIONS

**by M. Allender**

### 7.11.1 INTRODUCTION

Communication and public involvement are no longer optional elements of a successful public relations program for mining companies. They are obligatory–the roots of a basic strategy. Public relations awareness and expertise should be incorporated early into the planning process during exploration and permitting. Developing effective communications and public relations program can be critical to the success of project permitting efforts. No successful operation can afford to ignore public opinion or public concerns or the research required to identify and respond to them.

Today's project must invest in protecting the environment as required by law. Environmental concerns are here to stay, and public involvement must be addressed as part of that phenomenon. The considerable investment in environmental programs and mitigation can be recouped by describing those efforts in public information programs to establish confidence in the project. Public concerns can be raised about the economy versus the environment. Public opinion falls somewhere in between, and recent experience shows that economic benefit to the community is no longer an exclusive selling point for any project.

For a project proponent from outside the community, the challenge is to establish a constructive local relationship AND to determine what the local public needs to know and wants to know. This requires obtaining in-depth knowledge about the community and broadening communication beyond the technical level to a public want-to-know information range. Research can supply the fundamental data that will allow a communications program to anticipate public opinion and stay ahead of it. This section discusses the elements of successful communications and public relations programs.

### 7.11.2 RESEARCH – A COMMUNICATIONS TOOL

Reaching into a community to forge an effective communications program demands identifying an elusive target audience and designing a responsive strategy. Whether it is rural or urban, big or small, each community is unique in history, personality, and evolving attitudes. A comprehensive profile shaped from these elements is the foundation of meaningful dialogue and public participation.

Research is necessary for gathering information that contributes to the design of a proactive program. Research determines the scope of a problem, what provokes or remedies it, and how public attitude plays a role. Research also monitors the effectiveness and impact of public relations and communication efforts. An opinion survey may expedite the information gathering process. There are specialists who gather and analyze data. Exploring public records for relevant information is another option. Some methods for obtaining information about a community are presented below.

#### 7.11.2.1 Surveys and Sources

Surveys that obtain information by telephone or by mailed questionnaires are one method for obtaining information about a community. There are advantages and disadvantages to both methods related to cost and response ratio.

Much survey information is readily available to the public. Government and commercial organizations conduct national, regional and local surveys. Government sources include reports from the Bureau of Census and the State Department of Finance. Newspapers, television and news organizations report on surveys, and survey research centers function at most major universities. The latter materials may be free for the asking. Specialized material can be found in scholarly journals. For general feedback, press clippings and broadcast monitor reports

are always available from commercial services.

#### 7.11.2.2 Research Goals

Community input must be the foundation for all research. It is needed early and often, and should be supplemented by data from other resources. For example, research should focus on policies that guide decisions of elected officials and of agencies with jurisdiction over mining. Old newspaper files and minutes of meetings, taped or written, can answer questions like the following:

- Have decision makers consistently recommended Environmental Impact Reports? What are the impact and/or mitigation fees or conditions applied to industrial projects? Is there a pattern? What is the appeals process and how have appeals fared?
- Has public opinion and/or activism significantly influenced decision makers?
- What are the policies and requirements of planning, health and public works departments that consistently bear weight with decision makers?

#### 7.11.2.3 Public Views and Media Perspectives

Researching how the public, or a selected segment of it, views controversial projects or issues may reveal a consistent response pattern and provide clues for designing a proactive approach to predictable problems. Is the community aware of issues and responsive to them? Does controversy breed ambivalence or action? Is there a bellwether group or organization?

The proponent of a project can never know too much about a community. In creating a comprehensive profile, the economic and political power structure should be explored and views of influential figures on particular issues identified. It is important to sort out vocal action groups, representative leaders of the clergy, teachers, unions, professionals and industrialists. Pinpoint the protest and petition groups, special interests and dissidents. All of these components help shape the character and attitude of a community. Characterizing an opposition group as "small and vocal" and therefore ineffective can be a mistake. The reality is how that group can influence public opinion, and how credible its evaluation is to the community.

The health of the local economy is an issue that can shape the perception of a project. It must be addressed and researched. Recession or prosperity, growth or stagnation are revealed in local figures on bankruptcies and business failures, pace of home construction, help-wanted advertisements, vacant store fronts and statistics on sales tax revenue. Economy is invariably a major factor in the decision-making process.

Media attitude is a research priority. Is it positive or negative on projects that generate community conflicts over land use? Is it influenced by editorial policy on controlled-growth, no-growth or pro-growth? How are environmental factors evaluated? Does public pressure affect editorial policy to any significant degree? Media perception can be skewed by environmental or fiscal misinformation, or swayed by public sentiment.

### 7.11.3 SUCCESSFUL PUBLIC RELATIONS

An effective public relations program creates and sustains an accurate and consistent public awareness of the project. Public relations efforts and priorities must be established around a time line tied to permitting or other activities which may receive public scrutiny. A basic message which focuses on a limited number of points should serve as the foundation for all interaction with the public. The message points should be positive, should be based upon community issues, should consider demographics, and should rely on facts – not opinion. Successful communication and public participation programs are balanced and broad-based.

A public relations program must recognize that there are many publics and become acquainted with each and every one. There are general-interest groups, special-interest groups, service, civic, business and professional groups with varied concerns to address. Meetings designed for each segment may be advisable. Perspectives of opponents and advocates must be accounted for in developing a communications agenda. The finished product should recognize and respect conflicting views and shun antagonism.

In every presentation, it is imperative to establish a balance between facts and information. What people cannot understand, they mistrust. It is important to concentrate on facts and clarity when dealing with the public. In addressing the present and future of a project, always strike a positive note and be prepared with factual support. Stating that a project is "good for the community," a refining process "safe" or a serious environmental impact "easily remedied" is meaningless without documentation. Successful communication relies on fact, not on opinion or biased optimism.

As described in the following paragraphs, public meetings, printed material, and site visits can be used effectively to disseminate information about a project and to build a positive relationship with the community.

#### 7.11.3.1 Public Meetings

General interest meetings that attract a wide audience can promote positive community relations. Public meetings provide the opportunity for an open and positive presentation and a comprehensive and documented response to rumors or misinformation. Visual aids such as photographs, slides, videotapes, drawings and maps

are persuasive in rounding out a project presentation to the public. Clear and non-technical answers to questions from the audience are essential. Every query should be addressed. If the response must be delayed for necessary research, say so and deliver the answer as promptly as possible.

The economy is a priority concern in every community. Jobs are welcome news. How many jobs will a project create – and for how long? How many local residents will be hired? The payroll and the cumulative impact on increased purchasing power and tax revenues are recognized as a local fiscal plus.

Because there are diverse interests in every audience, focused meetings, as well as general meetings, can strengthen a community relations strategy. Concerns about particular environmental or health questions, traffic impacts and conflicting land uses are common and may best be addressed by qualified professionals at special meetings.

Service organizations and civic groups represent another collective community viewpoint. Support for schools, sports, social programs and fund-raising activities are traditional goals for these associations. Presentations to these groups should focus on what a project proponent can offer to any individual group and to the causes that they support.

Communications experts have recorded positive results from reaching into local classrooms through study aids for teachers. Supplying curriculum-related facts on products or natural resources associated with a proposed project has merit, as well.

#### 7.11.3.2 Printed Materials

No community relations program is complete without factual printed materials. In pamphlet or flyer form, with sketches or photos, information on a proposed operation must be current, community-oriented, accurate and positive in approach. It need not be a costly slick-paper, four-color job to deliver a credible message.

Materials should be made available to the public, the media, local government officials, relevant agencies and departments, business and financial interests. Information should be distributed at appropriate meetings and, if authorized, to schools.

#### 7.11.3.3 Site Visits

Because there is no substitute for being there, site visits offer visual and technical answers to a concerned and curious public. Printed materials are important supplements to site visits. Opening up a project for tours proves there is nothing to hide. The event makes its own direct statement. To be effective, tour leaders should be knowledgeable and equipped to address varied and special interests, as well as routine or technical questions. Besides organized tours, the public can be exposed to information at an open house, in local advertising, and through special events such as a ground breaking ceremony or a dedication.

### 7.11.4 COUNTERACTING MISINFORMATION

Tracking down sources of misinformation and preparing a rebuttal can be time consuming and frustrating. The process is wisely confined to issues of significance in the course of planning and decision making. The effort should concentrate on confronting major issues such as: unfounded allegations about threats to health and safety; traffic gridlock; destruction of wildlife or wildlife habitat; unmitigatable damage to the environment and devaluation of surrounding properties. Nit-picking is negative and tends to trivialize. It can also trigger another round of misinformation and response.

Documented response should point out and correct publicly circulated errors of fact or interpretation promptly and professionally. If the issue is fiscal, cite public records when feasible. Go to experts and authorities in the appropriate fields for technical or scientific answers. Consult reliable local sources whenever possible. It is best not to introduce jargon or opinion. Response is more effective when clearly expressed, focused and factual. Basic positive message points should be affirmed in every exchange and all correspondence. Discard any negative position that cannot clearly be justified.

In countering misinformation, consider more than one media vehicle. Besides the daily press, television and radio, small neighborhood newspapers that focus on purely local events typically welcome a newsworthy release of direct reader interest. Newsletters for a particular organization, industry, or business may be published monthly or quarterly and often reach a wide audience that includes executives and employees as well as government agencies, regional media and legislators. "Letters to the Editor" is another media arena for correcting errors, but it should not be over-used. Beware of the "rotating door" trap, where one letter prompts another and the exchange does nothing to advance the project position.

### 7.11.5 WORKING WITH THE MEDIA

An effective communications program connects early with the media to introduce and describe a project and open a dialogue. All media value a message that is balanced and complete and bears the stamp of authenticity. Personal contacts can be critical to your ability to provide that stamp and to relay your information to a community audience.

To build successful, direct media relations, be honest

and offer service. Don't complain. Don't ask for story kills. Don't produce a flood of releases. Getting to know a news editor and/or the news person assigned to report on a project is more than helpful. It may be essential to an effective information program and can be invaluable in emergencies.

Background material on a project is frequently requested and should always be available for prompt distribution. It must be accurate, clear and comprehensive. The basic information is used and reused as stories develop and should include the history and description of the proposal and anticipated economic benefits. The material should also address the history and current status of the proponent company, and identify top officials. The name, telephone and facsimile numbers of the project spokesperson or the general information source should be announced as soon as a designation is made.

Playing media favorites is amateurish, counterproductive and breeds resentment. Equal treatment earns respect and means releasing spot news as soon as possible and timed news and features based on an even break with required deadlines for the various reporters. Requests for photographs or for permission to take photographs are routine. Cameras make most people uncomfortable, and cooperation with the photographer will help abbreviate the process. If some areas are off-limits to cameras, explain why and suggest an alternative.

In dealing directly with the media, getting comfortable is the first hurdle. News persons ask questions to obtain information. Hostile or fragmentary answers will be reflected in what is printed or videotaped. So will courtesy and completeness.

A public interest viewpoint is always advisable, not that alone of the project or the company. Balanced presentation carries conviction. Recognize that all views are valid--to someone or some group.

Print and television media may approach the same news story from different angles, pressured by time constraints, print or visual emphasis, and the perceived extent of reader/viewer interest. Technical and professional journals have a narrower focus, more extended deadlines and tend to explore a subject in depth. All interviews and prepared materials should be tailored to fit the format and perspective of the specific media forum.

Daily or hourly deadlines and competition from other breaking news events influence how television and radio stations and newspapers play a story. Another determining factor is whether it is straight news or falls into the special feature category. Reporters are not responsible for where or how a story is played. That is the prerogative of the editor. Content and news – or shock – value are among the criteria applied.

Good media relations result from delivering a prompt response to any type of query. It is crucial to keep program files updated to include the history, performance and progress of a project and to guarantee accurate information. Material requested by newspersons pursuing stories on their own initiative is not for general release but for the use of that person, only.

If an error crops up in a story, a letter should be accompanied by a request for correction and addressed to the editor of the particular media department. In seeking a correction, the operative word is "request," not "demand." Provide convincing and conclusive information and push the fairness button. Courteous discussion of a correction with the reporter and/or editor can personalize the process and may establish a useful communications channel.

### 7.11.6 USING TECHNICAL INFORMATION

The majority of the public is not tuned in to the fine points of technical information. However, technical information can be integrated successfully into a communications program. Involving public relations and communications experts early during project planning is essential. It is important that the public relations manager become acquainted as soon as possible with significant technical and potentially controversial issues, with mitigation measures addressing environmental impacts, and with public and regulatory concerns. This knowledge can contribute to meaningful exchanges with the community at a later and more public stage of the planning process.

Clear and understandable technical information free of specialized vocabulary can be woven naturally and regularly into news releases and other printed material. Purely technical information is typically not understood nor welcomed by the majority of the media – or the public.

### 7.11.7 SPOKESPERSON TRAINING

From the corporate office to the mine or manufacturing site, company spokespersons need instruction and preparation for their role with the media and the public. Useful training tools are seminars conducted by a public relations expert, videotaped TV interview techniques, tips on public speaking, and rehearsing a model question and answer session.

Areas of responsibility should be defined for each designated spokesperson. Is it corporate finance, company policy, worker safety, environmental issues, a refining process or a community event? The spokesperson should have a complete grasp of the subject and the confidence to respond. Individual response limits must be clear. A casually-volunteered comment on an unfamiliar subject could be misinterpreted and create a public relations disaster.

Company policy should address the pros and cons of

telephone interviews. Communications miscues can occur where complex issues are discussed and the interviewer has no access to written backup material. Requests for interviews, in general, are not infrequent and should be reviewed by the public relations manager. It is acceptable to ask about the general subject of the interview and to provide supplementary information.

### 7.11.8 CRISIS COMMUNICATION

Prepared statements may be necessary where a serious emergency exists or where precise technical information must be imparted. A prepared statement may also be advisable as a direct response to allegations or charges generated from a public issues controversy. Any policy on prepared statements should allow for flexibility and accuracy based on the demands of a particular situation.

In emergencies, it is advisable to designate one spokesperson to funnel information to the media and the public, with backup from appropriate specialists. This response system must be carefully designed and positioned for action.

Crisis communication training programs are useful as preparation for confronting emergency response demands. Where stress is publicly present, questions should not go unanswered. Spokespersons must be well-grounded in how to present accurate and complete information in a crisis, while observing established policy limits and avoiding any perception of panic. A crisis communication program addresses these and other essential response areas with a prepared plan.

Company spokespersons facing controversial issues fare better with a positive approach: what is good about a project, not what is bad about the opposition. Trading insults is no substitute for a thoughtful response based on researched and reliable facts and for taking on issues directly and with conviction.

### 7.11.9 CONCLUSIONS AND SUMMARY

Communications and public relations programs must be proactive and designed to avoid a reactive or defensive mode. The programs should anticipate concerns and be prepared to respond. This requires maintaining updated files, keeping information and input current, and preparing upbeat presentations and printed material about the project.

A proactive program puts the opposition off balance, informs the public, and wins points for the proponent. This can be achieved by sponsoring informational meetings and site visits, submitting well-researched story suggestions to the media, and answering any and all questions. Creating an image of reliability and preparedness is critical.

Investing in public relations for a mining project is like any other important aspect of the project. A careful, consistent and focused program will help avoid major misunderstandings or unwitting blunders which can generate costly delays or stimulate demands for excessive mitigation – just as careful engineering can help avoid a future miscalculation.

Good relations with the many publics that show interest in a mining project deserves as much attention as any other aspect of the mine operation. It is, after all, problems with public perception and the processes of government which hold the greatest uncertainty – and therefore unanticipated costs – for mine operators.

## 7.12 POLITICAL INVOLVEMENT

**by K. W. Mote**

### 7.12.1 PARTICIPATING IN THE ISSUES

Just as advances in environmental science have increased geometrically for more than a generation, so has the growth of environmental law and regulation. At the outset of the age of environmentalism, science was the basis for describing the environment and the needed corrections, but in the political arena in which environmental considerations were cast, science and politics became confused. Therein lies the explanation of why the environmental practitioner must be deeply involved in the political process, both to help enact practicable and beneficial laws and workable rules, and to prevent their misapplication.

As this nation developed, captains of industry had a powerful voice in politics, and individuals had little or none. In the last three decades, however, the political system has opened up to the grass roots participation of all citizens in legislative and regulatory matters, giving rise to a large and powerful environmental lobby. Where industrial growth was once of greatest political importance, philosophical environmental and land use concerns have gained increased political importance.

Since the Wilderness Act of 1964 and the National Environmental Policy Act of 1969, new laws and regulations for land use, or non-use, and for environmental controls have flourished, often confusing the issues. For instance, the Wilderness Act of 1964 was designed to protect those "crown jewels" of the public lands, thought at the time to be comprised of 20 to 25 million acres of land unaffected by man, because adequate environmental protection laws did not then exist. Designated wilderness now includes more than 90 million acres, even though numerous environmental laws are now in place.

The National Environmental Policy Act of 1969 (NEPA) began as a set of guidelines against which Congress could judge the environmental implications of proposed legislation. These guidelines became law in the fervor of the growing environmental movement at the

moment. Frank B. Friedman wrote in the *Natural Resources Lawyer:* ( Journal of the Section of Natural Resources Law, American Bar Association, Vol. VI, No. 1, Winter, 1973; pgs. 44 and 45) "There is no indication that Congress considered the possibility that the provisions of NEPA would give rise to litigation or that NEPA would be regarded as creating judicially enforceable rights or duties." And further, " – this broad statute, with even broader implications, has been considered almost in a vacuum, and because of its broad language has, in turn, been subject to broad interpretations despite pleas by Federal personnel to the contrary." By making the intended guidelines standards, most of the resulting rules and new environmental laws were developed primarily by trial and error regulation and court decision. A great effort was put forth by the budding environmental community to pass NEPA, and the effort for change has grown and become more sophisticated and effective with time.

Although change is inevitable, the extent of reasonable, practical, or necessary change cannot be easily agreed upon, pitting environmental organizations, whose goals may seem more aesthetic and emotional, against miners whose response has been largely factual or data-oriented. Agreement on the definition of how clean is clean, or how much is enough, or what constitutes acceptable risk, is not likely to be decided in such an atmosphere. There seems little doubt that the solutions will tend to reflect the desires of the group with the best political involvement.

Long-standing differences between environmental activists and miners have often developed into a mutual distrust of motives and actions. Both are frustrated by what they see as a lack of adequate law and proper regulation on the one hand, and excessive control on the other. Because the political arena is the point of resolution, and politics is guided more by perception than fact, the mining industry has had to recognize that the best data and logic may not win. Because the industry is data oriented, changing the industry's approach has been difficult.

Fortunately, the industry is changing. Political involvement at all levels is becoming a way of life. The industry is becoming more politically active and is learning how to work with the environmental mainstream. The industry is learning how to become involved in the political process, certainly in part by recognizing the methods used by the environmental community.

## 7.12.2 HOW TO BECOME INVOLVED

### 7.12.2.1 Direct Participation

Direct participation in federal legislation is open to every citizen, by submitting formal testimony on a bill, by sending comments to Members of Congress on a current issue, or by communicating with Congressional staff. Such communications should clearly define the topic, and request specific action from the legislator. Concise letters and data presentation are typically more effective than lengthy presentations with abundant data. Including supporting data, information and references may be appropriate. However, these should be included as separate materials rather than in the body of a letter. Petitions and form letters or cards can be an effective way to add to the number of constituents taking a particular position, but may not have the same positive effect as a personal letter or call.

Professional societies and trade associations, can be an important source of political information and guidance on legislative issues. These organizations can typically provide information about the timing of Congressional activities, and can recommend key talking points for letters to Congress on proposed legislation.

Another effective way to communicate with a Member of Congress is to schedule a personal visit when Congress is not in session and when the Members are back home in their district offices. Meetings with the district office are a good opportunity for a focused discussion of key issues, and establishing a personal working relationship with a Member's district office can be a very effective way to work with Congress.

If possible, constituents should try to make personal visits to a Member's Washington, D.C. office. These discussions should focus on how the issue will affect the Member's constituents. Providing personal details can be particularly effective. The Member's office should be provided with written materials describing the issue and key concerns. To take maximum advantage of a trip to Washington, D.C., it may also be appropriate to visit the regulatory agencies with jurisdiction over mining. If time or funds are insufficient to support a trip to Washington, consider providing support for travel by others with similar concerns on an issue.

Perhaps the ultimate involvement is presenting testimony on your own behalf or that of your organization, at a hearing on legislation or proposed regulations of concern.

### 7.12.2.2 Indirect Participation

Other, less direct ways of political participation can also be important and may not be costly or time consuming. Indirect political involvement is important in educating the public, business community, peers and students on important issues. Trade and professional organizations should capitalize upon all requests to provide speakers on current issues or technical topics. Individuals interested in increasing the public's awareness of mining issues should participate in education committees or speakers

bureaus associated with trade and professional organizations.

Another effective way to educate the public and to develop public support for issues affecting mining is to meet with local newspaper editorial boards and business columnist. These visits should be issue specific and should be followed up with an offer to supply the publication with factual information about the industry. It is critically important that the industry respond quickly and effectively to inaccurate or distorted news articles or editorials.

### 7.12.3 THE MINING LAW OF 1872

One of the most difficult political issue that the mining industry has had to confront has been proposed changes to the Mining Law of 1872. This federal law, which has been under attack since before its passage, establishes the rules for access and use of public lands for finding and mining hard rock minerals.

Since the mid-1980s, the mining law has come under increasing scrutiny and pressure from conservation and environmental organizations, some of whom are demanding that the Mining Law of 1872 be replaced by laws eliminating the right of access by citizens to prospect for, and produce, hard rock minerals on the public lands. Others realize the need for access to the public lands, but want the environmental laws under different titles to be restated in the mining laws. Some extremists would like to halt all economic uses of the public lands.

The field for public activism has remained fertile, as environmental activists see unacceptable mining and reclamation practices of the past as the product of bad mining law, while miners blame the lack of environmental law at the time. Miners agree that old practices are unacceptable today, but argue that the laws enacted in the past two decades provide complete environmental protection, and sweeping new laws are not needed.

Environmental activists' demands are often seen by miners as physically or economically impossible or unnecessary, and miners are most often seen by environmentalists as intransigent and self-serving. The two sides, then, turn to elected and appointed officials to support their respective needs and viewpoints. The sheer number of members of environmental organizations, perhaps tens of millions, compared to less than a million miners, clearly shows the need to be actively involved in the political process which reacts more to numbers than to cold logic. The mining industry has always had to be technically correct and economically sound to succeed, but now must also be politically acceptable. It is the latter that has proved to be the most difficult and trying.

Several specific objections to the Mining Law of 1872 by the environmental community, and refutations by the mining industry, are in the political limelight each time amendment of the Law is proposed. Those arguments provide the basis for political sparring, and the very real need for political involvement. They provide familiar examples for discussion of the analysis of impacts.

Some of the key Mining Law issues include patenting, royalty payments, reclamation of abandoned mine lands, and environmental regulations. Dialogue about these issues has typically been polarized and emotional. The points of difference are so open to individual interpretation, to lack of specific definition, to arguments of old versus new, and to 'fact' versus emotion, that legislators have no clear determinant on which to decide which way to vote on mining law reform. Each issue by itself could be argued with volumes of data and interpretation. Collectively, it becomes clear that technical information can become overwhelming, particularly to busy legislators and staff. Critical points must not be overlooked, and any verbal presentation must be short, to the point, and in summary only. Reports, extended discussion, and data compilations can be offered for further study if a legislator or staff so chooses.

Some legislators and regulators have a predetermined position, some will follow the party leadership, and others may be convinced by public input. The stakes are high, the opposition is well organized and well financed, and has spent over two decades building their positive public image and political ties. The need for political involvement seems obvious; the means, slightly less obvious. Again, brief, direct statements are a necessity. Start out at a verbal scale of inch to the mile, and fill in inch to the inch as requested.

For instance, on the royalty issue, the statement may be made that miners *do* pay their fair share to the extent of a large percentage of the market value of their production. However, the industry has realized that the public has called for a production royalty, and industry has proposed a royalty based on net profit. Questions may be asked and answered, but pertinent data can be presented as reports and summaries for reference, in the detail requested.

On the patenting of mining claims, the message might be the reasons a patent supports assurance of future mining rights, but that industry does not object to paying a fair market value for the surface at the time of patenting. Or, if the conversation includes reference to the cost of patenting, the average real cost of proving the existence of an economic orebody may suffice, and the volumes of testimony and economic studies might be offered for further reference.

Involvement of the public in permission to operate a mine on public lands is less data-oriented. Discussion might point out the need for security of tenure, and then ask what information will clarify your position for your

audience.

### 7.12.4 ANALYZING LEGISLATIVE IMPACTS

Bills or legislative proposals can be confusing and intimidating even to many who regularly deal with the bill form. An ideal plan for analyzing the technical and legal aspects of proposed legislation may include a lawyer specializing in the subject matter, a practicing member of each technical and professional field directly or peripherally affected, a member of the financial management team, and lobbyists who participated in the development of the bill. Proper analysis will require both time and patience. No guidelines are offered other than dedication to thorough study and understanding of the legislation, and the patience to stick to it. A broad group analyzing the proposal will assure you a better chance of thorough understanding.

### 7.12.5 SUMMARY

Mineral industry engineers and technical specialists have, until recently, largely avoided politics. Until the environmental movement made everyone a player in the political game, 'someone else' looked after legislation and regulation – sympathetic legislators who understood the workings and the importance of the mining industry, senior company management with an established rapport with government officials, or an association with strong ties to influence. North American society was built around jobs and the economy, and had learned about the critical nature of minerals through two world wars and surviving a deep depression between them. Two generations of affluence have followed, allowing a different and sometimes unrealistic view of man's relationship to the environment, along with a more strident demand to protect that environment.

It may seem ironic that those least enticed into the realm of environmental politics are the most able to provide the balanced, insightful guidance for reasonable and realistic legislation and regulation. Mining industry professional's classroom for political understanding is personal political involvement. Mining professionals understand the environment, work in the environment, and have the desire and ability to protect the environment. Even though the art of politics is foreign to the science of mining, mining professionals must learn the language of politics and join in the era of environmental politics if mining and related industries are to flourish in the United States and Canada.

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# Chapter 8

# SYSTEMS DESIGN FOR SITE SPECIFIC ENVIRONMENTAL PROTECTION

edited by D. J. A. Van Zyl and J. N. Johnson

## 8.1 INTRODUCTION

**by D. J. A Van Zyl**

In modern mining operations, large volumes of tailings, waste rock, and heap leach ore are produced. The disposal and containment of these materials to provide site-specific environmental protection is a primary consideration during design and development of new mining projects as well as expansions of existing projects. In order to develop designs which are protective of the environment it is important to consider the complete system of site-specific environmental characteristics, waste material characteristics, and long-term land use objectives.

Previous chapters in this handbook have provided information on specific technologies and environmental considerations which should be made part of a system design for site-specific environmental protection. This chapter describes the integration of these technologies, environmental considerations, as well as specific design issues developed in this chapter. The major thrust in developing such integrated designs is to use site-specific information and to consider the protection of human health and the environment. The central theme of such designs should be designing for closure (Gadsby, 1990).

Much attention has been paid in academic circles to the design process. While there are certain guidelines and approaches in developing a site-specific design, it finally becomes a very individual endeavor. The next section of this chapter explores the design process and how it is applied to a specific facility to provide environmental protection

All mine waste disposal facilities are constructed with or on geological materials. Geotechnical considerations therefore play an important role in the development of protective designs. Section 8.3 provides a description of the geotechnical considerations required for mine development. Much has been learned over the last decade in the design of liner systems for containment of liquids. The technology has progressed from empirical approaches to more sophisticated quantitative evaluations. At the same time, a number of new synthetic materials have been introduced in the marketplace. Section 8.4 provides an overview and discussion of liner system design and how it is applied in practice.

Much attention was paid in the 1970s to the design of geotechnically stable tailings impoundments. Some of this was the direct result of failures which have occurred and the concerns expressed about large tailings impoundments near population centers. The design of such structures was formalized in terms of siting options, construction options and tailings deposition/management options. The industry concentrated on documenting successful operations and expanding their application to other sites. The major effort in the 1980's with respect to tailings disposal design has been the development of considerations for environmental protection. Containment systems, tailings management schemes, and tailings treatment were introduced and the ideas expanded to provide environmentally sound tailings disposal. Section 8.5 provides a review of the tailings characteristics and disposal design. It also provides consideration for the underground and marine disposal of mine tailings.

Open pit mines result in the production of considerable volumes of waste rock. The terminology "waste rock" is not universally accepted. In some states "waste" could be taxed on a per tonnage basis as the statutes define "waste" as referring to municipal waste and other trash. In the case of mining "waste rock" purely implies those rock materials which may or may not be mineralized and which are uneconomical for further processing at the time of mining. In some cases, it is conceivable that because of increased commodity prices the "waste rock" could become ore. Therefore the often quoted expression "today's waste is tomorrow's ore". Alternative terminology which have been proposed include "barren rock", "overburden" (often kept for the truly unmineralized materials), "rock", and "excess rock". The terminology used in this chapter will be "waste rock" acknowledging the sensitivities which are associated with such usage.

Section 8.6 provides a discussion on waste rock

disposal design. While waste rock disposal may be a simple matter in many environments because of low environmental sensitivity as well as topographical and other site features, it can also be a very complex problem at other mines. Waste dumps as high as 1000 meters are now being considered at some mines in high mountainous and high precipitation areas, these facilities obviously will require much attention in their design.

Extraction of metals through heap leaching has received considerable attention over the last ten to fifteen years. Although the technology for the extraction of copper through heap/dump leaching has been known for hundreds of years much progress has been made in applying the technology to gold and more efficient copper extraction over the last fifteen years. Containment of solutions and spent ore are important considerations in the development of heap leach facilities. These and other aspects are discussed in Section 8.7.

The water budget, or balance, of a project determines water needs, containment needs, and very often treatment and disposal needs. The development of a credible water balance as well as diversion controls are the topics of Section 8.8. Because of the uncertainties associated with many of the parameters, including climatic considerations, probabilistic evaluations of water balances are becoming more generally applied to allow operators to make risk-based decisions.

The best design can be rendered useless if there is poor construction quality control and quality assurance (QC/QA). QC/QA for earthen construction have been very well developed and broadly practiced during this century. However, much has been learned over the last decade about QC/QA of geosynthetics. Section 8.9 provides a discussion of the QC/QA approaches for earthworks construction as well as geosynthetic construction. A major consideration during QC/QA is the accurate documentation of activities and finally the preparation of a construction quality assurance or often referred to as an as-built or construction certification report. It is impossible to provide a comprehensive guidance document for the design of tailings, mine waste and heap leach facilities in one chapter. Due to the space limitations only highlights of the technologies and approaches can be provided. A large body of literature exist and the reader is encouraged to also consult parts of that, for example, Hutchison and Ellison (1992), ICOLD (1989), Koerner (1990), McCarter (1986), Smith and Mudder (1992), Van Zyl, Hutchison and Kiel (1988) and Vick (1990).

## 8.2 THE DESIGN PROCESS

**by D. J. A. Van Zyl, Z. T. Bieniawski, and M. Hames**

### 8.2.1 INTRODUCTION

The design process followed for a specific site very much depends on the site conditions, the designer's experience with similar site conditions and facilities, as well as the regulatory framework within which a design is developed. It is very possible that two designers will provide completely different designs for a specific site given the same set of criteria.

In developing a site specific design it is often useful to divide the process into considerations of:

Siting
Design and operations
Monitoring
Closure

Uncertainty remains throughout the design and construction of a facility because of the variable nature of geological materials. Design changes to the details of some elements are often necessary when site conditions are further exposed during construction. The design process is, therefore, not complete until the construction is complete.

This section provides a discussion of the design process, reviewing not only its technological background and recent proposals for formalizing the design process, but it also provides a discussion of how a mine design would be implemented to construct a series of structures and facilities which will be protective of the environment.

### 8.2.2 DESIGN PHILOSOPHY

Through the years, many presumptions about design, right or wrong, have evolved. These presumptions form the historical basis for our view or understanding of design. Engineering design has been historically viewed as a form of art and not as a technical activity. It has been thought that design primarily involves creativity and intuition, which are the spontaneous skills of the designer. Therefore engineering design is spontaneous and experience dominated. Because creativity occurs in random "flashes" and is not always dependable, design is primarily based on handbook information, empiricism, and individual designer experience, i.e., rules-of-thumb.

Through the years, concepts of systematic design have begun to emerge. An excellent historical background and discussion of the development of systematic design is provided by Pahl and Beitz (1984). The difficulty of tracing origins is realized, perhaps even dating back to the great designer, Leonardo da Vinci.

Asimow (1962) has contributed an excellent reference text on design. The text begins with a discussion on the philosophy of design, stating that the principles which lead to design are based on ones own experience. Choices of principles will inevitably vary from person to person, therefore only one philosophy of design will not exist.

The decision-making aspect of design is considered

very important. Incorporating a Bayesian statistical approach, that is the belief that subjectiveness or intuitive judgements should be introduced directly into one's analysis, Asimow has developed a theory of critical decision-making in design.

Design methodology is the collection of procedures and techniques that the designer can use in applying design principles to design. A significant contribution in this respect was made by Pahl and Beitz (1984) in Germany which eventually led to the publication of the standards for engineering design by the Verein Deutscher Ingenieure (Association of German Professional Engineers).

Most recently, working independently, major contributions were made to design theory by Suh (1990) and by Yoshikawa (1988). They developed an axiomatic approach to engineering design, identifying design axioms which constitute the basic principles for analysis and decision-making, and help the creative process of the design activity. Without them, design would be a mysterious creative process but with their contributions, it can be considered a rational and systematic activity. The Yoshikawa-Suh contribution is an important one because they were the first to suggest analytical tools for evaluation of the synthesized ideas so as to enable the selection of only good ideas and offer a basis for comparing alternative designs.

Yoshikawa (1988) defined design as a "mapping" from a functional space (specifications of objectives) to an attributive space (properties of the solution). He proposed a number of axioms and theorems relating the functional and attributive spaces. Suh (1990) crystallized these ideas by proposing just two principles of design, each pertinent to its own domain (i.e., space). In the functional domain, we must satisfy the objective of design by asking "what do we want to achieve?" In the physical domain, we must provide the solution of design by answering to "how do we want to achieve it. Interlinking these two domains is the design process.

In the fields involving geologic media such as mining and tunneling, very little attention has been paid to design methodology. There is only one book on record specifically introducing this subject (Bieniawski, 1984). Suh's work paved the way for proposing further design principles as well as incorporating them in a specific design methodology for rock engineering.

### 8.2.3 PRINCIPLES OF DESIGN

Using the approach advocated by Yoshikawa (1988) and by Suh (1990), six design axioms are proposed for geologic media as the principles for evaluating and optimizing alternative designs.

The following six principles of design have been proposed by Bieniawski (1990):

1. *Independence Principle:* There exists a minimum set of independent functional requirements that completely characterize the design objectives for a specific need.

2. *Minimum Uncertainty Principle:* The best design is one which poses the least uncertainty concerning geologic conditions.

3. *Simplicity Principle:* The complexity of any design solution can be minimized by creating the fewest number of design components forming a part of the design solution and corresponding to the appropriate functional requirement. In this way, the design objectives are uniquely satisfied in terms of the problem definition.

4. *State-of-the-Art Principle:* The best design maximizes the technology transfer of the state-of-the-art research findings.

5. *Optimization Principle:* The best design is the optimal design which is evolved from quantitative evaluation of alternative designs based on the optimization theory, including cost effectiveness considerations.

6. *Constructibility Principle:* The best design facilitates the most efficient construction of the structure by enabling the most appropriate construction method and sequence, and a fair construction contract.

A comprehensive design methodology is not just a sequence of flow charts for step-by-step design. To be comprehensive, a design methodology must incorporate design principles which can be used to evaluate designs and to select the optimum one fulfilling the perceived objectives. A design methodology must indeed recommend an order of design stages but these must be so structured as to assist in effective decision making and promote design innovation in accordance with the design principles.

### 8.2.4 COMMUNICATIONS

The design concepts and details have to be communicated effectively to:

*Regulatory agencies* for their review and approval.

*The public.*

*Vendors,* construction, and possibly operating contractors to insure that intentions and commitments are correctly interpreted and honored.

*Operating personnel* so that safe practices are implemented.

*Legislative and political bodies* so that technical progress can be reflected in the rules affecting mine development.

This is accomplished during the engineering, procurement, contracts preparation and construction management activities through:

*Manuals*, reports, plans and permit applications.

*Information* for public meetings and the media.

*Detailed drawings* and strict specifications that emphasize good quality materials, equipment, workmanship and control.

*Terms and conditions* for purchase orders and construction contracts that address safe transportation methods, emergency procedures and contingency plans in case of accidental spillage and the control of laydown areas, working hours or other restrictions such as burning seasons.

This Chapter provides extensive information on the technologies involved in developing an environmentally protective design. The remainder of this section concentrates on procurement, contracts preparation and administration and construction management. The successful completion of these tasks is necessary for the implementation of an environmentally protective design.

*Procurement.* While geologic materials form the bulk of the construction material for a site, specific equipment must be procured to complete the facilities. Equipment such as dust collectors and scrubbers that are used to protect air quality, for example, need to be properly specified, selected, installed, and tested and adjusted if they are to be effective.

Purchase orders are the primary documents that communicate design needs to equipment suppliers and place the responsibility on vendors to meet specified performance requirements. Under the terms of purchase, the vendor warrants that the goods will be designed, manufactured, supplied and delivered in strict accordance with the stated performance specifications, operating conditions and equipment standards. Furthermore, the vendor has to guarantee the equipment will perform the service required and provide a suitable warranty.

Although the owner, or his agent, normally checks the shipping documents and condition of the equipment when it is delivered, to make sure it is correct and undamaged, the equipment is only deemed "accepted" when it is installed and operating. Beyond that, it is covered by warranty for a period during which the vendor remains liable for the performance of the equipment and must take corrective action should it fail to perform the specified duty.

The role of the owner's "engineer" is to prepare the performance specifications, evaluate bidders' proposals and technical capabilities, review the vendor's data and commission the equipment checking it performs according to expectations. However, general purchasing conditions often stipulate that any review of vendor's data, inspections, or witnessing of tests by the purchaser shall not relieve the vendors of responsibility to conform to the specifications and comply with the terms of the purchase order. In addition to this formal declaration of responsibility, vendors wishing to enjoy continuing business have a vested interest in their equipment meeting expectations in order to maintain credibility and trust.

*Contracts Preparation and Administration.* The documents that directly control all construction activities, including mitigation measures such as liner installation, are the contracts. Contracts link the design requirements to the commercial terms and schedules under which the work is undertaken. The scope of work states what has to be done, while the "how" is dictated by the drawings, technical specifications and the general conditions. Built into the text are clauses requiring contractors to comply with all governing regulations, codes, standards and permits that cover protection of the environment as well as the quality of materials, equipment and workmanship inherent in the construction. In addition, the special conditions address site-specific issues, for example the need to restrict the schedule, size and routing of vehicles accessing the property.

Contracts also dictate the roles and responsibilities of the various parties including warranties and the terms of payment which stipulate who pays for what both when the scope is successfully executed and when acceptable work needs rectifying. Besides preparing and interpreting the technical information, engineers help select the contractors and usually oversee their work as construction managers and inspectors. However, the role of the owner's, or the regulators', "engineer" as inspector must be very carefully defined to avoid relieving contractors of their obligations to complete the work in strict accordance with the contract, or prevent unnecessary interference. Here lies a moot point. If contractors are to be held solely accountable for their work and must correct defects at their own expense, then they deserve the right to control and care for its proper execution. This argues in favor of making the contractor responsible for his own quality control (QC) and restricting the design and/or construction manager's engineers to providing quality verification (QA) through

independent inspection and testing. This division of QC and QA responsibilities can be appropriate for manufactured materials, however, the division between QC and QA on earthworks is not always that clear and division of the tasks can lead to unnecessary costs and duplication of efforts.

For the scenario described above, the contractor must provide the engineer with copies of his own inspection and test reports as well as access for independent verification. While the owner retains the right to halt the project until unsatisfactory work is repaired or replaced, the contractor can claim compensation for undue hindrance. In this case, no tests, inspections, or final acceptance relieve contractors of their obligations under the contract including their responsibility to correct defective work discovered during the warranty period that starts when the completion certificate is issued.

The alternative that places the onus for quality control on the owner or the design engineer gives them more "power", but can create a nightmare in terms of adjucating fair payment in the event of unnecessary stoppage or interference to the efficiency of the contractor's workforce.

*Construction Management.* The commitment to responsible development requires the early involvement of construction management personnel to help draft plans for: minimizing the impact of disturbances on site, developing suitable temporary services, transportation, procedures for handling hazardous materials and dealing with accidental spills, quality assurance/quality control and safety.

In addition to controlling progress, budgets and compliance with the design requirements to make sure facilities are built according to plan and the performance standards are met, construction management entails:

*Sequencing activities* that protect the environment during construction, for instance: installing silt fencing and/or sediment controls prior to disturbing an area, and the preparation of new wetlands sites ready to receive materials salvaged from existing wetlands affected by the construction.

*QA inspection and supervision* to enforce agreed QC measures such as testing requirements and dust control.

*Helping devise*, then enforcing construction methods that minimize impacts such as techniques for building low impact roads to access isolated sites.

*Administering safety and environmental* awareness programs that address items such as hunting regulations, restricted access and environmental protection procedures.

*Making sure necessary spill control* and cleanup materials are in place.

### 8.2.4.1 Safety and Contingency Plans

It is often part of the design engineers' responsibility to compile an Operating Manual that explains how to safely operate the process, water and electrical systems, plus their associated equipment. In addition, the manual usually describes safe handling procedures for hazardous materials together with emergency first aid procedures in the event of exposure to dangerous chemicals.

Spill prevention and control is another area that members of the design team, in cooperation with the contracts and construction management staff support, the owner's operators and agency personnel. Transportation guidelines that feature in the conditions of equipment purchase and construction contracts provide a spill response plan that sets priorities on safeguarding life and property, notifying the correct authorities, containment and cleanup, and reporting spills. The guidelines also address route and vehicle safety including: right-of-way priorities, speed limits, vehicle type, size and weight restrictions, loads requiring pilot vehicles, and emergency response kits. In addition, engineers help develop the spill response strategy for operations, their contribution being focussed on spill prevention through appropriate design details as well as the control and cleanup procedures. Fire protection is an integral part of the site service and building designs. However, emergency evacuation procedures are normally the preserve the owner's safety staff and fire marshall.

### 8.2.4.2 Monitoring

Engineers routinely assist the geoscientists, hydrologists and resource specialists in developing the monitoring programs that specify the frequency and nature of observations that must be taken. On the owner's behalf, they help identify the monitoring sites and constituents, then define the devices, access and procedures to take the measurements. For the regulators, they review the proposed plans for monitoring air and water quality, stability and waste rock characteristics for example. Engineers are also instrumental in planning and supervising the remedial action if the prescribed standards are not met.

### 8.2.4.3 Conclusion

How successful the engineering design requirements are in minimizing and controlling impacts depends not only on the skills and vigilance of the people concerned, but on factors including:

*Whether* the owner's and the regulator's technical staff are allowed to voice their input early enough in the planning phase to shape the project, and through such participation understand the overall objectives and variety of perspectiveness that need to be considered;

*How well* the requirements, commitments and decisions are communicated and implemented during detailed design, procurement, construction, commissioning and beyond; and,

*Whether* the ultimate need to reclaim the site is incorporated into the initial development plans.

While good management can coordinate activities, true integration of effort and purpose by the various engineering disciplines, scientists and the environmental resource specialists can best be achieved through their joint participation in planning the project.

Design engineers who are kept at arms length from the planning team remain largely ignorant of the environmental considerations inherent in a specific project and, lacking first-hand involvement, cannot contribute as effectively to their solution as they could if they better understood the ramifications of their designs. Enlisting their expertise at the planning stage, through brainstorming sessions, can help focus attention on the important issues, scope the areas and appropriate level of detailed design required to support the permitting process, and avoid unnecessary rework.

## 8.3 GEOTECHNICAL CONSIDERATIONS

**by D. L. Bentel**

### 8.3.1 INTRODUCTION

Freedom has eloquently been described as "availability of alternatives." Environmental responsibilities and political involvement have effectively limited the availability of mine planning alternatives to the degree that even a minor oversight regarding location and design of an operational component could lead to environmental and economic disaster, and possible well-deserved bondage.

For this reason, logic dictates that it is no longer merely desirable or economically astute, but critically essential, to determine specific engineering characteristics of rock and soil environments, before finalizing mine component locational and operational decisions.

This section discusses typical components requiring geotechnical evaluation, geotechnical site selection considerations, and philosophies appropriate to planning and implementation of preliminary and specific geotechnical data collection, which will allow environmentally and economically defensible design for mine operations, closure and reclamation.

### 8.3.2 COMPONENTS REQUIRING GEOTECHNICAL EVALUATION

The list below summarizes typical mine components that require geotechnical evaluations:

Open pits
Underground shafts, adits, stopes and chambers
Plant processing facilities such as thickeners, crushers, mills, vats, conveyors, pipelines, etc.
Haul and access roads
Stormwater diversion and control facilities
Heap leach facilities
Overburden disposal facilities
Tailings disposal facilities
Ore and growth medium stockpiles
Process fluid reticulation and storage facilities
Solid waste disposal facilities
Administrative, storage and maintenance structures
Sediment settling facilities
Fluid evaporation facilities
Borrow pits

### 8.3.3 GEOTECHNICAL SITE SELECTION

It is important in any site selection process to investigate the project components holistically, and not only as individual facilities, as the only absolutely fixed component of a mine is the ore body. To achieve the aid of economic and environmental stability, and an optimum facilities layout, all potential components must be considered at the site selection stage.

From a geotechnical point-of-view, to achieve component/site compatibility, certain site-specific properties must be considered. The degree to which a specific location satisfies the realistic geotechnical requirements, will provide the operator with essential information regarding design and operating feasibility, and additional site-specific requirements necessary to satisfy environmental responsibilities.

Relevant geotechnical site selection considerations for each of the listed components are discussed in the tables on pages 418–419.

### 8.3.4 PRELIMINARY EVALUATION OF SITE SUITABILITY

Prior to embarking on a program of detailed field work and laboratory analysis, it is economically judicious to carry out a preliminary evaluation of the overall site to determine the potential for site-specific, geotechnically

| Component | Relevant Geotechnical Considerations |
|---|---|
| Open Pits | Pit slopes stability during operations, post-mining and to suit reclamation requirements |
| | Overburden and ore engineering characteristics with regard to excavation, blasting, recovery and transportability |
| | Post-mining, pit invert and sidewall permeability characteristics with regard to pit hydrological and hydrogeological evaluations. |
| Underground Shafts, Adits, Stopes and Chambers | Engineering characteristics and mechanics of host rock to determine stability and hydrogeological properties and operational requirements, and methods of overburden and ore recovery. |
| Plant Processing Facilities | Foundation suitability with respect to settlement, heave, collapse, vibration, fluid containment and bearing capacity. |
| Haul and Access Roads | Cut and fill slope stability requirements. |
| | Trafficability with regard to foundation and surface requirement. |
| | Erodibility with regard to erosion and sediment control requirements. |
| | Source and suitability of road construction material.<br>*Reclamation requirements and techniques including stability and* revegetation. |
| Stormwater Diversion and Control Facilities | Ditch and berm stability requirements with respect to sideslope determination. |
| | Ditch and berm scour resistance with respect to hydraulic design and scour protection. |
| | Foundation characteristics for energy dissipation structures. |
| Heap Leach Facilities | Engineering characteristics of ore with regard to fluids infiltration, retention and through flow; methods of ore placement; operational and post-reclamation settlement and mass stability; surface stability; volume occupation; sediment generation; weathering and decomposition and reclamation requirements. |
| | Engineering characteristics of near surface foundation geology with regard to permeability, bearing capacity, stability, liquefaction potential, collapse potential, heave, gradability, suitability for base construction, suitability for liner or subliner construction. |
| | Engineering characteristics of deeper geology with regard to vertical and horizontal permeability, preferential flow paths, depth to groundwater, groundwater recharge potential, and attenuation potential. |
| Overburden Disposal Facilities | Engineering characteristics of overburden with regard to fluids infiltration, retention, and through flow; methods of placement; operational and post-reclamation settlement and mass stability; liquefaction potential; volume occupational sediment generation; surface stability; weathering and decomposition potential and reclamation requirements. |
| | Engineering characteristics of near surface foundation geology with regard to permeability, bearing capacity, stability, collapse potential and liquefaction potential. |

| Component | Relevant Geotechnical Considerations |
|---|---|
| Tailings Disposal Facilities | Engineering characteristics of tailings with regard to permeability, consolidation, strength, mass stability requirements, settling velocity, liquefaction potential, methods of deposition, methods of embankment phased lift construction, seepage evaluation and control, methods of drainage, methods of free water dissipation, closure and reclamation requirements. |
| | Engineering characteristics or near surface foundation geology with regard to permeability, strength, bearing capacity, collapse potential, liquefaction potential, gradability suitability for embankment construction, suitability for liner or subliner construction, seepage evaluation and control. |
| | Engineering characteristics of deeper geology with regard to vertical and horizontal permeability, seepage flow paths, depth to groundwater, groundwater recharge potential, attenuation potential, closure and reclamation requirements. |
| Ore and Growth Medium Stockpiles | Engineering characteristics of stockpile and foundation material with regard to mass stability, methods of placement, sediment generation and remobilization. |
| Process Fluid Reticulation and Storage Facilities | Engineering characteristics of near surface and deeper foundation geology with respect to gradability, embankment construction suitability, excavatability, suitability for liner of subliner construction, seepage evaluation and control, leak detection requirements, groundwater depth, groundwater recharge potential, attenuation potential, closure and reclamation requirements. |
| Solid Waste Disposal | Engineering characteristics of near surface and deeper foundation ecology with regard to gradability, liner construction requirements, daily or weekly cover construction, trafficability, seepage evaluation and control and final capping and reclamation. |
| Administrative, Storage and Maintenance Structures | Foundation suitability with respect to bering capacity, settlement, heave, collapse, vibration, etc. |
| Sediment Settling Facilities | Engineering characteristics of the sediment with respect to settling velocity, settling time, basin sizing, volume occupation and solids removal methodology and scheduling. |
| | Engineering characteristics of the foundation material with respect to excavatability, embankment stability, cut slope stability, permeability and seepage, scour resistance and protection requirements. |
| Fluid Evaporation Facilities | Engineering characteristics of the near surface and deeper geology with regard to gradability, embankment construction suitability, suitability for liner or subliner construction, seepage evaluation and control, leak detection requirements, groundwater depth, groundwater recharge potential, attenuation potential, closure and reclamation requirements |
| Borrow Pits | Engineering characteristics of the near surface geology with respect to excavatability, trafficability, quantity and quality of borrow material, cut slope stability, relative overburden quantity and quality, and reclamation requirements |

influenced environmental flaws, and then design a preferred preliminary component layout based upon these findings (see also Chapter 9 for "Fatal Flaw Assessments"). Alternative feasible layouts should also be identified. Subsequent detailed field work and investigation procedures, to provide site-specific quantitative data and verify or disprove previously identified potential flaws, can then be defensibly minimized, and cost effectively scheduled.

Listed below are examples of data gathering, records research that should be carried out during preliminary evaluation:

Topographical features from USGS or any other available topographical mapping

Local geology and hydrogeological indications from exploratory work already performed

Regional geology and hydrogeology from published state, federal or private sources

Federal and state guidelines for operation closure and reclamation of mine facilities

Plans of Operations, Closure and Reclamation Plans, and any other environmental or operational data pertaining to either neighboring operations, or similar operations with similar topographical, geological, hydrogeological, climatological or geotechnical conditions

Informal discussions with locally available technical and non-technical experts, e.g. consultants, State Mining Associations, local farmers, etc.

Site surface reconnaissance to provide an indication of surface geology and vegetation, validate topographical features recorded, i.e., springs, perennial streams, valley site, obtain a clear understanding of available access for subsequent field work, obtain an indication of neighboring and downgradient surface and ground water resources, and in general obtain familiarity with the site, which is often lacking at the planning stage.

The above data, together with envisioned operational tonnages and volumes, etc., should then be used to create a preferred facilities location layout, and alternative feasible layouts. Each component layout should indicate envisioned post-mining and post-reclamation disturbance.

In environmental jargon, this exercise should be seen as a pre-design phase I, geotechnical audit to help routinely identify potential environmental concerns and define the scope extent of phase II soil, rock and groundwater characterization required.

### 8.3.5 SPECIFIC DETERMINATION OF SITE SUITABILITY

Having completed the preliminary evaluation of the site and selected preferred and, where applicable, alternative feasible comparent locations, a site-specific evaluation of pertinent geotechnical data can be planned and implemented.

The intensity of field investigation and laboratory analysis should be directly proportional to the degree of uncertainty regarding site-specific geotechnical data, the nature and number of site-specific environmental concerns, the number of feasible alternative component locations identified, and the degree of variation in overall geologic uniformity.

As the data gleaned from geotechnical field work and analysis can be prone to subjective evaluation, and the need for additional investigation and analysis both costly and time consuming, it is best to characterize the data types required, and design an appropriate work plan which will satisfy all data requirements. Suggested data type characterizations are summarized below:

*Data Required for Standard Engineering Design* - This data typically included engineering characteristics, degree of uniformity, depth and aerial extent of surface, foundation and borrow source material which will allow the defensible performance of design for structure foundations, embankments, roads, cuttings, slopes, erosion and other standard engineered facilities associated with operational safety, resource determination and maintenance minimization. Also included under this data type, but not usually determinable during the field investigation stages of a project are exact engineering characteristics of mining overburden, ore and process solid waste such as tailings. This data should be realistically approximated from pertinent published data sets from similar operations. An appropriately conservative approximation of these data should be applied to avoid regulatory appeal against data used, as well as to insure that design integrity is met. Assumptions should be verified as soon as representative samples of relevant material can be analyzed, and any necessary modifications incorporated in the design. Conservative assumptions may result in beneficial modifications, whereas optimistic assumptions may necessitate costly changes to design and operation.

*Data Required for "Environmental" Engineering Design* - This data typically includes the characteristics of the surface and subsurface geology which govern the relationship between process fluids contained at surface, and the groundwater system beneath the site. For many

mining operations, zero discharge conditions are required, meaning no discharge of process related solution into site surface or groundwater systems. Whereas containment sizing and stormwater diversion amy be effectively used to achieve zero discharge to surface water systems, it is very difficult, if not impossible to totally eliminate seepage. To comply with environmental requirements, it is therefore necessary to define the degree of geologic and/or hydrogeologic containment applicable, and the degree to which this containment potential requires artificial reinforcement to ensure significant environmental impact to the groundwater system. The terms "significant" or "insignificant" may be subjectively used, and not necessarily quantitatively defined, and subject to negotiation with regulatory agencies.

For instance, if no groundwater exists, or the depth to groundwater is great, quantification of an impact may have little meaning. Conversely, if the potential for adverse impact seems high, identification and analysis of hydrogeological pathways, and hydrogeochemical reactions such as dispersion, attenuation decay or dilution of constituents contained in process solution, may be essential to realistically quantify the impact.

The environmental engineering data required should thus be tailored to suit the potential for adverse environmental impact and project sensitivity, and the site-specific field work and analytical program designed to fully incorporate these needs.

### 8.3.6 DISCUSSION

The "acceptance" of the absolute necessity for valid geotechnical data, and planning and implementation of an efficient data gathering and analytical program are critical to the concept of environmental sound mine planning, development, operation, closure and reclamation. As such, geotechnical evaluation should be rated as important as the ore reserve determination in the justification of the project feasibility, and not merely a necessary evil to satisfy regulatory curiosity, as has occurred in the past. This philosophy will likely increase initial project investigation costs, but allow defensible minimization of development, operational, closure and reclamation costs and long-term environmental liability, and maximize the acceptance and life of the mining industry.

## 8.4 LINER DESIGN PRINCIPLES AND PRACTICE

**by D. J. A. Van Zyl**

The major objective of a liner system is protection of human health and the environment. Liner systems are provided to contain solutions which can contaminate the environment when released (as in the case of cyanided tailings), or have economic values which are important to the economics of the project (as in heap leach facility), or both (as in heap leach facilities).

### 8.4.1 DEFINITION OF LINER SYSTEM

It is common to refer to a "heap leach pad liner" or "pregnant solution pond liner." While the main purpose of these "liners" is to contain solutions, their composition and construction may differ considerably. It is therefore incorrect to consider a low permeability member a "liner" because it has to interact closely with other elements of a complete liner system.

A liner system consists of a prepared foundation, a combination of low permeability elements and possibly granular drainage layers, and a cover layer. Each of these elements plays an important role in determining the reliability of the liner system. A prepared foundation is required to provide a base for the placement of a low permeability element. If the foundation can result in large settlements as a result of heap loading then specific precautions may have to be taken. These precautions could consist of replacing the weak materials with structural fill or providing extra fill so that settlement can be tolerated without changing the drainage on top of the liner system or the containment abilities of the liner system.

The low permeability elements are provided for containment. These elements can consist of natural clay materials, bentonite-amended materials, and geosynthetic materials (such as geomembranes). A liner system sometimes include drainage layers for leakage collection and removal. These layers can consist of natural drainage materials such as sands and gravels as well as synthetic materials such as geodrains. The combination of low permeability elements and drainage layers is what finally determines the reliability of the containment system. The next section will discuss this in detail.

A cover layer is provided on top of the liner system for a number of reasons. In the case of a clay liner a cover layer is typically provided to protect the liner from evaporation and subsequent dessication (contraction and cracking due to a removal of moisture from the clay liner). In the case of geomembrane liners a cover is typically provided to prevent wind damage, ultraviolet light protection, and protection against dynamic loading such as heap construction. It must be noted that the cover layer could consist of liquids as is the case in ponds.

In designing a liner system each of the components must be carefully evaluated to provide a reliable product which will provide containment under site-specific conditions. Because of the specific characteristics of certain materials, for example, the potential protection

offered by a geotextile to liner puncturing by granular materials, it is often suggested that such layers be included in a proposed liner system. Inclusion of such an element after completion of the system design, without a complete design re-evaluation, could result in serious consequences, such as instability of the overall structure, as the frictional resistance between a geomembrane and a geotextile is typically very low. It is therefore important that if one element of the liner system is changed that the performance of the total system be re-evaluated prior to accepting the change.

### 8.4.2 DEVELOPING RELIABLE LINERS

Two parameters determine the amount of leakage through a liner system: the hydraulic head on the liner and the permeability of the liner. By minimizing the head on the liner and minimizing the permeability a liner system can be developed that provides maximum containment. It is useful to consider liner performance on a qualitative or intuitive basis prior to presenting quantitative evaluations.

The permeability, or hydraulic conductivity, of a clay liner is determined by the flow of liquid through the available pores in the constructed liner. The "permeability" of geomembranes is dependent on the inherent hydraulic conductivity of the material (which is very low as will be discussed in future sections) as well as the size and shape of holes and imperfections in the liner.

Consider the case of a geomembrane, having a hole of say $10mm^2$, being suspended in the air and containing water. Water will freely flow through the hole in the membrane restricted only by the hydraulic resistance posed by the dimensions of the hole. If the same membrane is now placed on a gravel layer of high permeability, flow through the hole may not be restricted very much as the gravel will behave as an open porous medium similar to the free air. Next consider placing the membrane containing the hole, on a steel plate and providing perfect contact between the membrane and the plate. No flow will take place through the hole because of the low "permeability" of the steel plate. Finally, consider placing the geomembrane with the hole on top of a compacted clay having a low permeability. Furthermore, perfect contact is maintained between the geomembrane and the clay. Now the potential flow through the hole in the membrane is controlled by the head on the liner, the size of the hole and the permeability of the clay.

This qualitative analysis shows that an optimum liner system for containment can be developed by placing a geomembrane in direct contact with a low permeability soil layer to form a composite liner. By maintaining a low head on top of this composite liner, it is possible to reduce potential leakage through the liner to a minimum. The term composite liner refers to a geomembrane liner in intimate contact with a low permeability soil liner.

It is relatively easy to maintain a low head (in the order of 0.3 m to 1.5 m) on top of a liner for a heap leach pad. It is impossible to maintain a low head on a liner in the case of a tailings impoundment or process pond without inclusion of further liner elements. In the case of a tailings pond a high permeability granular drain can be placed on top of the liner to allow for drainage of the low permeability deposited tailings and therefore effectively providing a reduction of the head on the liner system. In the case of process ponds it is typical to place a drainage layer and another geomembrane on top of the bottom liner system. The top geomembrane liner serves as the first line of defense. Any leakage occurring through the top liner will be collected in the drainage layer and pumped out so that a low head is maintained on the bottom composite liner system. The drainage layer therefore performs as a leakage collection layer and functions to maintain a low head on the bottom liner.

### 8.4.3 TYPICAL LINER SYSTEMS

*Pond Liners* - Pond liners typically consist of two synthetic liners on top of a prepared base. A leak collection system is installed between the two synthetic liners so that any leakage through the top liner can be evacuated, thereby reducing the head on the lower liner. It is important to recognize that the amount of leakage through the top liner is never representative of the amount of leakage reporting to the environment. Figure 1 is a schematic of a typical pond liner system.

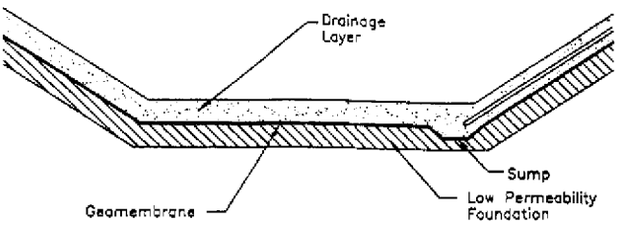



**Figure 1** Pond liner schematic.

*Pad Liner Systems* - Many designs have been used for pad liner systems. Harper, Leach and Tape (1987) provide a summary of some liner system configurations. The major consideration is site conditions, including the location of groundwater with respect to the pad liner and the materials available on site for pad construction. Other considerations are regulatory requirements and operator performance. A composite liner is appropriate for most pads. The saturated hydraulic conductivity of the soil component can be in the order of $1x10^{-6}$ to $1x10^{-7}$ cm/sec, both values will limit leakage losses through the

liner system. Heap leach pads are seldom subjected to hydraulic heads in excess of 0.5m. A second liner and a leak collection system will not reduce the head on the bottom liner sufficiently under these low hydraulic heads to justify their expense. Figure 2 presents a schematic of a typical composite pad liner system.

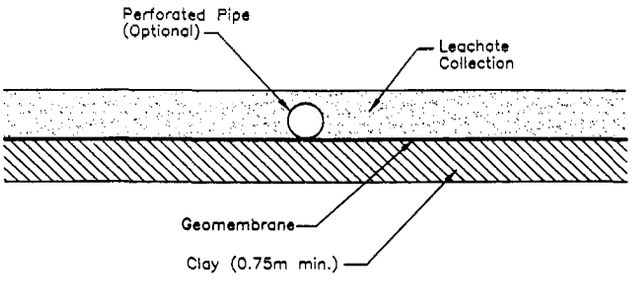



**Figure 2** Composite pad liner schematic.

A survey of geomembrane liner systems in the U.S. precious metal industry was conducted by Van Zyl (1990). This survey consisted of questionnaires sent to regulatory agencies, consulting engineers, and liner suppliers and installers. About 75 percent of the regulatory agencies and consulting engineers responded.

The major conclusion from this survey is that many states prefer the use of double liners and often triple liners, but do not necessarily have set regulations or published requirements for such design. These liner designs often form part of the final permit stipulations. It must further be noted that a number of States indicate that they require the clay layer of the composite liner system to have a hydraulic conductivity of at least 1 x $10^{-6}$ cm/sec.

*Tailings Impoundment Liner Systems* - Historically, tailings from flotation circuits have been deposited in unlined impoundments relying on the relatively benign nature of the tailings solids and liquids and the relatively low permeability of the consolidated slimes to minimize potential groundwater impacts. However, lined impoundments are relatively common for tailings subjected to chemical leaching such as uranium, gold and silver. Regulatory requirements for liner systems range from geologic containment only, through single soil or synthetic liners to multilayer systems. The regulations tend to emphasize the site-specific nature of tailings impoundment design and the additional contribution to seepage reduction provided by the relatively low permeability of the consolidated tailings.

Many tailings liner systems consist of a single soil or synthetic liner constructed on a prepared foundation and covered by a protective layer which may also function as a drain. For precious metal and uranium tailings the containment system may consist of a composite liner of compacted soil covered with a synthetic liner such as HDPE (High Density Polyethylene) or LLDPE (Linear Low Density Polyethylene). The compacted soil is usually a silty or clayey soil with relatively low permeability and may be amended with powdered bentonite to further reduce permeability. The composite liner is often covered with a protective cover of sandy or gravelly soil which may also act as a drain layer for seepage from the overlying tailings. Figure 2 presents a schematic of this liner system. By intercepting and directing seepage into a collection system, the protective cover/drain layer reduces the potential hydraulic pressure on the composite liner, thereby minimizing the potential for seepage losses.

## 8.4.4 LINER MATERIALS

### 8.4.4.1 Liner Selection

The selection of a particular type of liner material depends upon the conditions under which the liner must function, as well as the solution that is being contained. In a heap leach operation, the leach pad liner and the liner in the solution storage ponds contain the same solution. However, the type of liner selected for the leach pad may be significantly different from the type of liner selected for the solution storage pond. The leach pad liner is subject to the overall stresses imposed by the heap, as well as local stresses imposed by equipment used in constructing the heap. The pond liner is subject to the stresses imposed by storage of solutions. These differences may require selection of different liner materials on a strength basis.

For an expanding leach pad, the ore is placed on the liner and left there, such that the liner is exposed to the elements only during heap construction. At the edge of the heap, in collection ditches and in solution storage ponds, the liner is exposed to the elements on a continuous basis. This difference in exposure to the elements may dictate that a different material be used in ditches and ponds than beneath the heap.

In comparing a leach solution storage pond with a typical wastewater storage pond, the selection of a liner may differ due to the nature of the ponded liquid, even though the conditions for loading, hydraulic driving heads, and exposure are the same. A leach solution storage pond for precious metal leaching contains a high pH cyanide solution, whereas a wastewater pond may contain solutions of low pH or with organic solvents, or solutions with chemistry that changes over time. The liner for a leach solution storage pond must function under a much narrower range of conditions than a wastewater pond, and therefore, the designer may have a different range of liner materials to select form.

Based upon the factors and design elements outlined above, the liner for the particular component of the leach facility is selected. The materials to choose from primarily consist of geomembranes, soil liners, and

amended soil liners.

For geomembrane liners, considerations include the material type, bedding and cover materials, and methods of placement and seaming. For all soil and amended soil liners, considerations include material availability, soil composition, method of construction, and requirements for protection from weathering.

### 8.4.4.2 Clay Liners and Amended Soil Layers

Soil liners (commonly referred to as clay liners) consist of selected materials placed in lifts and compacted to prescribed moisture content and density, producing a liner with a hydraulic conductivity below a predetermined design value. This maximum value depends on site conditions and regulatory requirements. The performance of the soil liner is highly dependent upon the composition or characteristics of the material, the method of construction, and the method of liner protection.

Figure 3 illustrates grain size distributions of two soils: one a silty clay, the other a silty, clayey sand. In general, the higher percentage of fine-grained particles in a material (especially clay-sized particles) the lower the material permeability. Therefore, the silty clay maybe a more desirable material than the silty, clayey sand.

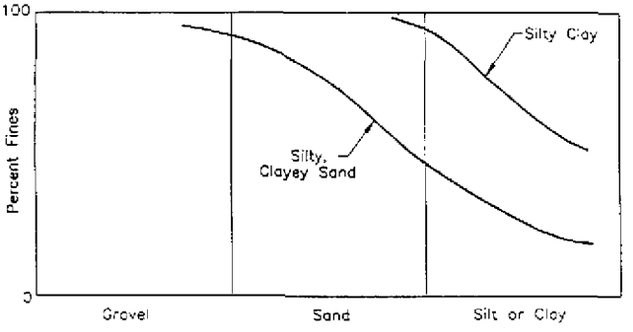



**Figure 3** Grain size distribution silty clay and clayey sand.

Figure 4 illustrates the plasticity characteristics of two soils: one a low plasticity clay, the other a high plasticity clay (determined from the plasticity chart). In general, the higher the liquid limit and plasticity index of a material, the lower the permeability. Based upon the plasticity chart alone, the high plasticity clay may be more desirable than the low plasticity clay. Other factors, such as construction and protection from weathering, may have an impact on material selection. The high plasticity clay will be more difficult to work during construction than the low plasticity clay. Also, the high plasticity clay may have a higher potential of shrinkage (upon drying) than the low plasticity clay, and may require more careful protection from drying. A silty clay of low to medium plasticity is more suitable for a clay liner than a high plasticity clay.

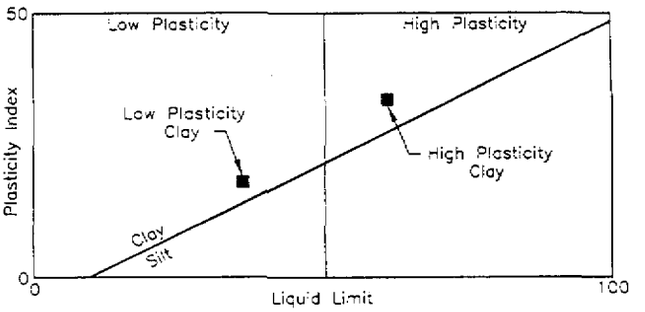



**Figure 4** Plasticity characteristics low and high.

The compaction behavior of soils is well described in a number of basic geotechnical engineering texts (such as Holtz and Kovacs, 1981). Laboratory compaction tests are used to investigate the compaction behavior of a specific soil. The most commonly used test is the standard Proctor test. Soil is compacted in a 4-inch (100m) diameter by 4 1/4-inch (108mm) high mold using a drop hammer. The soil is compacted in three lifts of even thickness, using 25 blows per lift from a 10-lb hammer (4.5 kg) which is dropped freely through 19 inches ( about 500 mm) (ASTM Test Method D-698). The results are plotted as water content (weight of water to weight of dry soil, expressed as a percentage) versus dry unit weight. From the typical compaction curve shown in Figure 5, it can be seen that the dry unit weight first increases with an increase in moisture content. A maximum dry unit weight is reached at a moisture content designated as the optimum moisture content, after which the dry unit weight decreases. This behavior is typical of all soils except clean sands.

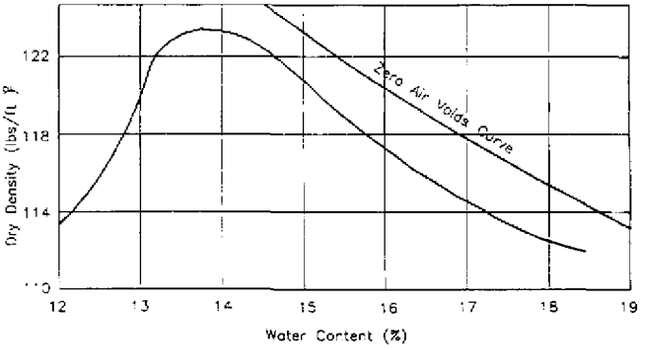



**Figure 5** Compaction curve.

The values of maximum dry unit weight and optimum moisture content are mostly dependent on the soil type and the compaction energy (e.g. weight of roller used). Other factors, such as type of compaction (e.g. sheepsfoot versus smooth steel drum) also play minor roles. The primary factors affecting compaction are summarized below:

*Soil type* - An increase in clay content increase the optimum moisture content and decreases the maximum dry unit weight. A silty clay has a much more peaked compaction curve than a high plasticity clay; therefore, a small change in moisture content affects the dry unit weight significantly for silty clay; and,

*Compaction energy* - An increase in compaction energy decreases the optimum moisture content and increase the maximum dry unit weight.

There is a significant change in soil hydraulic conductivity with change in compaction water content, and therefore dry unit weight. Figure 6 shows a typical set of results obtained from laboratory testing. Other test results are documented in Holtz and Kovacs (1981), Day and Daniel (1984), and Mudell and Bailey (1984). The hydraulic conductivity reduces about two orders of magnitude with a relatively small increase in water content. The lowest hydraulic conductivity is reached when the compaction water content is slightly higher than the optimum water content. It is important that careful control of compaction water content and dry unit weight is required to ensure that a clay liner has a low hydraulic conductivity.

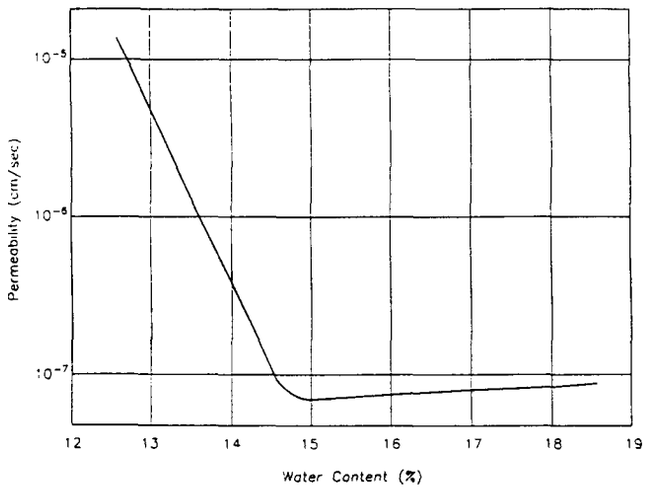



**Figure 6** Typical laboratory test results.

The clay mineralogy is obviously important in determining the permeability of a compacted clay liner. However, this cannot be changed in the field unless a clay amended soil liner is constructed. In general, montmorillonite clays have a lower hydraulic conductivity than kaolinite clays. Furthermore, a sodium montmorillonite is less permeable than a calcium montmorillonite.

Failure of a clay liner occurs when the hydraulic conductivity increases considerably above the design value, either locally or over a larger area. A clay liner can fail due to a number of reasons. Three major causes of clay liner failure are:

- Differential settlement of the foundation causing localized cracking of the clay liner.
- Drying out of the clay liner (desiccation) leading to the development of microcracks.
- Alteration of the liner permeability due to geochemical reactions between liner and leach solution.

The first type of failure (differential settlement) can be eliminated by careful site preparation. Attention must be paid to proper compaction of the subsoil prior to pad placement. Clay is quite flexible and can resist some differential movement without cracking, especially when it is compacted wet of optimum. However, large movements or strains up to 0.3 percent may cause cracking (Caldwell et al., 1984).

Dessication cracking of a clay liner can be minimized by keeping liner moisture content as close to the compacted moisture content as possible. If the time between liner construction and placement is short, the liner surface can be regularly sprayed with water to prevent drying. The best approach is to cover the clay liner with a layer of fine sand or tailings (if available) immediately after construction. This layer should be at least six inches thick, but may have to be ticker to prevent drying over a long period.

Failure of a liner due to geochemical reactions is prevented by careful evaluation of the liner during design. Although this is of more concern for solution storage ponds the potential for geochemical reactions between the contained solution and liner (such as cation exchange) should be tested. This is generally done by attenuation tests or long-term permeability tests.

Many soils do not satisfy the low permeability requirements for a liner but are sometimes close. For example, the site soil may be fine sandy silty with a hydraulic conductivity of $5 \times 10^{-6}$ cm/sec when compacted at a water content slightly above optimum. Addition of a suitable clay may reduce the hydraulic conductivity to an acceptable level. A suitable clay may be found in a borrow source close to the site or may have to be imported over long distances (e.g. pure bentonite in powder form). Addition of clay helps to reduce the void space and permeability. However, the physicochemical interaction of the clay with the seeping water plays a more important role. Some expansion of the clay lattice occurs, thereby filling the voids more completely.

The design approach for clay-amended soil liners is to find the percentage of clay required to reduce the hydraulic conductivity to an acceptable low value. Addition of clay will also change the compaction behavior of the soil. The laboratory testing program must, therefore, include compaction tests of each mixture, plus permeability tests at moisture contents slightly above the optimum.

Compaction tests are required for two purpose: to obtain the compaction behavior of the soil for construction specifications; and, to obtain the moisture content and dry unit weight for permeability tests.

The laboratory permeability test results are obtained from very well-controlled laboratory tests. A precise amount of clay can be evenly mixed with the soil, and the mixture can be allowed to cure at a specific moisture content prior to compaction. Such curing can be done in a covered container to allow the moisture to come in close contact with the clay particles. It allows for complete expansion of the clay at the specific moisture content. In the field, it is difficult to get an even mix of clay and in situ soil unless specific mixing equipment is used. It is also difficult to obtain complete curing of the clay because of evaporation and time constraints on construction.

The biggest variable in the field is soil type. Soils that require the addition of clay to reduce permeability are typically transported soils (such as alluvial and fluvioglacial deposits). Due to the nature of deposition, these transported soils are variable. This variability must be considered during laboratory testing and construction. A mixture of the site soil can be used, if sufficient mixing will occur during site preparation, or the coarsest soil can be used to obtain an upper bound clay requirement.

Construction of a clay-amended soil liner requires careful control of:

The amount of clay mixed with the in situ soil.
The mixing procedure.
The construction moisture content.
The compacted dry unit weight.

Two options are available for adding and mixing the clay with the in situ soil. The first is to spread a selected thickness of clay in a layer of in situ soil and to do the mixing with a grader, an agricultural disc, or a rototiller. The latter two methods will result in more even mixing. It is recommended that the clay and in situ soil should be dry during mining. This prevents "balling" and results in a more even mixture. Water, for compaction, should be added after mixing the clay with the in situ soil. Further mixing of the soil and clay occurs during the addition and the subsequent mixing of water and soil.

The second option for adding and mixing the clay is to use a pug mill for batch processing. Clay as well as moisture can be added to the in situ soil and the material transported to the pad area. This batch type operation will result in a higher quality product, but at a greater cost.

### 8.4.4.3 Geomembrane Liners

Thin synthetic films have been used as liner materials since the 1940's (Kays, 1977). Since that time much advances have been made in both the raw materials as well as the manufacturing of these synthetic liner materials. Because of the explosion in the number of synthetic materials used in earth construction new terminologies were proposed in the 1980's and these synthetic liners are now referred to as geomembranes because they are capable of containing solutions. Much has been published on the use of geomembranes and the design of liner systems (e.g. Koerner, 1990, 1993). The interested reader is referred to these and the other literature on this topic for a more detailed description.

The mining industry in the U.S. has used a variety of geomembrane liner systems for heap leach facilities and tailings impoundments. In the 1970s a number of heap leach facilities were constructed using polyvinyl chloride (PVC), while the use of high density polyethylene (HDPE) became common in the 1980's for both heap leach facilities and tailings impoundments. In the late 1980's very low density polyethylene (VLDPE) was introduced and was used extensively for heap leach pads and tailings impoundments. Throughout this whole period PVC has been used at a number of facilities. Other materials such as Hypalon™ and XR-5 (chlorosulfinated polyethylene) have also found application in the mining industry, however, in smaller quantities. Lately, LLDPE has been specified as an alternative to VLDPE.

In the case of reusable leach pads the low permeability member of the liner system is typically a low porosity asphalt and/or a layer of rubberized asphalt. The latter is a mixture of ground-up tires and asphalt and is applied by spraying it in a thin film over the area of application.

The characteristics of the various geomembrane liners must be considered in selecting the appropriate material for the site. Extensive information is available from manufacturers as well as from the literature on geomembrane characteristics. Furthermore, new materials are developed on a regular basis and changes are made to the formulations of existing materials and therefore the designer must stay up-to-date with such information to ensure that such information is included in the design of new facilities.

The three materials most often used in the mining industry as geomembranes are PVC, HDPE, and LLDPE. The rest of this section will provide a brief discussion of the characteristics of these materials:

*PVC* - PVC is manufactured through calendaring. The material is typically shipped as folded liner on pallets. Typical off-the-shelf thicknesses for PVC liner are 20 mil, 30 mil, and 40 mil (one mil = 0.001 inches). Other thickness can be specified and specially manufactured.

The characteristics of PVC are that it is a flexible material with a relatively low coefficient of thermal

expansion, so that there are not large expansions and contractions of the material during installation. The stress/strain relationship of PVC shows a continuous strain with increasing stress without a clear break between elastic and plastic behavior. Break occurs at about 300 percent elongation.

Panels of PVC are glued together using an adhesive. The bonding of this adhesive results in a seam of high strength. The area to be bonded must be dust-free and dry. After applying the adhesive the two sheets are pushed together using a hand-held small roller. It is therefore important to have a stable, firm foundation to work on. Factory seams are often included in the panels as the calendared panel widths are typically narrower than needed for installation.

Quality assurance of seams are done through mechanical point impact (screwdriver) or an air lance (ASTM Test Method D4437-84 and GRI GM6).

Because of the flexibility of the PVC, it easily deforms when subjected to loading of granular materials. Furthermore, the impact of sharp edges does not result in the puncturing of PVC material. Laboratory tests have been performed to evaluate the typical stacking height of heaps on top of PVC overlying a clay liner. Estimates of equivalent loads as high as a heap stacked to 1000 ft have been made from these tests.

PVC is chemically resistant to acids and alkalis in the pH range of mining solutions. It is not completely resistant to organics.

*HDPE* - HDPE is manufactured through extrusion of molten resin. The material is delivered in rolls and typical liner thicknesses are 40 mil, 60 mil and 80 mil. Other thickness can be specified and manufactured upon request.

The stress/strain behavior of HDPE shows a clear distinction between elastic and plastic behavior. Yield typically takes place at small strains, in the order of 10 percent. Break takes place at high elongations, in the order of 800 percent, however, the material does not behave elastically in this region. HDPE has a higher coefficient of thermal expansion than PVC and therefore elongates considerable when subjected to sunshine.

Panels of HDPE are welded through extrusion welding, molten HDPE resin is extruded at temperatures of approximately 400°F. A variety of extrusion welding equipment is available on the market.

Quality assurance testing of liner seams can be done by vacuum box or applying pressure to the opening between a double- welded seam. Although other methods have been proposed these are the most commonly used today.

HDPE material is more rigid than PVC and is easily scratched by granular materials. The impact of such surface scratches can be to weaken the material finally resulting in formation of small holes in the liner. It can also result in the initiation of tears if the material is exposed. HDPE is also chemically resistant to the overall pH range of typical mine solutions.

*LLDPE* - LLDPE is manufactured through extrusion of molten resin. The material is delivered in rolls and typical liner thicknesses are 40 mil, 60 mil and 80 mil. Other thickness can be specified and manufactured upon request.

LLDPE is a flexible material having characteristics similar to that of PVC. The stress/strain behavior is similar to that of PVC, no specific yield point is present and break occurs at an elongation of about 300 percent. The chemical resistance of LLDPE is like that of HDPE. It is resistant to materials in the full pH range used in mining applications.

The relative flexible nature of LLDPE makes it resistant to impacts of sharp edges on crushed materials such as heap leach ore. It has thermal expansion behavior similar to that of HDPE.

### 8.4.5 LEAKAGE THROUGH LINER SYSTEMS

Seepage losses through clay liners are controlled by slow mass liquid flow through the pores of the clay layer. The lower the hydraulic conductivity of the clay layer the lower this mass flow until it is finally mostly controlled by physicochemical considerations and flow takes place by diffusion. In general the seepage through a clay liner can be calculated using Darcy's equation:

$$Q = kiA \qquad (8.4.5\text{-}1)$$

where:

Q = seepage quantity
k = hydraulic conductivity
i = seepage gradient
A = surface area through which seepage takes place

Water vapor transmission can occur through intact geomembrane liners (Koerner, 1990). An equivalent hydraulic conductivity can be estimated for geomembrane liners. The equivalent hydraulic conductivity of estimating vapor transmission through geomembrane liners using Darcy's equation is in the order of $1x10^{-11}$ cm/sec.

The calculation of leakage rates through geomembrane liners is more difficult because its magnitude depends on the size and shape of the opening in the liner, as well as the material underlying and overlying the liner. Empirical equations have been proposed for calculating leakage rates through holes in geomembrane liners (Bonaparte et al., 1989):

(a) Rate of leakage due to defects in geomembranes overlain and underlain by high permeability materials (e.g. pond primary liners with geonet, or other high-permeability leak collection system):

$$Q = C_B a(2gh)^{0.5} \quad (8.4.5\text{-}2)$$

(b) Rate of leakage though a geomembrane resting on high permeability material and overlain by a medium permeability drainage material (e.g. heap leach pad liner overlain by ore and underlain by a leak collection system):

$$Q = 3a^{0.75}h^{0.75}k_d^{0.5} \quad (8.4.5\text{-}3)$$

(c) Rate of leakage through a composite liner with a hole in the geomembrane, good contact between geomembrane and clay (e.g., synthetic liner on clay):

$$Q = 0.21\ a^{0.1}h^{0.9}k_s^{0.74} \quad (8.4.5\text{-}4)$$

In equations b to d, the symbols are defined as follows:

Q = steady state rate of leakage through one hole in geomembrane layer ($m^3/s$)
$C_B$ = dimensionless coefficient, $C_B = 0.6$
g = acceleration of gravity, g = 9.81 $m/s^2$
a = area of the hole in the geomembrane ($m^2$)
h = head of liquid on top of the geomembrane (m)
$k_s$ = hydraulic conductivity of the low permeability soil underlying the geomembrane (m/s)
$k_d$ = hydraulic conductivity of the drainage material overlying the geomembrane (m/s)

The leakage rate through a hole in a geomembrane member of a composite liner is considerably lower than that through other boundary conditions. It is further interesting to note that the water vapor transmission through a geomembrane may result in higher losses per acre than the leakage through a composite liner.

As was intuitively derived above, quantitative evaluations of Equations a to d show that if the synthetic liner is underlain by a low permeability layer the leakage rate through a hole in the synthetic liner will be much lower than that through a hole in a freely drained single synthetic liner. The same is true for a single (non-composite) clay layer. In a composite liner, the hole restricts the flow into the clay liner to a small area and flow into the clay therefore takes place under unsaturated flow conditions. The behavior of the synthetic and clay liner composite is therefore more beneficial than that of any layer by itself.

Leakage through liner systems can be estimated by using equations a to above. Based on research in the solid waste and hazardous waste industries, as well as experience in the mining industry it is recommended that a hole size of $10mm^2$ be used in the evaluations. It is further assumed that one hole per acre occurs.

## 8.5 TAILINGS DISPOSAL DESIGN

**by J. M. Johnson**

This section describes the disposal methods of tailings and the related design issues. Geotechnical stability issues received most of the attention until the late 1970s, because tailings dam failure was perceived to be the most obvious threat to human health and the environment. In the 1980s and 1990s other environmental control issues such as seepage containment and control of oxidation/acidification to minimize impacts to surface water and groundwater, and tailings liquid detoxification to protect wildlife have assumed increased importance in the design process. The requirement that tailings disposal be done so as to be protective of human health and the environment is a leading principle for the design engineer. The descriptions in this section will highlight how this can be achieved. A large body of literature exists on tailings disposal methods and the interested reader is specifically referred to the bibliography on tailings disposal published by the International Commission on Large Dams in 1989 (ICOLD, 1989).

### 8.5.1 TAILINGS PRODUCTION, HANDLING AND TRANSPORT

For this chapter tailings are defined as the relatively fine-grained mineral processing waste produced by milling operations. Tailings are typically clay, silt and sand-sized mineral fragments with some chemical residues from the extraction process. Overburden, waste rock and spent heap leach ore are not tailings under this definition and are described in subsequent sections on waste rock and heap and dump leaching. Process wastes such as sludges and smelter wastes (slag and flue dust) are also excluded under the definition and are described elsewhere.

Mineral processing operations which produce tailings commonly include the following processing steps:

Crushing
Grinding
Physical and/or chemical removal of mineral values
Dewatering
Transport
Disposal

Crushing reduces the size of the ore fragments from the run-of-mine gradation achieved by blasting fragmentation to a size acceptable as feed to the grinding

circuit. Multiple stages of crushing are commonly used to attain the desired particle size. Further reduction in particle size, to essentially the final gradation of the tailings product, is then achieved in the grinding circuit.

Physical and chemical processes are used to extract the mineral values from the finely ground ore produced by the grinding circuit. Common extraction processes include:

Gravity separation (washing)
Magnetic separation
Flotation
Leaching
Heating

**Table 1** Froth Flotation Reagents

| Class | Use | Compound |
|---|---|---|
| Collectors | To selectively coat particles with a water-repellent surface attractive to air bubbles | Water-soluble polar hydrocarbons, such as fatty acids |
| Modifiers | | |
| pH regulators | To change pH to promote flotation, either acid or basic | NaOH<br>CaO<br>$Na_2CO_3$<br>$H_2SO_4$<br>$H_2SO_3$ |
| Activators and depressants | To selectively modify flotation response of minerals present in combination | Metallic ions<br>Lime<br>Sodium silicate<br>Starch<br>Tannin<br>Phosphates<br>Sodium cyanide |
| Frothers | To act as flotation medium | Pine oil<br>Propylene glycol<br>Aliphatic alcohols<br>Cresylic acid |
| Oils | To modify froth and act as collectors | Kerosene<br>Fuel oils<br>Coal-tar oils |

After Vick (1990).

Gravity separation, magnetic separation and heating generally require no or few chemical additives and produce relatively benign tailings with reduced potential for adverse environmental impacts. Flotation and leaching generally require a range of chemical additives, producing tailings with an increased potential for adverse environmental impacts. These chemical additives include froth flotation reagents and lixiviants for leaching. Typical flotation reagents are summarized in Table 1. These chemicals are added to change the surface characteristics of the minerals and allow them to float to the surface of the slurry. Common leaching lixiviants include acids, cyanide and alkaline agents. Acid leaching can be used to process copper ores and is often applied to phosphate concentrates and uranium ores. Cyanide leaching is typically used to process gold and silver ores although other lixiviants such as thiourea, thiosulfate, bromine, chlorine and iodine are possible alternatives (Von Michaelis, 1987). Alkaline leaching is often used to process bauxite ores and uranium ores.

Dewatering processes are used to increase slurry density or reduce the moisture content of the tailings for transport and disposal. Typical dewatering techniques include:

Thickeners
Hydrocyclones
Centrifuges
Vacuum filters
Pressure filters
Gravity drainage

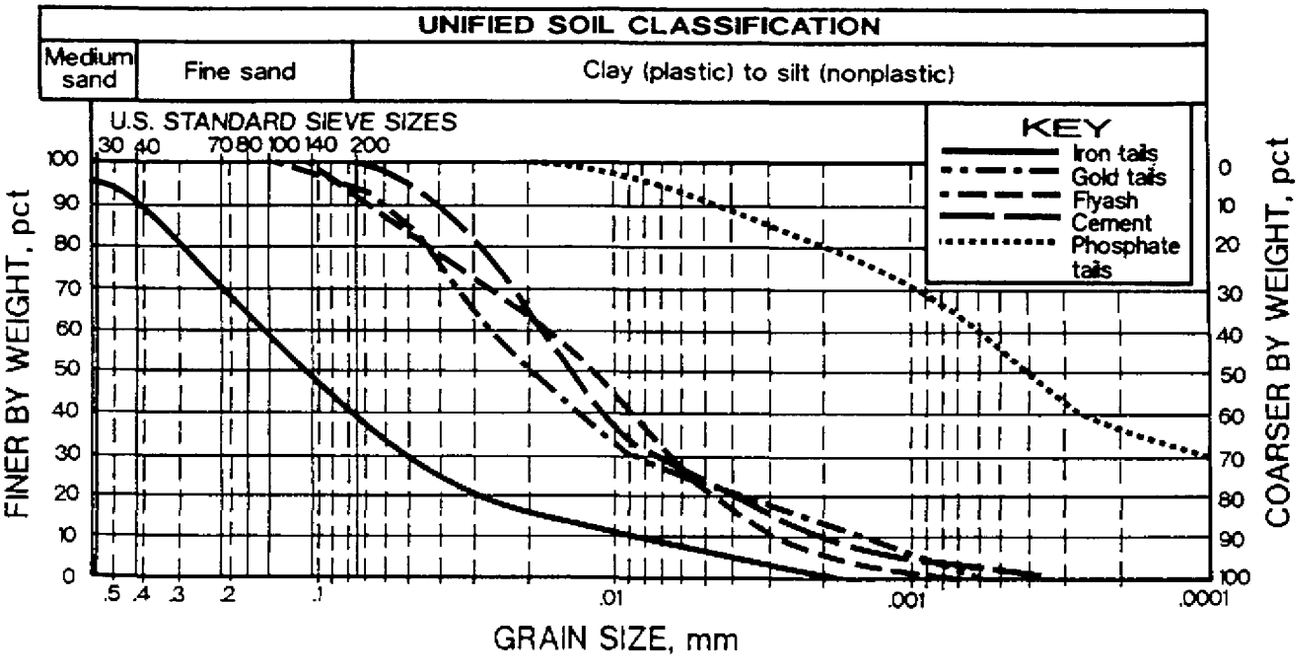
Thickeners are commonly used to increase slurry density prior to delivery in slurry form to the tailings disposal area. Hydrocyclones with gravity drainage, centrifuges and filters are sometimes used to produce what are commonly called "dry" tailings which can then be transported by truck or conveyor to the tailings disposal area. Gravity drainage alone is relatively uncommon as it is useful only on the coarsest, very sandy tailings. "Dry" tailings are generally expected to have reduced potential for adverse environmental impacts because of the low moisture content but may have greater potential for air quality impacts than slurried tailings.

Slurried tailings are usually transported from the mill to the disposal area by pipeline using either gravity flow or pumps where the topography is unfavorable. Some operations still rely on gravity flow in open launders for delivery of slurried tailings. "Dry" tailings are usually transported by truck.

Vick (1990) provides more extensive descriptions of tailings production from various types of mining operations including treatment and preparation methods.

### 8.5.2 TAILINGS CHARACTERISTICS

The geotechnical and chemical characteristics of the tailings are directly related to the characteristics of the ore, the specifics of the crushing and grinding circuits and the chemicals used during metal extraction. In general, the physical and geotechnical characteristics of




**RANGES OF PARTICLE SIZE DISTRIBUTION FOR VARIOUS TYPES OF TAILINGS**
(After Boldt et al., 1989)

**Figure 7** Particle size distributions.

the tailings are determined by the mineralogy and weathering state of the ore and the degree of particle size reduction achieved during crushing and grinding. Typically, the physical characteristics are not altered by the extraction process. However, there are cases where the chemicals can alter the characteristics significantly, for example, alkaline leaching of uranium ores can result in gypsum formation in the resulting tailings. The chemical characteristics and therefore the overall requirements for environmental containment or other controls are in most cases a function of the chemicals used during metal extraction. There are also cases where naturally occurring minerals such as sulfides can also effect containment requirements and other environmental controls because of the potential for oxidation and acid generation leading to leaching and migration of metals and other ions.

A summary of typical geotechnical characteristics of various tailings products is provided in Section 7.2.2. These include Atterberg limits and specific gravity, in-place densities and void ratios, minimum and maximum densities of sand tailings, average in-place relative density of sand tailings, typical tailings hydraulic conductivity, typical values of compression index, typical values of coefficient of consolidation, typical values of drained friction angle and typical total stress/strength parameters. Particle size distributions for some typical tailings products are shown on Figure 7. These typical values can be used as a guide in design however site-specific testing should be performed to obtain design parameters.

The chemical characteristics of tailings liquid vary greatly from site to site. The characteristics of the water source will have some impact on the resulting water quality of the tailings. However, the largest impacts are usually the result of the chemicals added and metals and other ions liberated during the extraction process. Oxidation of sulfide minerals and the resultant liberation of metals and other ions under acidic conditions may also influence the chemical characteristics of the tailings liquid. Some chemical species which are potentially mobile in tailings liquid are summarized in Table 2. Table 3 provides disposal concentrations from a copper tailings vat leach. Reagent consumption and cyanide concentrations for a carbon-in-pulp cyanide vat leach at a gold mine are presented in Table 4. Much has been written about the treatment methods of tailings solutions. Environment Canada published a study on mine and mill wastewater treatment in 1975 (Scott and Bragg, 1975). Smith and Mudder (1992) provide a

**Table 2** Potentially Mobile Chemical Species in Tailings Liquids

| Chemical Groups | Mine Tailings | | |
|---|---|---|---|
| | Flotation | Concentrate | Undifferentiated |
| Cations and Metal Cations | calcium, ammonia, transition metals [1]lead, mercury, and barium | calcium, transition metals, lead, mercury and barium | calcium, transition metals, lead, mercury, and barium |
| Anions | nitrate, sulfate | nitrate, chloride, sulfate | nitrate, chloride, sulfate |
| Amphoteric Species | arsenic, antimony, chromium, molybdenum, selenium | arsenic, antimony, chromium, molybdenum, selenium | arsenic, antimony, chromium, molybdenum, selenium |
| Cyanide Complexes (where cyanide is used as a process reagent) | (2) | Free cyanide (CN and HCN) | |
| | | Weak metal cyanide complexes (e.g., zinc, copper, nickel cyanides) | |
| | | Strongly complexed cyanides (e.g. iron, cobalt complexes) | |

Notes:
(1) Transition metals include: chromium, cobalt, copper, nickel, zinc, iron, manganese

(2)Trace amounts of cyanide may be present for a short period of time if sodium cyanide is used as a modifier in the flotation circuit.

After Hutchison and Ellisyon (1992).

complete review and discussion of cyanide chemistry and related treatment processes. A summary of geochemical characterization and prediction techniques is provided in Section 7.2.1.

### 8.5.3 DISPOSAL METHODS

Tailings are typically disposed in engineered surface impoundments or as backfill in underground mines. Less frequently, tailings are discharged directly from the mill to a nearby body of water such as a river, lake or ocean. Historically, discharge to rivers and lakes was relatively common but is now rare. Underwater marine disposal has been practiced at a number of sites (Vick, 1990) but is increasingly difficult to permit in the existing regulatory climate.

The tailings can be discharged from the mill as a dilute slurry in the order of twenty to forty-five percent solids (percent solids is the ratio of the weight of the solids to the total weight of the slurry expressed as a percentage). Conveyance of the slurry is through pipelines which may include specially designed facilities such as drop boxes to keep a low flow velocity in the pipelines and thereby controlling pipeline scour. The deposition behavior of these high liquid content slurries produces very flat tailings profiles away from the point of deposition with slightly steeper profiles in close, depending upon sand content, discharge velocity, and beach width. The sedimentation behavior of tailings along a beach is discussed in more detail in section 8.5.4.

The tailings slurry can also be physically treated to obtain a higher percent solids while still in slurry form. Through the use of thickeners and other mechanical devices it is possible to obtain slurry densities as high as 55 to 60 percent. The deposition behavior of such thickened tailings differs from that of the more dilute slurries, producing a relatively flat conical mass of tailings radiating from the point of discharge at approximately a six percent slope. This process is known as the "thickened discharge method" and is described in more detail by Robinsky (1979) and Palmer and Krizek (1987).

Belt filters or other mechanical filter equipment can be used to reduce the moisture content in the tailings even further. Solids contents has high as 80 to 85

**Table 3** Example of Waste Characteristics. Copper Tailings Vat Leach Reprocessing

| Constituent | Reprocessed Tailings Disposal Concentration (mg/l) |
|---|---|
| Arsenic | 0.22 |
| Barium | 0.34 |
| Cadmium | 0.15 |
| Chromium | 1.84 |
| Lead | Not Detected |
| Mercury | 0.01 |
| Nitrate (as N) | 58 |
| Selenium | 0.12 |
| Silver | 0.07 |
| Calcium | 51.1 |
| Chloride | 32 |
| Copper | 271 |
| Hardness | 1928 |
| Magnesium | 437 |
| Manganese | 42 |
| pH | 2.55 |
| Sodium | 211 |
| Sulfate | 15800 |
| Total Dissolved Solids | 23990 |
| Zinc | 7.14 |
| Organic Substances | Not Detected |

**Table 4** Example of Waste Characteristics. Gold Mine

| Reagents Used in Mill Circuit | Consumption (lbs/ton ore) |
|---|---|
| Sodium Cyanide (NaCN) | 1.20 |
| Calcium Hydroxide (CaOH - Lime) | 2.00 |
| Sodium hydroxide (NaOH | 0.05 |
| Nitric Acid ($HNO_3$) | 0.10 |
| Fluxes (silica, sand, borax, fluorospar, etc.) | 0.02 |
| Carbon | 0.03 |
| Treated Tailings Slurry | |
| Total Cyanide | 70 mg/l |
| Free Cyanide | 30 mg/l |
| Untreated Tailings Slurry | |
| Total Cyanide | 1461 mg/l |
| Free Cyanide | 577 mg/l |

percent can be obtained from such devices. The resulting tailings have been referred to as dewatered tailings, dry tailings, and tailings paste. A later section will discuss the production and disposal of these materials.

### 8.5.4 TAILINGS SEDIMENTATION

Characterization of master beach profiles and depositional behavior is important for the more accurate modeling of tailings deposition which in turn influences the geotechnical characteristics of a tailings deposit. The sedimentation behavior of tailings along a beach following deposition has been studied by a number of researchers and has resulted in the definition of a beach profile as well as the particle size segregation along the beach. The deposition of particles from the slurry and, therefore, the segregation along the beach, as well as the beach profile, are functions of specific gravity of solids, percent solids in slurry, and discharge rate of the slurry. Melent'ev et al., (1973) proposed a model for the development of a beach, as well as segregation of particles along the beach. Melent'ev's model has been shown subsequently to be valid and can be applied successfully to the deposition of gold and platinum tailings (Blight, 1987). Considerable effort in this area, combined with seepage analyses, have also been presented by Abadjiev, (1985).

The profile of a beach is generated by the gravitational sorting of particle sizes as the slurry flows down the beach. A reduction in particle size occurs along the beach which results in the reduction of the hydraulic conductivity of the tailings as a function of distance from the depositional point (Blight, 1987). A master profile of the beach is developed which can be expressed as:

$$\frac{h}{Y} = \left(1 - \frac{H}{X}\right)^n \qquad (8.5.4\text{-}5)$$

where:

$H$ = length of beach
$Y$ = elevation between point of deposition and pool
$X$ = distance along beach
$h$ = elevation between pool and point x
$n$ = the dimensionless constant dependent on tailings characteristics

Blight (1987) shows that the expression models the master beach profile for various tailings materials.

Abadjiev (1976, 1985) has suggested the following relationship for the change of saturated hydraulic conductivity for deposited tailings as a result of the material segregation along the beach.

$$k = ae^{-bH} \qquad (8.5.4\text{-}6)$$

where:

$a$ and $b$ are constants characteristic of the beach, and
$H$ = the distance along beach from deposition point.

Sedimentation and beach development behavior can also be evaluated using bench scale testing in the

laboratory using a project specific tailings grind. Fourie (1988) provides results for three of these tests conducted on bauxite, nickel and coal tailings.

### 8.5.5 TAILINGS IMPOUNDMENTS

The siting and design of a tailings impoundment consists of integrating many alternatives for the various systems so that a site- specific design can be developed. This section will review a number of these options and how they have been applied in the industry.

#### 8.5.5.1 Site Selection and Characterization

Site selection and characterization is typically the first step in the overall design process. Site selection can be an informal process or can also follow a much more formal approach. Van Zyl and Robertson (1980) and Vick (1990) describe typical approaches to site selection of tailings impoundments. The site selection process described by Crouch and Poulter (1983) is fairly representative. This process consists of the seven steps listed below:

Regional screening to eliminate unsuitable areas and locate potential sites.
Elimination of sites with obvious environmental constraints.
Qualitative ranking of site evaluation criteria.
Quantitative ranking of sites.
Field investigation of top ranking sites.
Evaluation of field data.
Selection of preferred sites.

Typical criteria used in the regional screening step are summarized below:

Distance from the mine and mill
Topographic features
Climatic features
Land use and ecologic features
Hydrologic conditions
Geologic features
Possible zones of mineralization

Examples of unfavorable topographic features could include areas with difficult access and terrain too steep for earthwork or liner installation. Climatic features could include areas subjected to high winds, deep snowfalls, excessive precipitation, or freezing conditions. Important recreational areas, critical wildlife habitat, areas with sensitive ecosystems and areas of archaeological or ethnographic significance are examples of possible land use and ecologic features. Hydrologic conditions could include excessive upgradient catchment area, unfavorable water balance due to climatic conditions or pit dewatering requirements and poor conditions for surface water diversions. Geologic features could include active faults, landslides, karst terrain and unstable or unsatisfactory foundation materials.

Typical criteria used in the fatal flaw screening step are listed below:

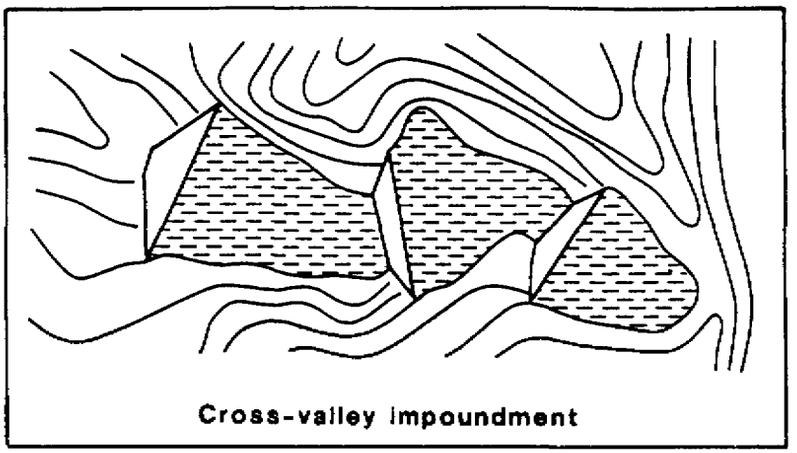
Visual impact
Land use and ecologic features
Airborne release potential
Surface water discharge potential
Seepage release potential
Stability
Site storage capacity
Site access
Development and operating costs

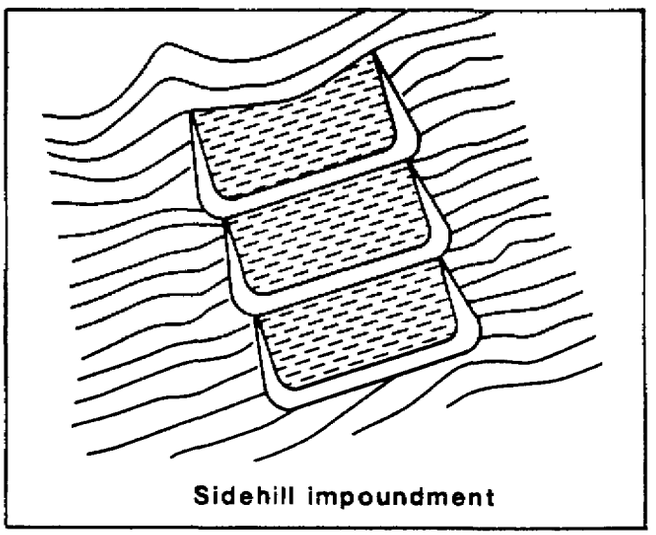
Site characteristics of interest are summarized below:

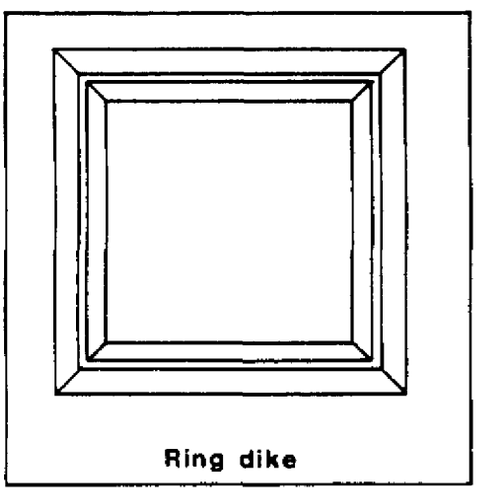
Impoundment maximum volume
Impoundment area
Embankment height
Embankment volume
Catchment area
Ratio - catchment/impoundment area
Distance from the mill
Elevation change to mill
Distance to major creek
Nearest residence
Geology
Depth to groundwater
Ownership
Valley geometry
Land use
Access

Proximity to the mill has always been an economic advantage in tailings impoundment siting. Shorter pumping distances are required and operational controls are easier to institute. Topographic features must be considered in site selection. This issue is obviously closely related to the type of impoundment and deposition method which will be considered. In the case of a cross valley impoundment, it is always better to site a new impoundment close to the drainage divide so that the upstream catchment area is limited. Impoundment sizing, associated freeboard, and potential water diversions are functions of the site climatology and hydrology. These issues must be considered during site selection and site characterization.

Impoundment foundation conditions are related to the site geology. A thorough understanding of site geology should be developed during the site characterization and can also be a discriminating factor in terms of site selection. For example, it would be more advantageous



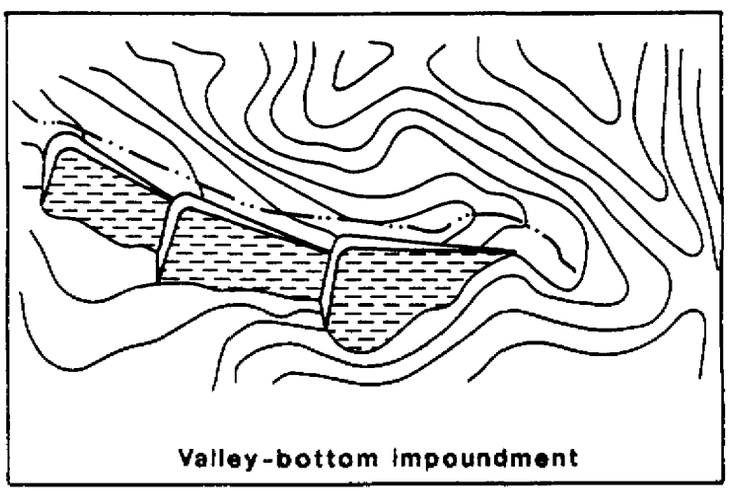




**Figure 6** Examples of impoundment types.

to locate the tailings impoundment over a low permeability formation such as shale and mudstone than to place it on an alluvial formation. If both such formations are available at the same distance from the mine, then the site with the most favorable geologic foundation conditions should be selected. Geologic

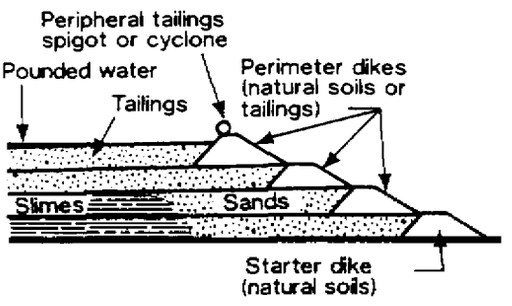
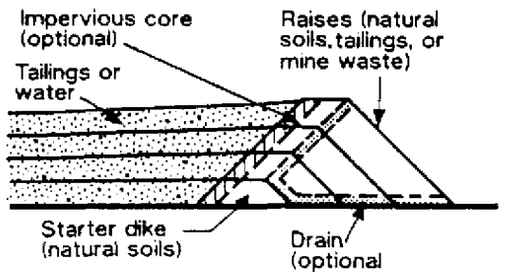
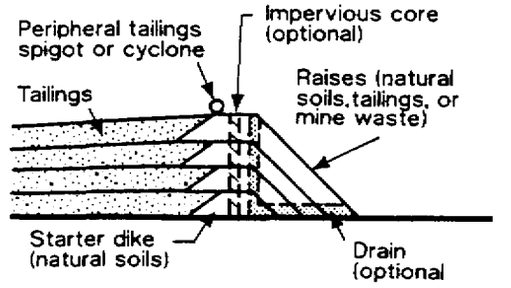
| DAM TYPE | ADVANTAGES | DISADVANTAGES |
|---|---|---|
| **Upstream Method**   | 1. Requires least quantity Of dike fill material<br>2. Often least costly method | 1. Requires careful attention and control of tailings discharge and water decanting<br>2. Rate of height increase may be limited<br>3. Not well suited to large runoff inflows or water storage<br>4. May be susceptible to liquefaction in high seismic areas |
| **Downstream Method**   | 1. Compatible with any type of tailings<br>2. Can be used for water storage<br>3. Good seismic resistance | 1. requires greatest quantity of dam fill<br>2. Dam fill volumes increase for each successive raise<br>3. Often most costly method |
| **Centerline Method**   | Shares both advantages and disadvantages of upstream and downstream methods | |

**Figure 9** Typical sections embankments.

hazards must be identified. Such geologic hazards can include active faults, landslides, glaciers, solution cavities (karst), collapsible soils, very pervious foundation materials, low strength foundation materials and dispersive soils, amongst others. The potential impact of geologic hazards on the operational and longer term stability of the tailings impoundment must be considered.

The site hydrogeology must also be evaluated at an early stage to understand the potential for geologic containment, contaminant migration, groundwater contamination and related issues.

### 8.5.5.2 Impoundment Types

Tailings impoundment geometry is generally dictated by the topographic conditions at the site. General impoundment categories include:

Cross valley
Sidehill
Ring dikes
Valley-bottom

Examples of each of these impoundment types are shown on Figure 8.

Cross-valley impoundments are most appropriate for incised drainages in hilly terrain and generally provide a large volume of tailings storage per unit volume of embankment construction. The need to divert or store storm flows from the upgradient catchment is the most common limitation on use of this impoundment type.

Sidehill impoundments typically have three sides and are most appropriate on outwash pediments or other sites with large expanses of sloping terrain and relatively constant slope. Storage efficiency is generally lower than for cross valley impoundments but storm diversion and storage requirements are usually smaller.

Ring dike impoundments are fully enclosed by embankments and are most appropriate for flat terrain. This category has the smallest storm diversion and storage requirements but storage efficiency is usually low, particularly for segmented impoundments.

The fourth category, valley-bottom impoundments is a variation of the cross-valley and sidehill layouts identified by Vick (1990). Storage efficiency is similar to sidehill layouts but the valley-bottom configuration allows for diversion of stormwater flows between the impoundment and the opposite valley wall.

### 8.5.5.3 Embankment Types

Tailings impoundments can be constructed using tailing sand or borrow materials. Tailings have been used as construction material in many historical tailings impoundments and are still used for the construction of embankments to contain flotation tailings impoundments. Compacted borrow materials are typically used for the construction of embankments to contain tailings containing residual extraction chemicals such as cyanide. Soil and/or synthetic liner systems are often included in the embankment design for non-flotation tailings. General embankment types include upstream, centerline and downstream

Figure 9 provides typical sections of these embankments as well as the listing of their advantages and disadvantages, after Vick (1981). Selection of any of these three construction methods is determined by the amount of coarse tailings material or natural soil available for embankment construction, as well as the potential for seismic loading in the area. Downstream construction requires the most tailings sand or borrow but results in a well-drained embankment with higher stability during seismic loading. Upstream construction requires the least embankment material but is typically not recommended for areas of high seismicity because of the potential for embankment instability following liquefaction of the tailings in response to earthquake shaking.

### 8.5.5.4 Liner Applications

Liner systems have been proposed and used extensively for the containment of uranium and cyanided tailings from precious metal mines. The liners are installed to prevent seepage losses of contaminants during operations as well as in the long-term. In order to enhance drainage during operations and also to expedite reclamation after operations a drain layer is often constructed on top of the liner. Another major advantage of a drain layer on top of the liner is that low hydraulic heads are maintained on the liner during operation thereby reducing the potential leakage from the impoundment (Cincilla et al., 1991). Various liner materials can be used for tailings impoundments as long as they are compatible with site-specific requirements such as expected loading and deformation conditions, exposure to weather, sunlight and ultraviolet radiation, and stability. A more detailed discussion of liner materials and liner system design is presented in Section 8.4.

### 8.5.5.5 Deposition Methods

Deposition methods for dilute slurried tailings include single point discharge, spigots, and cyclones. For single point discharge systems the tailings are discharged into the impoundment from one or two points and very little control is exercised on the pool location as well as beach formation. Usually the discharge point is located along or near the main embankment to form a beach and thereby minimize potential for pooling of the tailings liquids against the embankment. This simplifies embankment design as the hydraulic gradients and potential for seepage through or under the structure significantly reduced. In addition, this configuration generally provides the largest volume for stormwater storage. However, some facilities are designed to operate with the discharge point located away from the embankment and tailings liquids pooled against the structure. In this case more attention must be paid to surface water diversions and stormwater storage, and the embankment must be designed to withstand higher hydraulic gradients.

For spigot systems a series of point discharges are located along the tailings embankment and potentially elsewhere along the impoundment circumference. Tailings deposition is carefully managed by opening a small number of spigots at any one time allowing the correct combination of tailings discharge velocity and slurry density to develop and maintain the desired beach. For example, by reducing the discharge velocity through using more spigots for discharge, a steeper beach is formed than when higher discharge velocities are maintained. This method allows extensive control over beach formation and pool location.

Cyclones are simple mechanical devices without moving parts which allow for the separation of coarse and fine materials through centrifugal forces. A section through a typical cyclone is shown in Figure 10. Through centrifugal forces the coarse product is separated from the fines and discharged at a relatively low moisture content through the bottom of the cyclone. This product known as underflow can then be stacked to form the sand portions of the various embankment types described in

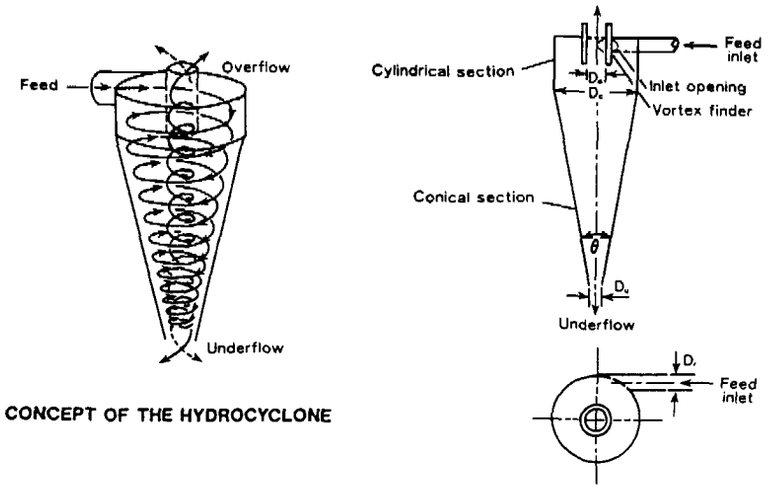



**Figure 10** Section through cyclone.

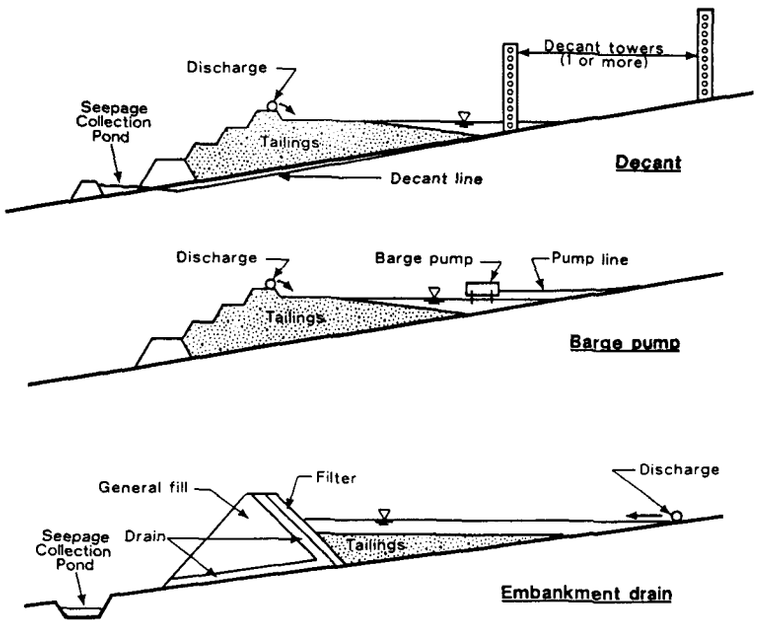



**Figure 11** Floating barge, decant tower, embankment drain systems.

Section 8.5.4.3. The overflow, or fine product, is discharged to the tailings pool away from the sand embankment.

Tailings deposition can be managed to be subaerial (under air) or subaqueous (under water). The management of such deposition is done through control of the pond size as well as the depositional pattern. Subaerial deposition has the advantage that evaporative drying of the tailings surface can increase the overall density of deposited tailings. Such evaporative drying is not effective in all climates and careful evaluation is necessary before a subaerial management system is implemented. If the annual evaporation rate is low and the precipitation is high then it is less certain that subaerial deposition techniques will succeed. In the case

of potentially acid generating tailings, it has been found that subaerial deposition or cyclone deposition can lead to acid generation of the materials subjected to continual wetting and drying.

Subaqueous deposition is typically practiced for control of acid generation or for dust control. For example, subaqueous deposition is used at the Cyprus Northshore Mine in Minnesota to reduce the potential for aerial transport of dust. In Canada subaqueous deposition has been practiced by discharging tailings into lakes, however, the long-term maintenance of the tailings in a saturated condition in lined impoundments constructed above the local groundwater level is a concern and warrants careful evaluation.

The thickened method described in section 8.5.3 typically uses a single point discharge if a conical pile is desired of multiple points if a more planar surface is desired.

Deposition methods for dry tailings are described below in Sections 8.5.6 and 8.5.7.

### 8.5.5.6 Decant Methods

The supernatant remaining after sedimentation of the tailings as well as precipitation falling on the tailings impoundment or runoff to the tailings impoundment is typically decanted for re-use in the mill. It is also possible that such decanted tailings solution can be treated and discharged to the environment. Typical decant methods include floating barges, decant towers, and embankment drains. These systems are depicted in Figure 11.

Floating barge systems can be used successfully, however, a high enough water pool must be maintained on the tailings to allow for efficient pump operations. The barge is typically anchored and is equipped with vertical turbine pumps for water return. The tailings water should be free of sediments otherwise excessive wear of the pump components can occur.

Decant towers can take on many different forms. These range from vertical penstocks where inlet height is controlled by closing holes at various elevations or adding rings to the penstock to make it higher. Such penstocks must always be accessible and catwalks are typically used for such access. In sloping terrain, decant towers can be constructed against the sloping hillside and accessed from the top through a ladder. The water level can then be controlled by inserting wooden slats or other devices in the decant tower.

Embankment drains can be used as a decant. In this case deposition must take place away from the embankment and flow must be towards the embankment. The slimes will therefore collect against the embankment and the supernatant will be drained off. Although this system seems to work well in theory, there are a number of practical issues which must be considered. Geotextile materials have been used to cover the embankment drain, thereby reducing the possibility of decanting turbid tailings water. The problem is the geotextile can clog and prevent drainage from occurring efficiently. Even in the case of granular filters, it is possible that either drainage will not be efficient or that some turbidity will be released from the tailings impoundment. The continued operation of this system is also dependent on the outlet pipes not being damaged due to embankment loading. The biggest advantage of an embankment drain is that it requires very little operational maintenance if it operates as intended with all drainage by gravity flow. It is necessary to install a collection pond downstream of the tailings impoundment to collect the decant water. A pump system is then required from this pond to return the water to the mill.

### 8.5.5.7 Design Considerations

Tailings impoundment design requires knowledge of site characteristics and tailings characteristics, combined with knowledge of the regulatory requirements and understanding of the available disposal technologies. Knowledge of the performance of existing and historic tailings impoundments is also critical to the success of the design process. USCOLD (1994) presents data on reported tailings dam failures by cause, including overtopping, slope instability, earthquake, foundation, seepage, structural, erosion, mine subsidence, and unknown.

Initially, the storage capacity of the site must be evaluated to ascertain if sufficient capacity is available for planned production and reasonably foreseeable expansions. The available storage capacity must also include an allowance for stormwater storage, wave runup and freeboard. This will require an evaluation of site hydrology and topography to determine the size and location of surface water diversions and the volume of water to be stored. Data presented by USCOLD (1994) for both active and inactive impoundments, indicates that insufficient freeboard for water storage leading to overtopping has been the primary cause for at least 16 percent of reported tailings dam failures.

Tailings chemistry must be evaluated to determine containment requirements. The permeability of the native foundation materials will also impact possible liner requirements. If the tailings are sufficiently benign chemically for the sand fraction to be used for embankment construction, a cyclone study must be completed. The relative proportions of tailings sands and slimes and the schedule for production may then dictate the type of embankment selected and the need for alternate construction materials such as waste rock or borrow. If the tailings are not chemically benign, containment consisting of a liner system will probably be required and the tailings sand fraction will probably

not be available for embankment construction.

In addition to having sufficient storage capacity the tailings embankment must be stable under both static and earthquake loading conditions. The USCOLD data (USCOLD, 1994) indicates that at least 22 percent of reported tailings dam failures have been caused by slope instability with another 17 percent caused by the effects of earthquake shaking. Consolidation and/or compression of the materials underlying the embankment and impoundment must be restricted to ranges acceptable for retention of continuity of liner systems and outlet pipes. The proposed filling rate must then be evaluated to determine if the rate of rise of the tailings surface will allow drainage of the recently deposited tailings and dissipation of induced pore pressures in the buried tailings. The location of the phreatic surface must be controlled to maintain embankment stability and minimize the potential for seepage from the face of the embankment. Control methods include maintenance of an adequate beach between the embankment and tailings pond, liner systems to inhibit seepage, filters to prevent particle migration and drains to intercept and direct seepage flow. The USCOLD data (USCOLD, 1994) indicates that at least 9 percent of reported tailings dam failures have been caused by seepage.

The design should be evaluated for constructibility and expected operating requirements. Simpler construction and operating requirements may lead to a more successful facility and result in significant cost savings over the long-term. More complex systems may be appropriate but should only be implemented based on a clear understanding of the operating requirements. Geotechnical instrumentation should be included in the design to allow monitoring of facility performance. Instrumentation is described in Section 8.5.5.9.

### 8.5.5.8 Analytical Methods

Analyses to support tailings impoundment design can be grouped into four general categories: volumetric/mass balance analyses, hydrologic analyses, geotechnical analyses, and geochemical analyses.

Volumetric/mass balance analyses are used primarily in support of the site selection, impoundment sizing, embankment type selection, and cost estimating processes. The hydrologic analyses are used primarily in support of the evaluation of freeboard and surface water diversion requirements and the evaluation of liner requirements based on potential groundwater impacts. The geotechnical analyses are used primarily to evaluate the overall stability of the impoundment structures, the engineering characteristics of the tailings at selected stages of the impoundment life and the structural requirements to inhibit or control seepage.

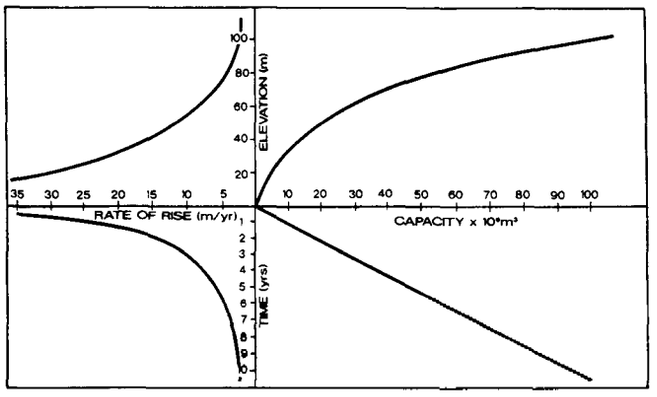
Geochemical analyses, used to evaluate potential impacts to human health and the environment due to toxicity, are critical to the selection of pre-discharge tailings treatment systems and the design of containment systems at the impoundment. These analyses include chemical characterization of the tailings in the as-discharged state plus analyses used to evaluate possible future behavior related to generation of acid rock drainage. Analyses to evaluate the chemical attenuation capabilities of soil liner materials or soils beneath the impoundment may also be completed. The geochemical test methods and predictive techniques are described in Section 7.2.1.

*Volumetric/Mass Balance Analyses* - Simple volumetric calculations are used during the site selection process to evaluate storage volumes and associated embankment heights. These calculations are typically generated using large scale topographic maps with 40-foot contour intervals. Because great accuracy is not necessary at this stage of the design process equations based on approximate geometric forms such as cones and pyramids can often be used to estimate volumes. Alternatively, the average end area method or refinements of this method can be used to calculate volumes after dividing the impoundment into vertical or horizontal layers. Once a preferred site (or sites) has been selected more accurate topographic information is obtained and the same methods are used to develop more accurate volume estimates. These methods have been incorporated into many computer codes and are widely available in forms which are compatible with computerized topographic data systems. Use of the computerized systems allows rapid calculation of storage volumes and construction volumes during the design process.

Once the volumetric characteristics of the impoundment and embankment structures are established the tailings production rate and deposition behavior can be used to generate stage diagrams. An example of a stage diagram is shown on Figure 12. Stage diagrams are used to evaluate embankment height requirements and tailings rate of rise at various stages of mine life. The results of hydrologic analyses such as freeboard requirements and accumulated free water storage are typically superimposed on the tailings curves to provide an indication of total required storage at any given time.

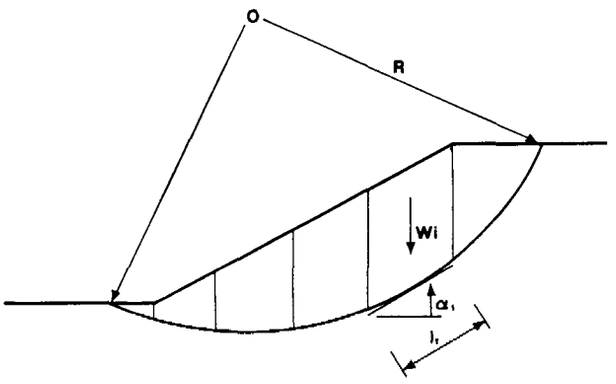
*Hydrologic Analyses* - Hydrologic analyses for surface water include sizing and routing inflow design floods, hydraulic sizing of water transmission and diversion structures and water balance analyses. These analyses are described in Section 8.8.

Hydrologic analyses for groundwater include saturated and unsaturated flow modeling which may be coupled with contaminant transport and attenuation analyses. Detailed discussion of these analyses is beyond the scope of this chapter. However, many references on this subject are available including Vick (1990), Freeze and Cherry




THE STANDARD STAGE CURVE
(After Caldwell and Smith , undated)

**Figure 12** Stage diagram.




EXAMPLE STABILITY GEOMETRY

**Figure 13** Slope and slip surface geometry.

(1979), and McWhorter and Nelson (1979).

*Geotechnical Analyses* - Stability evaluations include static and dynamic analyses to address critical stages of embankment construction, operation and closure under static and earthquake loading conditions. Static analyses typically focus on stability during mining operations, stability at closure, and long-term post-closure stability. Many references are available on this subject including Morgenstern and Sangray (1978), Vick (1990), Ladd (1991), Johnson (1974) and U.S. Army Corps of Engineers (1970). These analyses use limit equilibrium methods to calculate a stability factor of safety. Morgenstern and Sangray (1978) have defined factor of safety as "that factor by which the shear strength parameters may be reduced in order to bring the slope into a state of limiting equilibrium along a given slip surface." The shear strength parameters may be based on total stress or effective stress. If effective stress parameters are used pore pressures must also be evaluated for input to the analyses. An example of slope and slip surface geometry for input to an analysis using the method of slices is shown on Figure 13. This method, applied to an upstream tailings embankment is shown on Figure 14.

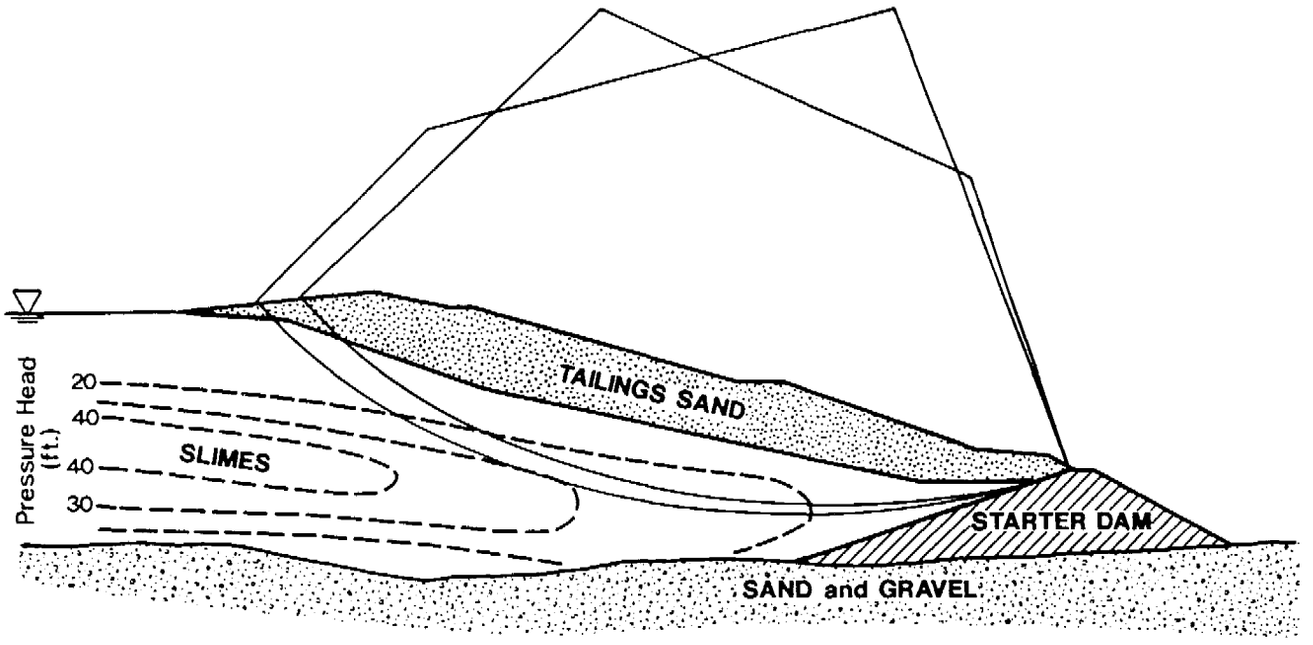
Static analyses should also consider the potential for liquefaction of the tailings under static loading conditions. This phenomenon, which is less common than liquefaction under dynamic loading conditions, can occur when tailings or soils subject to strain-softening are sheared beyond their peak strength.

Liquefaction has been defined by Poulos et al., (1985) as "a phenomenon wherein the shear resistance of a mass of soil decreases when subjected to monotonic, cyclic, or dynamic loading at constant volume." If the shear strength of the tailings, embankment or foundation materials are reduced below the prevailing shear stresses they may experience large strains with the appearance of flow, possible leading to failure of the tailings impoundment and downstream release of a large quantity of tailings. Examples of tailings flow failures are presented by Berti et al., (1988) for the Prestavel Mine at Stava de Tesero, Italy, and Jennings (1979) for the Bafokeng slimes dam in South Africa. Methods for estimating tailings flow failure runout distances under certain conditions are presented by Lucia (1981) and Vick (1991).

Dynamic stability evaluations typically address potential for loss of shear strength due to liquefaction of tailings and other granular materials under earthquake loading and subsequent impacts on structural deformation and factors of safety from limit equilibrium analyses. The appropriate earthquake loading for design is site-specific and is obtained using deterministic or probabilistic methods. Deterministic methods rely primarily on energy attenuation relationships to translate earthquake accelerations from known active faults to the site. Probabilistic methods rely primarily on historical earthquake records to develop acceleration-frequency relationships for broad areas and specific sites. Many references are available on seismicity including Slemmons (1977) and Algermissen et al., (1982 and 1990).

Historically, limit equilibrium stability analyses modified to incorporate a factored horizontal loading were used to evaluate embankment stability under earthquake loading conditions. This procedure, known as a pseudo-static stability analysis, is not appropriate for embankments containing or founded on materials which may lose shear strength or liquefy under cyclic loading. For non-liquefiable materials the method is still used by some practitioners as a general indicator of overall stability and as input to embankment deformation analyses.

If liquefiable materials are believed to be present in the embankment or foundation the potential for structural




**TYPICAL SLIP SURFACES FOR AN UPSTREAM TAILINGS DAM**
(After Ladd, 1986)

**Figure 14** Slope and slip surface geometry/upstream tailings embankment.

failure or damage may be evaluated initially using an empirical screening relationship presented by Smart and Von Thun (1983) for water storage dams and developed further by Conlin (1987) for tailings impoundments. This method uses a plot of earthquake magnitude versus epicentral distance for historic earthquake events at sites susceptible to liquefaction as an indicator of liquefaction potential at any proposed site. If this magnitude and distance point for a proposed site falls within the no liquefaction zone further analyses are probably not necessary. If the point falls within the zone of possible liquefaction, a more extensive analytical effort will be necessary.

The resistance of tailings and soil materials to liquefaction can be evaluated either by testing representative and undisturbed samples in the laboratory or through the use of in-situ tests such as the Standard Penetration Test (SPT) or the Cone Penetration Test (CPT). Seed and Harder (1990) present an SPT-based method for liquefaction analysis and determination of post- liquefaction residual strengths which is generally applicable to tailings impoundments.

If liquefaction is unlikely stability can be evaluated using the limit equilibrium techniques and shear strengths used for static stability analyses with the addition of pseudo-static analyses. If the pseudo-static analysis factor of safety is low, deformation analyses may be necessary to evaluate available freeboard following earthquake shaking. If liquefaction is likely, stability can be evaluated using limit equilibrium techniques and residual shear strengths. Deformation analyses are likely to be more critical for this case than for the no-liquefaction case.

Deformation analysis techniques range from relatively simple methods relying on sliding block models or pseudo-static methods to more complicated models relying on computerized finite element and finite difference solutions. Descriptions of some of the simpler methods are provided by Newmark (1965), Sarma (1975) and Makdisi and Seed (1977). Finn (1987) provides a summary of some of the more complicated methods.

Consolidation and settlement analyses are often necessary to evaluate the final expected density in the tailings impoundment as well as the amount of settlement that may be expected after deposition ceases or due to the placement of a cap. A realistic evaluation of consolidation can only be done using the unrestricted or finite strain consolidation theories originally published by Gibson et al., (1967 and 1981). In this case it is necessary to know the relationship between hydraulic conductivity and void ratio as well as effective stress and void ratio. Such analyses are very useful in the overall evaluation of tailings consolidation and potential seepage losses induced by consolidation (Caldwell et al., 1984).

Schiffman and Carrier (1990) describe the use of these analyses in tailings impoundment design.

Seepage analyses must be performed for tailings impoundments to evaluate the pore pressure conditions to be expected for the stability analyses as well as estimating seepage losses from the impoundment. Originally, hand-drawn flow nets were used to evaluate flow gradients and seepage quantities. Terzaghi and Peck (1967) and Cedargren (1977) provide descriptions of the flow net method. In the case of simple boundary conditions analytical methods can be used as described by Van Zyl and Harr (1977). Computerized finite element and finite difference methods are also available for more complicated analyses.

Water balance evaluations must be performed to determine the amount of decant water available to the plant, amount of decant water which may have to be treated and discharged and to evaluate water supply requirements for the project. Water balance evaluations are further discussed in Section 8.8.

#### 8.5.5.9 Performance Monitoring

The design should incorporate geotechnical instrumentation located to evaluate the performance during construction, operation and closure of critical facility components. Many references are available on geotechnical instrumentation including Dunnicliff (1988) and Bartholomew, et al., (1987). Typically instrumentation is installed to monitor total stress, pore pressures, settlement, and slope movements. Total stress measurements may be valuable in the vicinity of buried structures such as decant towers and outlet pipes to assist in evaluation of their performance. Pore pressure measurements are a relatively common performance monitoring tool and are obtained from many locations including within the embankment, the foundation and the deposited tailings mass. Settlement measurements may be valuable in evaluating the consolidation of the tailings and movement of the embankment and buried structures. Slope movement measurements are used to detect translational or rotational movement of the embankment.

#### 8.5.5.10 Closure/Reclamation

After completion of mining, the tailings impoundment must be closed and reclaimed so as to retain physical stability, chemical stability, protect human health and the environment, and satisfy the selected land use. Planning for such closure should start at the beginning of the project and not when mining has ceased. A number of activities are necessary to complete closure and reclamation. These activities are discussed in this section.

The remaining free water on the tailings impoundment must be decanted and discharged or treated before discharge. Evaporation can also be used as a method of dewatering the surface of the tailings impoundment if climatic conditions at the site are appropriate. After removing the water from the surface it is necessary to recontour the surface to fit in with the surface drainage plan developed for the site. In some instances, it is acceptable to have some water storage on the impoundment while in other cases, positive drainage should be maintained. The latter is especially true if recharge through the tailings could lead to unacceptable leachate quality.

After contouring of the surface some treatment may be required. In areas of low precipitation where wind erosion is the biggest problem with respect to stability of the tailings impoundment as well as being a nuisance, covering the tailings with waste rock may be sufficient surface treatment. Revegetation of the tailings impoundment can be done if it is part of the overall closure plan. There are sites where revegetation of the tailings impoundment may not be necessary for acceptable closure as long as wind and water erosion can be limited.

The design and construction of covers for tailings impoundments is a complex topic which must be considered on a site- specific basis. Depending upon the tailings characteristics, site-specific climatic conditions, and regulatory requirements, acceptable cover systems may range from a single layer of soil as a growth medium to a more complex, multi-layer cover incorporating stabilization layers for support of construction traffic, seepage barriers, drainage layers, capillary breaks and root barriers. Very often it is necessary to wait for a period after ceasing mining to allow for consolidation and settlement of the tailings surface so that any cover will be protected in the long-term. This waiting period in some cases be as long as five years. Closure requirements are discussed in considerable detail in Hutchison and Ellison (1992).

### 8.5.6 UNDERGROUND BACKFILLING

Underground mine backfilling has been used as: a work platform, ground support, an aid to ventilation control, overall ground (subsidence) control, and a means of minimizing surface waste disposal impacts. Backfill is defined as "waste sand or rock used to support the roof after removal of ore from stope" (Thrush, et al., 1968). Since the dictionary was compiled in 1968, backfill material has included much more than sand or rock, and has done much more than supported the roof. There are a number of specific mining methods utilizing backfill as part of the system. Choosing a mining technique depends on, but is not limited to: depth of the deposit, the shape and spacial orientation of the orebody, operators' preference and experience, available machinery, milling

and processing, regulatory requirements, etc. It is not the intent of this section to describe mining techniques in detail. The reader is guided to more comprehensive literature such as SME Underground Mining Methods Handbook (Hustrulid, 1982) or specific topic forums such as the International Mining With Backfill conferences such as Innovations in Mining Backfill Technology (Hassani, et al., (ed), 1989), or Backfill in South African Mines (SAIMM, 1988).

Backfill material types range from mine waste products such as mill tailings and development waste, to quarried sands and rock. The environmental considerations for active mines will depend on the reactivity of the placed material, the reactivity of the surrounding rock, and the ambient conditions surrounding the backfilled stope (e.g. saturation, ventilation, etc). Backfill additive materials such as portland cement or flyash may add structural competency, but it is important to note that the additives have the potential to interact with the underground environment. For example, additives may provide buffering to acid drainage, decrease the porosity of the mass, or interact to cause vapors that may be of concern. Interactions may be due to the chemical activity, large surface area of small particles, and oxygen and water availability. Oxidation of the exposed surfaces causes oxygen depletion (Bayah et al., 1984), spontaneous combustion (Rosenblum et al., 1982), or acid mine drainage and resultant heavy metal mobilization (Doepker, 1989).

Classified mill tailings or "sandfill" has historically been used as a backfill material in underground metal mines. It is the coarse fraction of cycloned or otherwise classified processed mill wastes. It is used for ground support or ground control, a working floor, a means of waste disposal, control of ventilation, and surface subsidence prevention. Hydraulic transportation techniques of mill tailings have been well developed and documented and has seen widespread application by the industry. The physical nature of this technique places certain limitations on the design of the delivery system and the materials which may be transported. Particle size and velocity must be carefully controlled to eliminate settling and the potential for plugging. The amount of slimes, or fine fraction, is limited so that the water can be decanted and the consolidation can rapidly occur once the fill is placed in the stope. Fill of this type requires engineered structures such as bulkheads, drains, and decants for confinement, as well as release excess water (Smith and Mitchell, 1982). The slimes or fines (minus 0.002 mm diameter) of the mill tailings are separated from the mill stream by hydrocyclones. The overflow, or fines are then sent to surface ponds for disposal. The underflow, or coarse sands are mixed with make-up water and "flushed" underground through a series of pipes to the targeted stope for backfill. Typically, hydraulically transported, classified sandfill is between 60 and 75 percent pulp density. Mitchell and Smith (1979) presented calculations to determine hydraulic material volumes from mill streams, drainage requirements, and recommended laboratory testing.

More recently, dewatered total mill tailings or "paste fills" have been used for fill. This type of material is mechanically dewatered, usually by vacuum filters which retains much of the slimes fraction. Because most of the slimes are retained in this dewatering process, the material has a low porosity and does not dewater or consolidate quickly merely via gravity. Therefore there is a need for removing as much of the water as possible. Additionally, cement is added for structural strength. Cement also utilizes residual pore waters during hydration, thus the removal of "free" water from the fill is not required. The paste- consistency material, consisting of about 80 percent pulp density, is transported by positive displacement pumps (Vickery and Boldt, 1989). Total tailings, "paste" backfill has a low permeability, which restricts groundwater flow and related heavy metal contaminant dissolution and migration through the mass. Possible variations in concentration of heavy metals in the coarse and fine fractions dictate care in determining the contaminant potential of various particle size fractions. Inorganic precipitates have been absorbed more on the silt-sized portion than on the sand particles (Brookins et al., 1982; Thompson et al., 1984 and 1986). Paste fills introduce less water into the active underground mine environment, and reduced surface tailings disposal volumes. There is, however, more water taken from the tailings on the surface during the filtering operation which must be dealt with effectively, either by recycling to the mill or disposing of in an environmentally acceptable manner.

### 8.5.7 ABOVE GROUND DRY TAILINGS DISPOSAL

Dry disposal, dewatered tailings, or paste fill is the result of special mechanical drying of the tailings slurry. Such drying could occur by more natural means such as gravity drainage and enhanced evaporation, however, in order to treat relatively large production rates, it is necessary to have mechanical equipment. A summary of equipment available as well as the disposal process has been provided by Robertson, Fisher and Van Zyl (1982).

The most common methods of moisture removal are filter presses and belt filters. In the case of filter presses, a pressure technique is used to remove the moisture while in the belt filter a vacuum is applied below a slow moving porous belt on which the material is spread and dried. The filter cake is discharged at the end of the belt and must be moved from that point. Pumping of a tailings paste is possible using special displacement pumps.

The capital cost associated with belt filters or filter

presses is relatively high and the operating costs are also higher than a regular low density slurry tailings disposal.

It must be noted that paste backfill is taking on very high importance in underground mining for stability and environmental reasons and therefore many underground mining facilities have equipment available to allow dewatering of the tailings. In the past some facilities have re-slurried the tailings in the plant instead of considering the dry tailings directly for disposal.

Apart from pumping the tailings with special equipment it is also common to transport the dry tailings on the back of a truck or on a conveyor. Winter operations are often difficult because of freezing conditions, especially on conveyor belts it is difficult to maintain the material in an unfrozen state.

When the material has reached the disposal site, it is typically unloaded and placed with earthmoving equipment. The tailings are compacted in the process and a modified surface impoundment is formed. Figure 15 shows a typical surface impoundment of dry tailings.

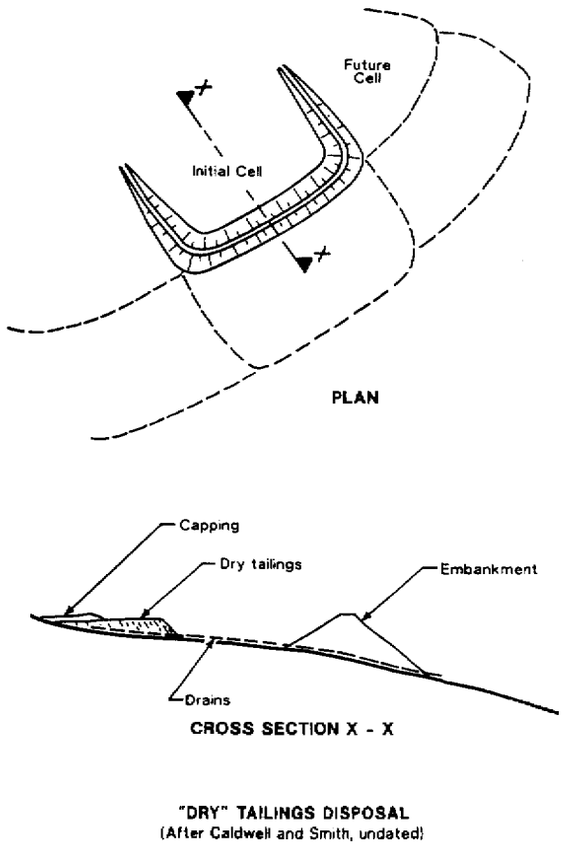



**Figure 15** Typical surface impoundment of dry tailings.

A big advantage of dry tailings is that ongoing reclamation can be performed thereby reducing the size of the disturbed area at any one time. The surface of the impoundment area can be covered with growth medium and vegetated as the facility develops.

Examples of two applications of dry tailings are the Green's Creek Mine on Admiralty Island in Alaska and the Jardine Mine near Gardiner, Montana. In both of these cases, more tailings liquid is discharged from the tailings than originally expected under gravity drainage. The design of the underdrain system to accommodate such drainage is a very important of the total design. The surface facility can further also be stabilized using cement as an additive to the tailings.

## 8.6 WASTE ROCK DISPOSAL DESIGN

**by A. Kent**

This section describes and discusses current design approaches for mine waste rock disposal facilities ranging from piles up to 500m high located in steep mountainous terrain to mine overburden soil placed in 5m thick layers over weak alluvium. Consequence-based risk analysis is suggested in response to environmental criticism of rock pile failures. Potentially, the economic health of the mining industry in some parts of the world depends upon a rational acceptance of the possibility of failures, and their consequences under controlled circumstances.

Mine rock dumps over 500m high have been constructed or are being planned. Apart from very high dumps, disposal of very weak or highly weathered mine overburden presents challenges with respect to physical stability and environmental control. This section discusses practical experience, and attendant geotechnical issues, affecting mine overburden waste disposal and management.

Vandre (1986) has proposed the standardization of methods of geotechnical modeling, and recommended that accepted standards be upgraded as experience is gained. This approach is compatible with the Observational Method which requires the engineer to evaluate possible consequences of his design assumptions being in error. More severe consequences warrant either elevated scrutiny of the standardized analyses or elevated conservatism in setting the acceptance criteria for assessing the results of the analysis. This section is intended to promote appropriate standards of analysis based on carefully selected precedents since elevated conservatism has negative economic implications.

An increase in the frequency of waste dump failures has been observed in recent decades at coal mines in mountain terrain as production rates have increased. This elevated rate of failure may also correspond to increases in dump height, and rate of disposal (typically defined as volume per day per unit crest length). In British Columbia, (B.C.), Canada, the mining industry, regulatory agencies, consultants, and research groups

have responded at various levels to the actual and perceived problems caused by past failures and ongoing dumping practice. Most importantly, there has been an atmosphere of cooperation and exchange of experience between all parties with the objective of learning from past events and evaluating their real effects. A compilation and review of available data for coal mine dump performance and failures in B.C. was presented by Golder (1987), (1992a). Subsequently, in 1991 and 1992 interim design, operation, and monitoring guidelines were prepared (Piteau (1991), Klohn (1991), and HBT (1992)). In the U.S. various guidance documents for the design of mine dumps have been compiled e.g. Vandre (1981), U.S.D.A. Forest Service (1991).

Kent (1992) discusses a number of technical issues affecting mountain dumps. Mine waste rock disposal has evolved to the point where safety can be assured and the risks associated with mine waste management can be assessed qualitatively. The quantitative risk analysis of all major dumps is not yet practicable due to some unresolved technical issues. Confidence in the prediction of pore water pressures and of failure runout characteristics needs improvement based on well documented precedent.

The following sections describe in more detail the potential conditions which may be experienced at various dumping sites.

### 8.6.1 PLANNING PARAMETERS

Practicable geotechnical engineering must address the typical mining situations described in the following sections.

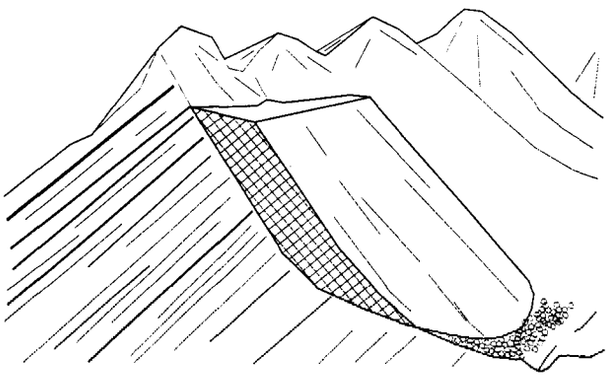


**Figure 16** Mountain dump scenario.

#### 8.6.1.1 Mountain Dumps

Large elevation changes in mountain terrain between pits and dump platforms may not be economic, as illustrated in Figure 16. High dump faces often may be feasible, even with some accepted risk of failure. Rehabilitation and re-activation of failed dumps typically is practicable. Maximum advantage of topographic containment should be taken. The use of wrap-around dumps to create a series of terraces for final dump surfaces is advisable to promote stability, erosion control, revegetation, wildlife habitat, and to reduce cost.

#### 8.6.1.2 Lowland Dumps

Where topographic relief is relatively flat, construction in thin lifts is practicable, as shown on Figure 17. This practice is compatible with mining economics and appropriate if weak alluvium is present. Also, reclamation and control of surface water is relatively straightforward.

#### 8.6.1.3 Dragline Spoils

Typically, large draglines create windrows of waste material up to about 30 to 40m high. Stability concerns usually are of a short-term nature until coal can be removed, and focus on the presence of weak footwall layers, as shown on Figure 18.

#### 8.6.1.4 Coarse Coal Wash Refuse

This material typically consists predominantly of sand and fine gravel sizes with variable amounts of fines. Design concerns include spontaneous combustion and the prevention of build-up of pore water pressures. This material is a useful construction material for tailings dams and for impact barriers. Erosion may not be a large problem if the coarse refuse is placed and compacted in relatively thin lifts, although it is difficult to revegetate.

#### 8.6.1.5 Process Slag Piles

Slag may be dumped molten or granulated, it is similar to coarse coal refuse but more durable. Foundation slopes typically are gentle for many slag or refuse piles. Deep foundation soil profiles consisting of fine grained soils may fail rapidly as the result of accumulating pore water pressure.

#### 8.6.1.6 Overburden Dozing

At some mines the upper barren portion of thick residual soil profiles, may be dozed down to loading points. Relatively rapid loading of benches in the residual soil may result in rapid failures affecting operator safety.

#### 8.6.1.7 Pit Backfilling

An ongoing sequence of mining and backfilling is practicable for some mines. Clearly, active mining beneath active dumping is unsafe. Undercutting inactive dumps is likely to be hazardous. Coarse competent mine

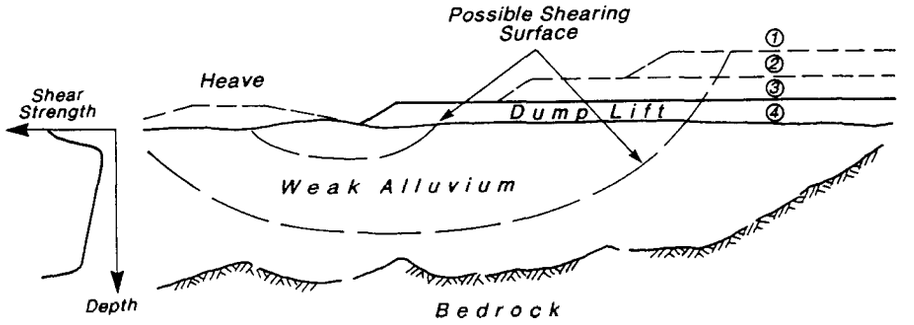



**Figure 17** Lowland dump scenario.

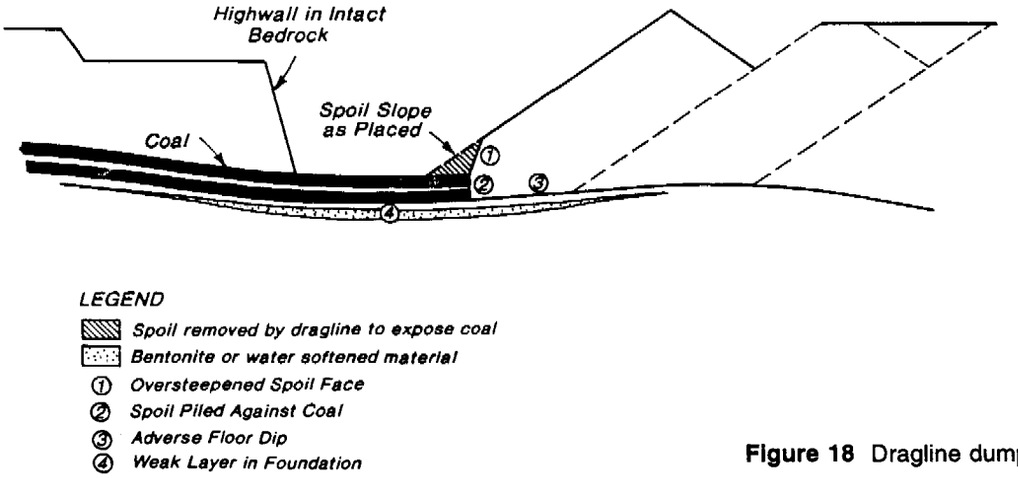



**Figure 18** Dragline dump scenario.

waste rock will remain stable on moderately steep footwalls inclined at up to about 30 degrees. Fine grained soil or weathered mine rock may remain stable in the short-term, but should be buttressed against completed highwalls in the long-term.

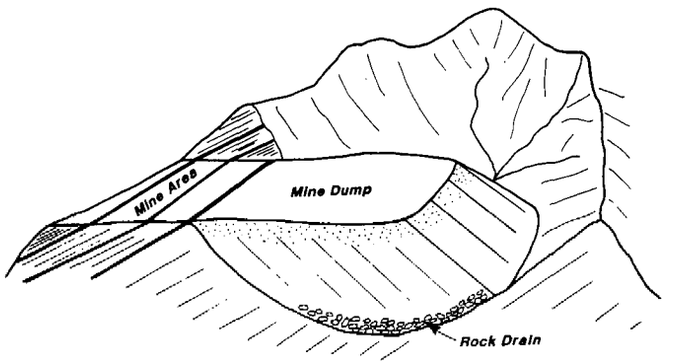



**Figure 19** Rock drain scenario.

### 8.6.1.8 Rock Drains

In mountain terrain valley fills may obstruct substantial drainage areas, as shown on Figure 19. Major rock drains are feasible, with certain controls and limitations, and ongoing research is addressing potential technical problems. Full scale instrumented trials are underway in B.C., justified by major economic and environmental implications. Routing of surface flows through abandoned pits or acceptance of some intermittent upstream inundation under extreme events should be considered by mine planners.

### 8.6.1.9 Reclamation

Resloping dump faces has become a normal expectation as part of reclamation planning. However, costs are high, potential for blocking underdrainage is significant, and creep and surficial slumping of surficial fines may occur. Long uniform slopes are susceptible to erosion and gullying even if resloped. Much can be learned by observing existing old waste piles. Resloping the terraces of wrap-around dumps is preferable to mass resloping of single long dump faces, as shown on Figure 20.

### 8.6.1.10 Haul Road Fills

Haul road fills on steep terrain should be monitored in

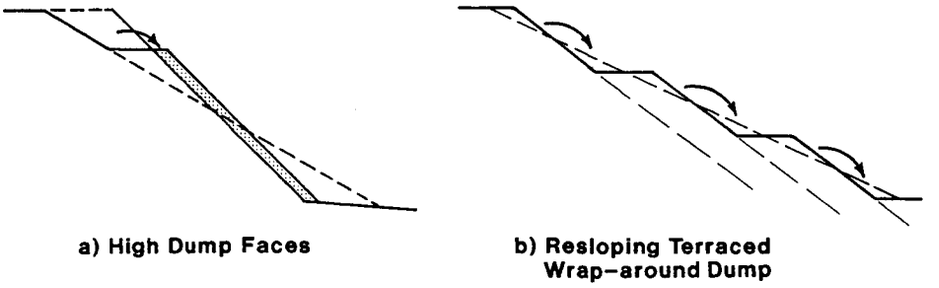



**Figure 20** Dump reclamation.



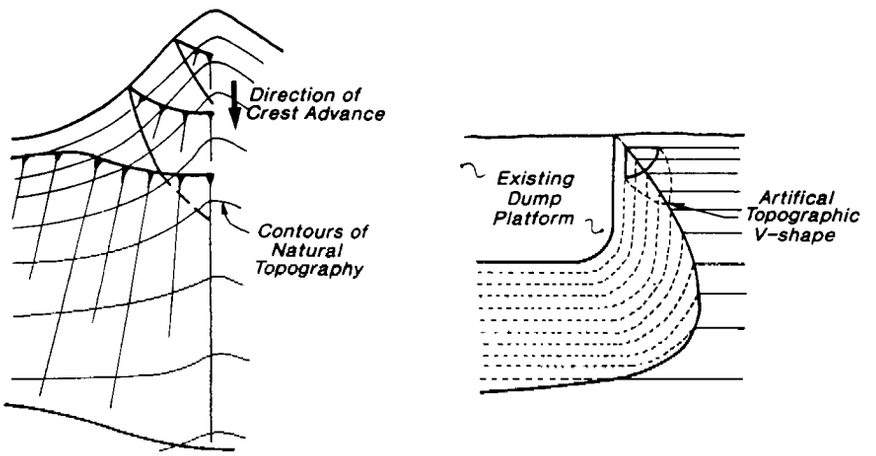




**Figure 21** Types of mountain dump sites.

the same way as abandoned spoils, particularly if mine or public infrastructure is present nearby in the path of potential failures.

### 8.6.1.11 Surface Water Control

Any measures which retard surface water flow velocities are desirable. Dump platforms should be graded away from dump faces. Terracing of dump faces controls erosion by slowing runoff and by trapping sediment eroded from the sloping face above.

### 8.6.1.12 Overburden Modeling

Modern mine planning computer software is capable of simulating the characteristics of overburden and interburden materials. Bench-scale modeling of the waste materials should be considered to provide a schedule of anticipated material quality. This schedule can be compared with the scheduled stages of dump development. Conflicts between material quality and critical items such as rock drain formation by segregation should be anticipated and resolved. This approach is preferable to attempting to impose material classification at the point of entry to the mine dump.

### 8.6.1.13 Operational Involvement

Dump development plans must be practical in terms of flexibility and monitoring. Operations personnel must be informed of critical aspects of designs and should be involved with monitoring dump performance and providing essential feedback to the supervising planning engineers.

## 8.6.2 MINE ROCK DISPOSAL SITE CONDITIONS

### 8.6.2.1 Topographic Settings

*Mountains* - Figure 21 illustrates typical dumping scenarios in mountainous terrain where relief is large and foundation slopes typically increase with increasing elevation.

*Plains* - The foundations of dumps on broad flat valley floors are more likely to be weak in certain climatic conditions, but are more economical to construct in thin lifts over larger areas than mountain dumps. Very weak foundation materials such as peats may be displaced successfully. Problems may arise later if all of the weak material is not displaced. Field trials are advisable before committing to long-term plans.

There are areas of flatter terrain where foundation conditions can be excellent for waste dump construction, for example, the alluvial fans in Nevada.

### 8.6.2.2 Foundation Materials

This section discusses the influence of foundations materials on the performance of mine dumps.

*Mountain Slopes* - Typically in Canada, the foundation areas for mountain dumps are mantled by colluvium consisting of a broadly graded mix of angular rock fragments and silty sand and gravel and glacial till. The colluvial soils are usually in a loose to compact state. The degree of saturation of the colluvium may vary widely depending on the time of year. Saturation is likely to occur after the dump is in place. The glacial tills typically are a silty sand or sandy silt with a trace of clay. The upper 1 to 2m of the till often is in a compact to dense state, and appears to have been softened by processes such as frost action and by root penetration. At depth the till is hard and very competent.

For end-dumped spoils on steep slopes, foundation pore water pressure maybe a potential problem. Experience with mountain dumps in B.C. indicates that foundation slopes steeper than about 20 degrees may be cause for concern if the foundation soils are not predominantly granular and free draining. It is a reasonable assumption that such foundation materials ultimately approach saturation. Theoretical analyses of simultaneous loading and pore water pressure dissipation are complex but feasible. Such predictions should be supported by critical back-analysis of past comparable instabilities, because the rate of generation of pore water pressure is difficult to predict reliably.

Saturation, particularly during a spring thaw, of thin colluvium has resulted in failure of inactive spoils or roadway fills on steep terrain, i.e., slopes steeper than 25 degrees. Clearly, rapid loading of weak fine-grained lacustrine sediments may result in failure, particularly if no layers of pervious soils are present. Thus, careful definition of the extent of drainage is essential for reliable evaluation of performance. Dump heights and overall slopes may be severely limited. Again, field trials offer the greatest confidence for major long-term undertakings. Residual soil foundations may exhibit rapid loss of strength when loaded to failure with dangerous consequences.

*Bedrock Dip Slopes* - The strength of the weakest stratigraphic unit of a dip slope will control foundation stability. Extrapolation of strength tests on core samples or block samples should attempt to account for the effective roughness of the strata, particularly if the weakest layer is thin. Coarse mine rock may be supported on dip slopes inclined at angles of up to 30 degrees. Back-analysis of such observations provides realistic designs.

### 8.6.2.3 Hydrogeology

*Water Balance Evaluation* - The construction of large mine dumps is likely to influence groundwater systems, as illustrated on Figure 22. Peaks of recharge are likely to be reduced. Discharge of groundwater may be impeded by poorly draining spoil materials. It is essential to develop a balanced appraisal of the ability of the as-placed spoils to conduct groundwater discharge freely. Failures of inactive spoils are rare except if caused by particularly steep terrain or if finer grained spoils as a result of saturation. Clearly, the designer must search for suitable precedent, and must follow up during operations with appropriate monitoring. Fortunately, installation of piezometry within fine grained spoils is practicable. Techniques for modeling unsaturated flow through spoil materials can be adapted from analyses for unsaturated flow through soil (Chahbandour and Van Zyl, 1994). Failure of fine grained spoil may occur as a result of saturation over the long-term. In the short-term, fine grained spoils may be acceptable without drainage measures provided that stable long-term containment is provided in the event of saturation.

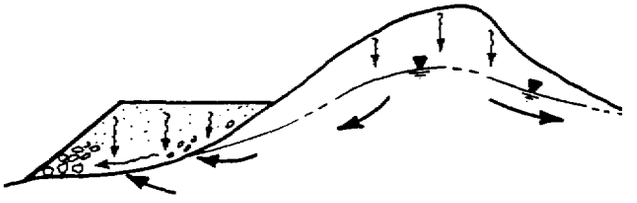


**Figure 22** *Mountain dump groundwater regime.*

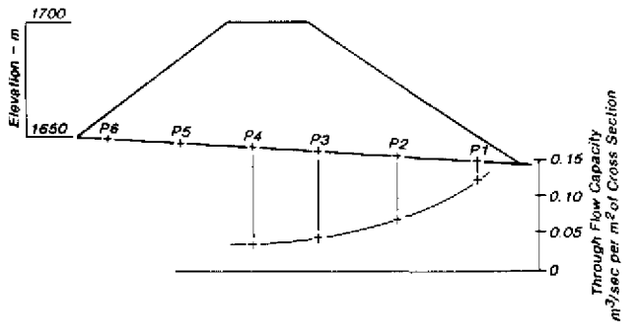



**Figure 23** Rock drain capacity measurements.

Assurance is required that the permeability of the spoil is significantly greater than that of the foundation, with extra allowance for the possibility of springs, and taking into account final spoil thicknesses.

*Rock Drain Evaluation* - Campbell (1986) describes the results of monitoring the performance of a rock drain beneath a 50m high waste dump. The results indicate that flow-through capacity (cubic meters per second per square meter of gross wetted cross section) decreases with increasing thickness of waste rock above the rock drain, as shown on Figure 23.

Other instrumented studies of high end-tipped dumps are in progress. Long-term degradation of mine rock in the basal zones of waste dumps is not a major concern. The interior of waste dumps is a relatively stable environment in terms of temperature and humidity. The particles which reach the toe are likely to be the most competent and durable available. Major long-term rock drains will not be satisfactory if rock quality is poor. The design of rock drains must be integrated with reclamation plans. Downslope dozing to flatten dump faces may not be compatible with rock drains formed by the natural segregation of coarse competent rock particles, and their accumulation in the region of the dump toe. Construction of ultimate dump surfaces by a series of wrap-around dump platforms is preferable. Evidence of deep-seated distress which can affect drain performance among inactive or reclaimed mountain mine dumps is uncommon. Nevertheless, mine operators should remain vigilant, particularly where infrastructure lies within the runout paths of potential failures.

Campbell (1990) addresses concerns regarding blinding of rock drains by sedimentation and degradation. Monitoring of one instrumented rock drain over a 10 year period has indicated that no significant reduction in through flow capacity has occurred. Discussion of the durability and degradation of rock drain material is given elsewhere. Erosion protection against peak discharge should be provided for long-term dump faces.

*Effects of Partial Submergence* - Practical experience indicates that mine waste fills on footwalls, which become partially submerged due to flooding after cessation of mining, are not adversely affected in the short to mid-term. The long-term strength of wetted mine rock may decrease gradually. However, the worst outcome is likely to be creep, slumping, and flattening of the dump face.

### 8.6.2.4 Waste Material Strength, Durability and Drainage

The selection of the distribution of appropriate material parameters within mine dumps for design is a major challenge, particularly if no local experience is available. This section discusses some of the factors that may influence this process.

*Effects of Mode of Disposal*

*End-dumping on high faces* - Commonly, the waste rock mined by truck and shovel is dumped over the crest. Large trucks are used to haul the waste rock to the dump. It is well known that segregation of particle sizes occurs as the waste rock moves down the face of the dumps. The largest and most durable fraction rolls to the dump toe. This zone of coarse segregated rock becomes covered as the dump face advances and results in beneficial basal drainage. Internally, the dump is multi-layered with sequences of alternately coarser and finer material aligned parallel to the dump face. Evidence of this stratigraphy was presented by Campbell (1986). Figure 24 shows the results of a scale model of segregation.

*Lift Construction* - Construction in relatively thin lifts will result generally in a more homogeneous deposit of waste material. Special drainage layers may be necessary to prevent saturation of the spoil.

*Mine Rock Quality Prediction* - The strength, durability, and size of waste material varies considerably from site to site, and upon individual site geology and mining practices. Broad generalizations as to the expected quality of material can be developed, and the design engineer should attempt to characterize the likely range of material strengths, durabilities and sizes anticipated, and their tendencies to vary as mining proceeds. Planning of critical phases of dump development can minimize situations where anticipated poorer quality waste might exacerbate other adverse conditions such as steep topography, or might disrupt the formation of a coarse rock drain in the base of a drainage. General pit geotechnical assessments will yield information on rock type, strength, and durability.

Observation of actual behavior of each principal rock type when exposed to the elements should also aid the

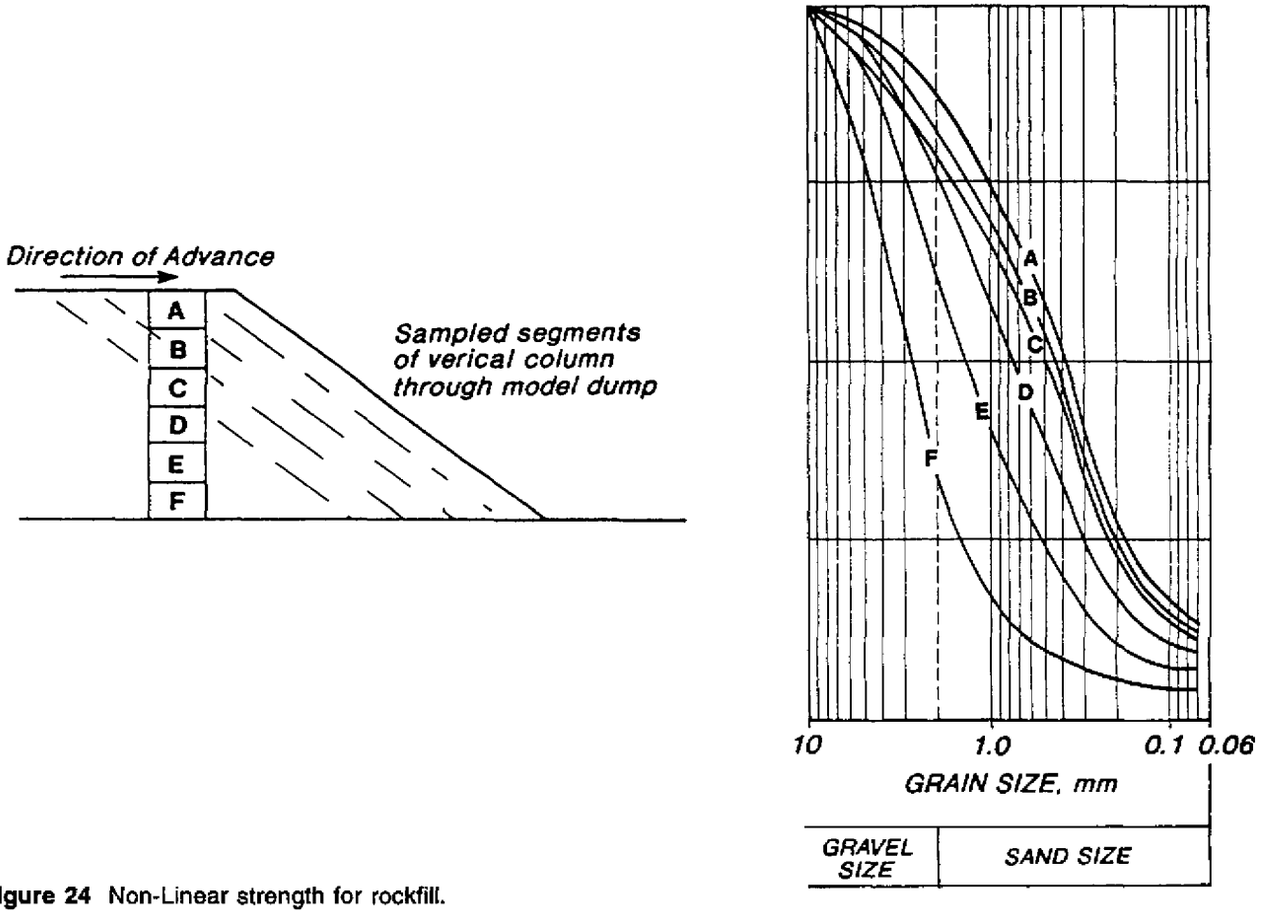



**Figure 24** Non-Linear strength for rockfill.

engineer's judgment. More difficult to assess, particularly for a new project in a new area, is the expected range of particle sizes. However, careful review of the proposed blasting design, and comparison with other mines where similar bedrock strata are being excavated, will often yield adequate information.

*Spoil Stratigraphy* - As indicated on Figure 24, it is to be expected that fines from one layer of an end-dumped spoil would not be able to pass through lower coarser layers. Evidence of significant internal erosion within mine dumps has not been observed in the field. However, the engineer should examine relevant past experience and justify his assumptions accordingly.

*Strength* - Unless a sudden collapse mechanism, involving saturated or near-saturated relatively fine-grained spoils, is considered possible it is probably adequate to assume frictional strengths equal to or slightly greater than the observed angle of repose. Relatively small overestimates of the drained strength of spoils are unlikely to result in serious failures.

Uhle (1986) has compiled a database of potentially relevant strength test results. Judgement is required to select appropriate test materials in terms of gradation and relative density. These parameters and their variation within end-dumped spoils must be appraised by the engineer.

Other practical strength relationships have been developed by Leps (1970) on the basis of test data, as shown on Figure 25, and by Barton and Kjaernsli (1981), based on comparison with the behavior of loose jointed rock masses.

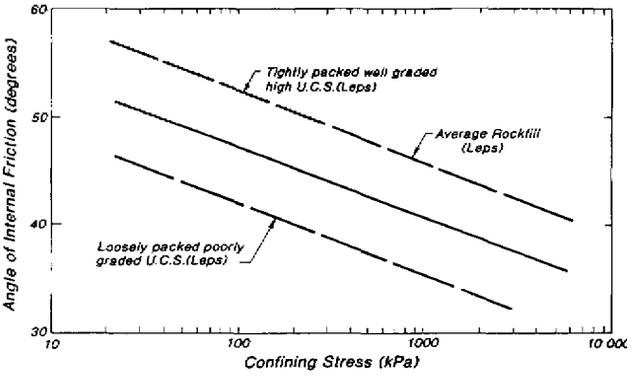



**Figure 25** Non-Linear strength for rockfill.

*Durability* - Durability criteria depend on individual design requirements. Durable materials are required in basal rock drains and where long-term armoring is

required. Campbell (1986) has inferred the effects of increasing stress on the porosity of coarse sedimentary mine rock at one rock drain site.

The USFS (Vandre, 1993) propose a specification for durable mine rock intended to serve as long-term "permanent" facing of spoils. The specification utilizes tests for the specific gravity, absorption, and compressive strength to classify the durability of rock particles. In addition sulfate soundness durability tests are considered to provide good indications of degradation resistance.

Evidence that degradation of mine rock occurs at depth within dumps has not been established. Degradation is likely influenced greatly by changes in temperature and humidity. These parameters are not expected to fluctuate greatly at depth within a dump. Experience with the excavation of the base of one coal mine spoil, some ten years after dumping, indicated negligible degradation. More such examples are required. Other evidence would include observations of abandoned spoils.

Construction of mine dumps in relatively thin lifts may be required for non-durable materials or may be convenient if the terrain is flat. The performance of the dump is more likely to be controlled by the finer portion of the feed material from the pit. Characterization of the finer portion of the waste material is straightforward. More compaction of the waste material is likely to occur. The potential requirement for provision of drainage measures to conduct groundwater discharge must be evaluated.

### 8.6.2.5 Geochemistry

Acid generation from sulfide waste rock is a significant concern. Geochemical characterization is described in Section 7.2.1. A number of mitigation measures can be considered if acid drainage occurs. These can be broadly classified into source control and migration control (collection and treatment).

Interception and treatment of the acid drainage from a dump is a major long-term cost. Perpetual collection and treatment must be assumed and covered by a reclamation bond. The net present value of the reclamation bond at the mine is based on the results of modeling.

Acid generation and migration can be minimized by sealing off ingress of oxygen and water as much as practicable. Alternatively, complete inundation by water may be feasible. For example, soil covers with a relatively low permeability of $10^{-6}$ cm/sec may reduce peak rates of acid generation by more than 90 per cent. Knapp, Schaver, Pettit et al., (1992) describe the Reactive Acid Tailings Assessment Program (RATAP) computer model and correlate results with field measurements of the acid generation in a sulfide-rich mine waste rock dump.

The diffusion of oxygen through a compacted soil cover is modeled on the basis of laboratory testing. The results are affected significantly by the moisture content, as is the liquid permeability.

The RATAP model considers the acid generation from fine and coarse particle sizes separately. Oxidation of pyrite results in the degradation and fracturing of larger particles. Peak acid production rates increase as the fines content increases and are sustained for longer durations. The internal temperature of the pile affects acid generation which is an exothermic reaction. The RATAP model accounts for temperature variations, based on calibration with field measurements.

The transport of oxygen through a rock pile is modeled on the basis of the void space and moisture content estimated for the mine rock and the laboratory testing of diffusivity and permeability of the soil cover.

The results of simulating several soil covers of varying degrees of compaction are shown in Figure 26. The principal concern should be the selection of realistic, and conservative, parameters which incorporate field variations in mine rock and soil cover properties over the long-term. Decline in the rate of acid production is very slow and may accelerate rapidly if the cover is compromised. Thus, care and maintenance of the cover system must be considered a very long-term requirement.

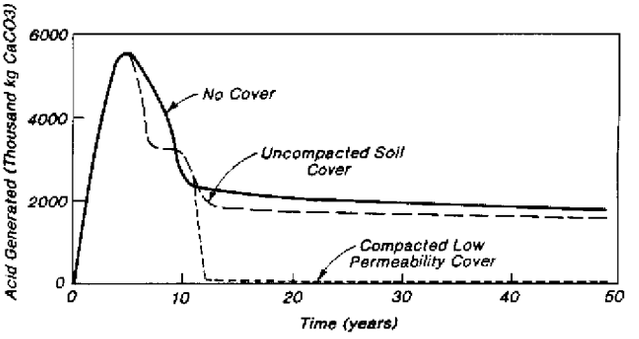



**Figure 26** Acid generation modeling for soil covers.

Much has been published about acid generation processes and controls. The interested reader should refer to conference proceedings and publications of the Canadian MEND program.

### 8.6.2.6 Construction Methods

The influence of various possible construction methods on waste material parameters was described in the preceding section 8.6.2.5. This section highlights the main influences of construction methods on dump performance.

*Lift Thickness* - High dumps constructed in thick lifts experience large deformations but may have greater capacity to conduct surface runoff. The risk of failure of

such dumps generally is greater than for dumps constructed in thin lifts. However, underdrainage to intercept groundwater and/or purpose-built rock drains are likely to be required for dumps constructed in thin lifts.

*Weak Foundations* - Displacement of very weak foundation materials is feasible, as illustrated in Figure 27 but must be carefully controlled. The inadvertent inclusion of weak soils within lower dump lifts may fundamentally jeopardize the stability of subsequent dump lifts.

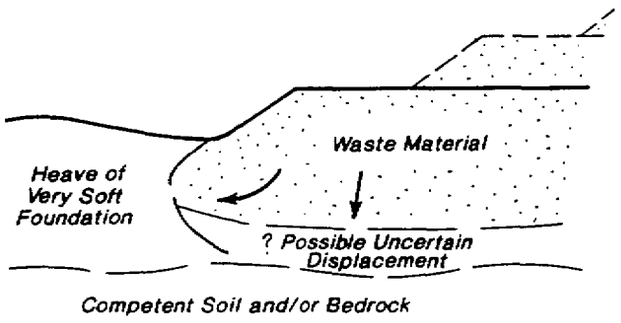



**Figure 27** Displacement of very weak foundations.

*Loading Rate* - The rate of loading of foundation soils is much lower for construction in thin lifts than for end-dumping. For example, a loading rate in excess of about 200 bank cubic yards per yard of crest length per day may result in marginal stability for a dump up to 1000 ft high, due to accumulating foundation pore water pressures.

Control of waste material quality relies on operational judgement but pro-active planning should try to schedule with respect to critical phases of a particular dump development, such as the formation of rock drains.

### 8.6.2.7 Practical Monitoring

The over-riding requirement for instrumentation of mine dumps is simplicity and robust construction. HBT (1992) conducted a review of available methods. Simple manual and automated wireline extensometers are effective for high mountain dumps, as illustrated in Figure 28.

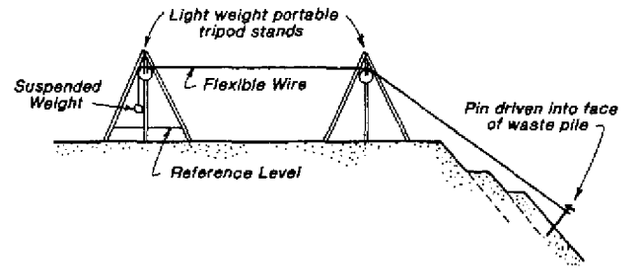



**Figure 28** Wireline extensometer and typical monitoring results preceding failures.

Any foundation or internal dump instrumentation must take into account possible deformation anticipated during or following construction. Foundation or internal instrumentation may not be practical if large deformations are expected. The control of stability using such instrumentation and pre-set criteria for cessation of dumping is not advisable. Situations may become uncontrollable if the instrumentation or its connections fail at critical times. Instrumentation may serve to confirm design assumptions where small deformations and relatively large factors of safety are expected.

Criticism that wireline monitoring of high dump crests can be misleading is unfounded. The key objective is the detection of trends of accelerating movement rather than the absolute measurement of total displacement.

Ongoing research includes the monitoring of rock drains and development of sensors capable of burial within or beneath dumps without pressure tubing or electrical connection leads. Monitoring of acoustic emissions from the fracturing of mine rock particles has been proposed by various workers but has not yet been demonstrated to be a practical approach. Special situations, such as dumps adjacent to critical infrastructure may warrant a trial of the method.

### 8.6.2.8 Observed Performance

*Typical Deformation of High Dumps* - Detailed geometric measurements of the normal deformations of dump surfaces or of the post failure geometries of high mine dumps are not commonly available. Eyewitness accounts of dump failures are few. Typically, an active slide is enshrouded in a dust cloud. Thus, precise definition of failure surfaces is not available. However, field observations of dump surfaces preceding failure events, and during normal operations, can provide meaningful indications of their internal geomechanics.

Waste rock tends to be in a relatively loose state when end-dumped. Deformation occurs internally and on the surface due to both compressive and shear strains. Surveys of dump surface movement have measured vector directions inclined at between 50 and 60 degrees below horizontal in the vicinity of the dump crests. The magnitude of displacement decreases with increasing distance behind the dump crest, diminishing to negligible values within a setback of about 30 per cent of the dump face height.

Patterns of horizontal striations or ridges are commonly observed over the upper part of the dump faces. These patterns are interpreted to be the result of the strain within the upper portion of the dump, associated with Active Rankine stress conditions. These conditions result from both internal compression and shear deformation within the lower portion of the dump.

Figure 29 shows the results of survey measurements on the face of a dump about 100m high, supported on a

foundation slope inclined at about 20 degrees. The vectors near the crest were inclined at 50 to 60 degrees, agreeing with model testing, stability analyses, and other observations. The direction of the vectors show a trend of flattening with decreasing elevation, probably corresponding to deformation along the dump-foundation contact zone.

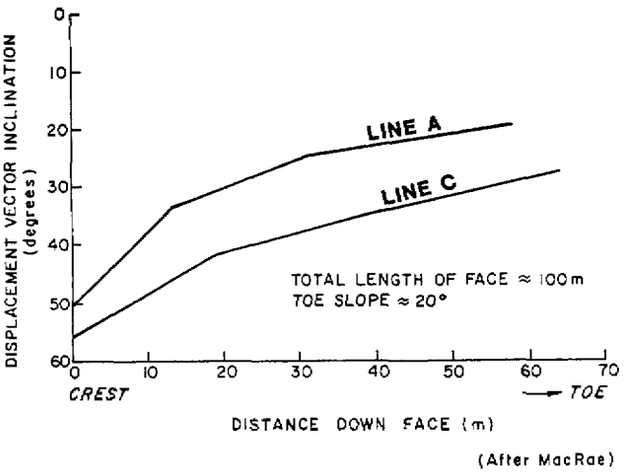



**Figure 29** Survey measurements for high dump face.

*Failure Modes* - Figure 30 shows typical modes of failure inferred from the available records. A commonly inferred mode is termed the double-wedge mechanism, as illustrated in Figure 31. This mechanism is analogous to the development of the Active Rankine state in the backfill of a retaining wall. In this analogy the toe region of the dump is the retaining structure, which is capable of deforming sufficiently that the Active condition occurs within the waste material above and behind the toe. Oversteepening of the upper part of dump faces is quite common due to the presence of relatively fine-grained material in the region of the dump platform. Sliver failures of the oversteepened upper face typically involve a relatively small volume of material, and the failure runout is minor. Bulging of the dump face is often detected, with deviations of up to about 5 degrees steeper than the typical angle of repose of 37 to 38 deg. The bulging may progress to a failure of moderate size.

Rapid loading of localized foundation areas mantled by lightly consolidated fine grained soils may cause toe spreading. Highly mobile slides have occurred where larger areas of surficial saturated organic soil have been loaded rapidly by sliding debris. Deep-seated sliding surfaces have not occurred in high mountain dumps often because most mountain side-slopes are underlain by overconsolidated soils or bedrock at relatively shallow depths. Usually, potential dump sites underlain by lightly consolidated soils have been avoided.

*Failure Database* - Golder (1987), (1992a) and (1993) provided a database of up to 50 mine dump failures in B.C. over the past 25 years. The nature of the failures, the runout of the sliding debris, and the environmental consequences were examined in these references.

Examples of failures are discussed by Campbell and Kent (1993). Few experienced geotechnical engineers have been eye witnesses to these events. Also, comprehensive investigations, such as might be undertaken following civil failures of comparable size, have not been typically undertaken. Thus, caution is advisable when interpreting accounts of failure mechanisms. Nevertheless, the professional engineer has a responsibility to avoid undue conservatism by designing on the basis of practical observation and its interpretation.

*Effects of Climate* - The presence of a waste rock dump within a watershed tends to reduce peak flows, and to increase base flows. Heavy rainfall may exacerbate pre-existing conditions which are near to failure. Such conditions may include steep foundation slopes or excess pore pressures generated by strain within foundation soils. The available meteorological records indicate that the incidence of failures increases during spring thaw when recharge and discharge can be expected to peak.

Snowfall normally is not a major problem for active mine dumps. It is conceivable that shallow burial of thick layers of snow could lead to instability but there are few such instances documented.

In one case an abandoned dump on steep terrain failed, apparently as the result of thawing of old snow and ice. Simple but effective crest monitoring provided ample warning for the protection of men and equipment.

*Erosion and Sediment Control* - The treatment of sediment laden runoff from mine dumps and slide debris is proven to be effective using suitable settling ponds and by the addition of flocculants during major storm events. Some mine environmental staff assert that passage of mine runoff through waste dumps and dump slide debris results in improved water quality. Golder (1993) present the results of a survey of the environmental, public and operational consequences of selected dump failures. Detailed documentation of such outcomes may provide an acceptable basis for the future design of mine dumps and water treatment facilities.

## 8.6.3 DESIGN GUIDELINES

This section is intended to provide guidance in the overall design process. Standardization of design methods for clearly defined categories of dump situation is desirable for expedient design and regulatory approval. More generalized procedures and broader classifications

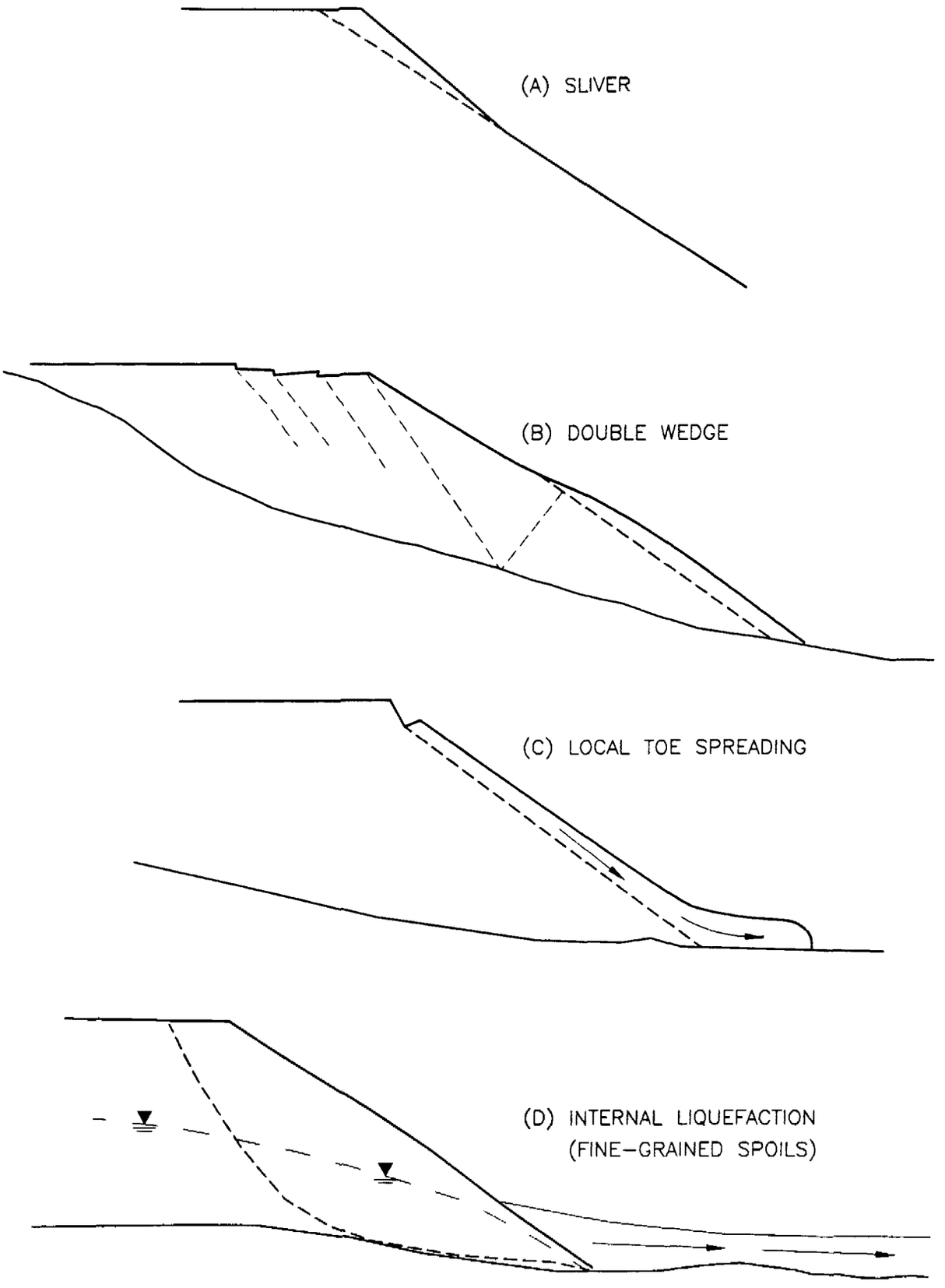



**Figure 30** Typical failure modes.

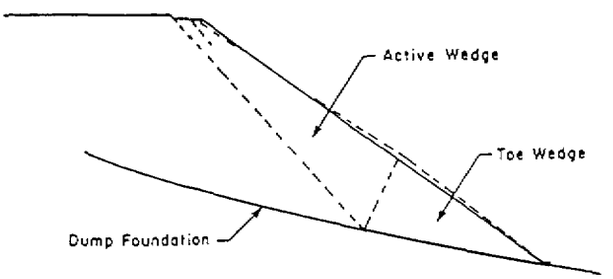



**Figure 31** Double-wedge failure mechanism.

are likely to result in more costly and conservative designs.

### 8.6.3.1 Risk-Based Approach

A risk-based approach to dump design provides a rational site-specific design framework, if acceptable to regulatory authorities. Standardized analytical methods and assumptions can be incorporated into the framework. Explicitly documented risk analyses result in up-front acceptance or dispute of predicted dump behavior. Subsequent performance monitoring information can be fed back into the framework during dumping operations.

Overall, risk is defined as the combined effect of possible hazards, potential modes of failure, and of potential impacts of failures. Prediction of the likelihood of potential failure impacts requires the estimation of the runout behavior of slide debris and its resulting impacts on the environment, on the public, and on mining operations.

Risk analyses can be conducted in a variety of ways,typically sub-divided into qualitative and quantitative methods. Studies of the application of risk-based approaches to the design of mine waste dumps in British Columbia have described possible qualitative and quantitative approaches (Morgan, 1992; Golder, 1993).

A risk-based classification of mine dumps has been suggested as a tool that will assist designers to determine the scope of design effort required and to demonstrate the present and future security of the dumps to the client, regulator and public.

Risk-based classification should be developed on the basis of an intimate understanding of the technical processes which link causes to their effects, i.e., failure modes to the impacts they cause. Prediction of consequence can be sub-divided as follows:

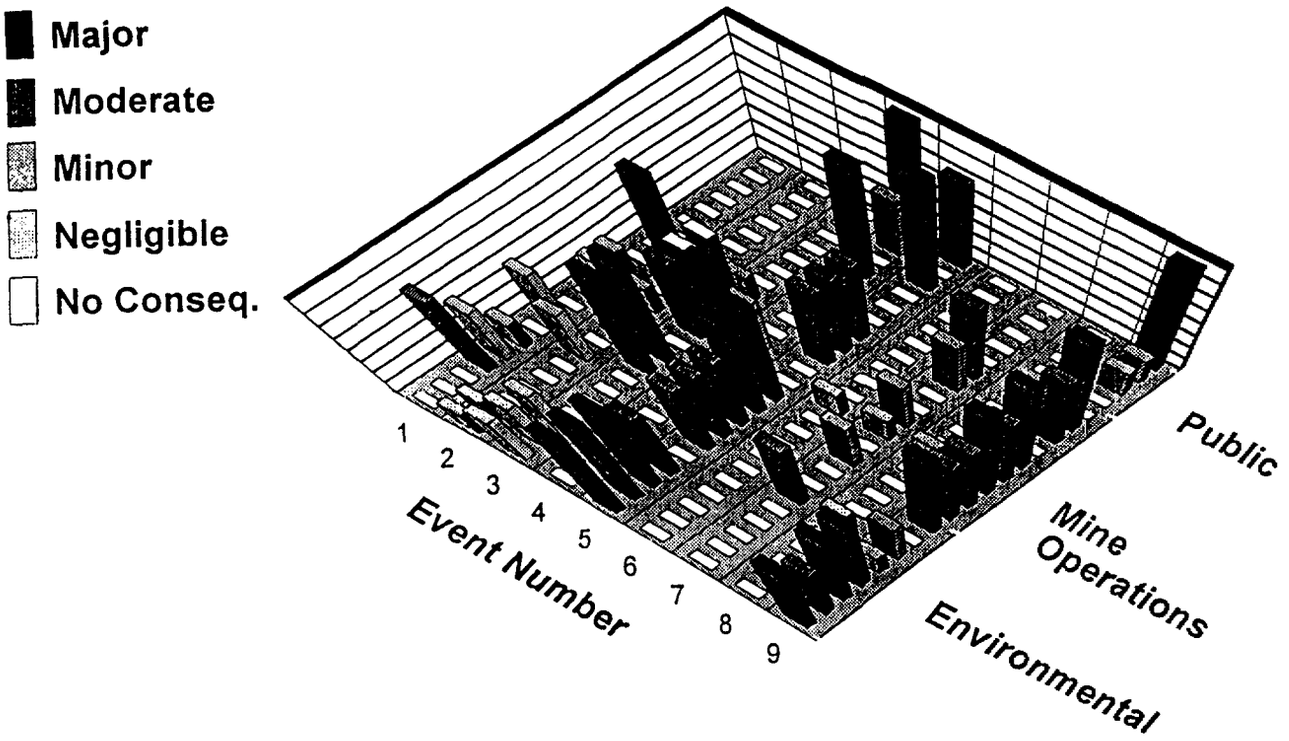
- Runout prediction in terms of expected distance, ideally a probability density function, but practically characterized as upper and lower bounds, and expected values; and,
- Prediction of impacts of the runout in terms of water quality, habitat quality or loss, nature and cost of reclamation and clean up, and nature and cost of mitigation measures such as barriers or deflection berms. Ideally, the ranges of these impacts should be expressed as probability density functions, but only qualitative assessments are practical.

Golder (1993) studied the consequences of failures, and presented an objective review of case histories in terms of documented consequences and costs. The study characterized the consequences of mine waste dump failures, and developed a database.

Consequences of a biological nature were rated in accordance with the impact significance definitions proposed by Conover, et al., (1985), as presented in Table 5, and which are generally used to describe impact significance in current environmental impact assessments. Impacts related to total suspended solids (TSS) are related to the permitted levels specific to each waste dump, although the question of TSS duration above permitted levels has not been addressed in the literature. The overall impacts of the events are derived using the data base and consequence rating for each failure event. Figure 32 shows a three- dimensional representation of the measured impacts of a selected group of mine dump failures. This type of data presentation provides a useful basis for risk assessment.

Consider the scenario of large mine waste dumps (100 to 400m high), in steep mountainous terrain, operated under severe economic constraints. A dump, situated on very steep terrain, with a high probability of failing, may be located well away from any infrastructure, with a large sediment control pond downstream. The consequence of the dump failing may be small in terms of the effect on water quality downstream of the sediment control pond. Thus, the overall level of risk posed by the dump to the environment may be low. Alternatively, a high dump founded on relatively flat and generally competent terrain may pose an unacceptably high risk if the dump is located immediately adjacent to a major element of infrastructure such as a tailings pond or a busy railroad. The consequence of even a relatively small sliver failure may be unacceptable in terms of the cost of repair, lost production, or loss of life or injury.

There is sufficient observational experience from the past 25 years to identify levels of hazard for each possible failure mode with reasonable certainty, despite several technical limitations of predictive modeling and monitoring. Most major mine dumps have been operated safely, with minimal loss of life, injury, or damage to infrastructure. Impacts on the environment have been variable. Traditionally, the adequacy of a dump design has been rated through a set of factors of safety with respect to stability for various stages of development. The factor of safety serves as a catch-all for the possible adverse effects of unfavorable conditions. Certain values of the factor of safety are interpreted differently by




CONSEQUENCE ASSESSMENT

MINE WASTE DUMP FAILURES

| RATING | ENVIRONMENTAL | MINE OPERATIONS | PUBLIC |
|---|---|---|---|
| Major Impact (long term) | mortality<br>habitat loss<br>whole population<br>TSS/land use | lost reserves<br>equip./infra. lossed<br>dump lost | loss of life<br>loss of land<br>high costs |
| Moderate Impact (medium term) | no mortality<br>habitat replaceable<br>portion of population<br>TSS/land use | dumping interrupted<br>equip./infra. damaged<br>capacity affected<br>long hauls | serious injury<br>land reclamable<br>moderate costs |
| Minor Impact (short term) | no mortality<br>habitat replaceable<br>localized group<br>TSS/land use | slight interruption<br>slight damage<br>capacity not affected<br>hauls not affected | no infury/loss of life<br>land slightly affected<br>low costs |
| Negligible Impact | no mortality<br>no habitat lossed<br>no effect on pop.<br>TSS/land use | no interruption<br>no damage | no injury/loss of life<br>land slighlty affected<br>mimum costs |
| No Impact | no interaction | no interaction | no interaction |
| Positive Impact | population increase<br>habitat improvement | cost savings | cost savings |

**Figure 32** Three-Dimensional representation of dump failure impact rating.

**Table 5** Biological Consequences. Impact Significance

| | |
|---|---|
| Major Impact | This impact is one affecting a whole stock or population of a species in sufficient magnitude to cause a decline in abundance and/or change in distribution beyond which natural recruitment would not return that population, or any population or species dependent upon it, to its former level within several generations. |
| Moderate Impact | This impact is one affecting a portion of a population that results in a change in abundance and/or distribution over one or more generations, but does not change the integrity of the population as a whole. The impact may be localized. |
| Minor Impact | This impact is one affecting a specific group of individual sin a population at a localized area and/or over a short period of time (one generation or less), but not affecting other trophic levels or the integrity of the population itself. |
| Negligible | This impact is one affecting the population or a specific group of individuals in a localized area and/or over a short period in such a way as to be similar in effect to small random changes in the population due to environmental irregularities and having no measurable effect on the population as a whole. |
| No Impact | In some instances either no interaction occurs, or the interaction does not result in any impact of any sort. |
| Positive Impact | In some cases a positive impact may be identified, using the sam definitions as above, with the positive nature of the impact being described. |

Note:Conover, et al., (1985) describes a biophysical rating methodology using four population-based criteria (major, moderate, minor and negligible), a no impact and a positive impact criteria as listed above.

**Table 6** Example of Qualitative Risk Assessment

| **Hazard** | | **Exposure** | | **Consequence** | **Risk** |
|---|---|---|---|---|---|
| Initiating Effect | Immediate Effect | Mitigation | | Extent of Impact | Overall Effect |
| Major Dump Slide | Sediment Erodes | Pond Removes Sediment | Contaminated Water Spills | Fish Affected | Occasional slides reduce habitat quality for short period if pond spills |
| Low Likelihood | High Likelihood over Short Term | 90% Effective for 95% of Time | Sediment Concentration 1,000 - 10,000 mg/l | Moderate Loss of Growth & Mobility | |
| **Low Hazard** | | **Low Exposure** | | **Low Consequences** | **Very Low Overall Risk** |

different individuals, leading to varying levels of concern if the design fails to perform as expected. The implicit consideration of both hazard and consequence is built into this interpretation of the factors of safety.

Systematic and explicit description and evaluation of risk for each component of each available alternative for a dump disposal project apportions the responsibility for design, approval, and operation fairly between the mine operator and the regulator. This process clearly explains the benefits and potential deficits for each alternative in terms of cost, environmental impact, and public concern.

Risk analysis is now being applied to mining projects with varying levels of sophistication, both qualitatively, Van Zyl and Bamberg (1991) and

quantitatively, Kent, Roberds and Van Zyl (1992). Examples of the results of each of these levels of study are shown on Table 6 and Figure 33, respectively. The analyses can be used to focus design studies cost-effectively in the areas of greatest risk. The explicit nature of the process can serve as a vehicle for communicating both cost and risk to all concerned. The concept is simple and good communication with both regulatory authorities and the public benefits the mining industry.

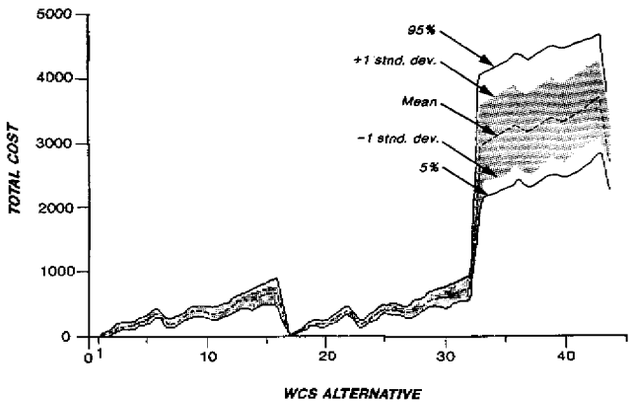



**Figure 33** Quantitative assessment of mine waste alternatives.

The development of methodology for predicting the consequences of dump failures consists of prediction of the behavior of the failure debris, i.e., runout distance and direction, and prediction of the consequences of the failure runout. Data on the characteristics and runouts of over 40 mine dump failures have been collected, providing a basis for empirical prediction based on analysis of selected comparable case histories.

*Application to Mine Waste Dumps* - Table 7 shows an example of a dump stability assessment and a qualitative risk analysis. The information presented in the table provides an explicit basis for subjectively or qualitatively evaluating risk. This approach, while not difficult, requires thorough and detailed analyses, and has been well received by both mine planners and regulators in British Columbia.

Generally, the consequences of mountain dump slides vary according to the time of year, the facilities in the potential runout path, and the remedial action taken immediately following the event. In the majority of cases studied by Golder (1993), the slide runouts remained within the approved ultimate dump limits and have since been covered by waste material.

Settling ponds and drainage control structures, designed to handle sediment loads generated by spring runoff, 24 hour precipitation events, and 10 year return period storm flows generally are efficient in mitigating runoff generated from waste dump failure events in the short and long-term.

Mine operations are inevitably affected by failure events because of the need to find alternative dumping locations while the waste dump stability is confirmed and the failure crest is rehabilitated.

Qualitative evaluations, based on conceptual engineering and judgment, should be performed first. Subsequently, quantitative risk computation may be considered only if the effort and cost is justified and the waste system model is well understood.

The selection of any method of risk analysis should remain the prerogative of the mining company provided that the approach is explicit and is based on fundamentally sound scientific relationships and parameters. Uncertainty may be compounded by instituting generalized rating systems. Evaluations should be site-specific, based on geotechnical analysis and prediction of performance; comparison with relevant precedent; engineering judgement; and consequence analysis.

The approach should be graduated, as follows:

1) Conceptual design of dump stages, evaluating risk and cost qualitatively.

2) Feasibility design, including focussed site investigation.

3) Final design specifications, including management and monitoring procedures.

4) Monitoring during operations, with periodic design/performance review.

5) Abandonment/closure design, taking into account past dump performance.

### 8.6.3.2 Stability Analyses

The prediction of hazards of dump construction should include assessment of the following aspects:

Probable variations in dump foundation soil and groundwater conditions.

Expected variations in waste rock material strength, gradation, and durability.

Stability of planned stages of dump development in terms of foundation topography under the dump toe and direction of advance.

Rates and methods of construction.

Table 7

**EXAMPLE**

SUMMARY OF STABILITY ASSESSMENT AND RISK ANALYSIS
SOME CREEK WASTE DUMP
HAZARD ANALYSIS

| DUMP STAGE | CREST LEN-GTH (ft) | LOAD-ING (BCY/ DAY) (*1000) | LOAD RATE (BCM /M/ DAY) | CREST ADV-ANCE RATE (m/ DAY) | ANAL-YSIS CROSS-SECT. | TOE LOP (deg) | FACE HT (m) | FACE ANGLE (deg) | INDIC-ATED SAFETY FACTOR | RISK ASSESSMENT | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | POSS-IBLE EVENT TYPE | POTENTIAL EVENT CAUSE | EVENT RISK RATING | RISK DURATION | POSS-IBLE FAIL-URE VOL. (M3* 1000) | POSS-IBLE FAIL-URE RUN-OUT (m) | OUTCOME | OUT-COME PROBAB-ILITY RATING | OUTCOME REPAIR RELAT-IVE COST |
| I | 800 | 50 | 157 | 11.1 | A | 11 | 60 | 37 | 1.5 | I | FINES/HIRA | MOD VL | SHORT | 1 | <500 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | II | LOCAL SATUR/ ORGAN.FNDN | | SHORT | 3 | <500 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | III | PWP-FOUN | VL | SHORT | 20 | <500 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | | | | | | | OBSTRUCTS CRK | L | L |
| | | | | | | | | | | IV | PWP-DUMP | EL | SHORT | 40 | 2000 | INCR.SEDIMENT | H | M |
| | | | | | | | | | | | | | | | | OBSTRUCTS CR | H | M |
| II | 800 | 120 | 376 | 5.0 | B | 14 | 320 | 37 | 1.4 | I | FINES/HIRA | MOD | SHORT | 10 | <1000 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | | | | | | | ENTERS CRK | M | L |
| | | | | | | | | | | II | LOCAL SAT ORGAN.FNDN | VL | SHORT | 15 | <1000 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | | | | | | | ENTERS CRK | M | L |
| | | | | | | | | | | III | PWP-FOUN | VL/EL | SHORT | 350 | <500 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | | | | | | | OBSTRUCTS CRK | L | L |
| | | | | | | | | | | IV | PWP-DUMP | EL | SHORT | 1000 | >3000 | INCR.SEDIMENT | H | M |
| | | | | | | | | | | | | | | | | OBSTRUCTS CR | H | M |
| | | | | | | | | | | | | | | | | CROSSES ROAD | M | H |
| III | 1200 | 120 | 251 | 2.5 | C | 14 | 420 | 37 | 1.5 | I | FINES/HIRA | MOD | SHORT | 10 | <1000 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | | | | | | | ENTERS CRK | H | L |
| | | | | | D | 0 | 300 | 37 | 2.4 | | | | | | | | | |
| | | | | | | | | | | II | LOCAL SAT ORGAN.FNDN | VL | SHORT | 15 | <1000 | INCR.SEDIMENT ENTERS CRK | M | L |
| | | | | | | | | | | III | PWP-FOUN | VL/EL | SHORT | 700 | <500 | INCR.SEDIMENT | M | L |
| | | | | | | | | | | | | | | | | OBSTRUCTS CRK | L | L |
| | | | | | | | | | | IV | PWP-DUMP | EL | SHORT | 3000 | >3000 | INCR.SEDIMENT | H | M |
| | | | | | | | | | | | | | | | | OBSTRUCTS CR | H | M |
| | | | | | | | | | | | | | | | | CROSSES ROAD | H | H |
| III-RECL--AIMED | | | | | C | 14 | | 27 | 1.9 | IV | PWP-DUMP | VL/EL | LONG | 1700 | >3000 | INCR.SEDIMENT | H | M |
| | | | | | | | | | | | | | | | | CROSSES R6AD | H | H |

[1] RISK OF OUTCOME OCCURRING AS A RESULT OF EVENT

Correct selection of the potential trial sliding surfaces for stability analyses is fundamentally important and can be the source of large errors in practice (ACADS, 1989; Vandre, 1986).

*Steep Terrain* - Golder (1987) indicated that a factor common to many mountain dump failures was a steep foundation slope, often exceeding 25 degrees. Failures that occurred where foundation slopes were flatter could usually be attributed to other adverse conditions such as pore water pressures in the foundation. A dump supported on a slope of more than 25 degrees could normally be expected to have a factor of safety of less than 1.2 under drained conditions. Relatively small values of pore water pressure acting along, or at shallow depth below the dump-foundation contact could be responsible for de-stabilizing such dumps. It should be noted that for reasons of economy mining in mountain terrain must often proceed from the top downwards, necessitating high level waste rock disposal over relatively steep terrain during the early stages of mining.

When waste rock is consigned to a steep-sided V-shaped gully the three-dimensional wedging action enhances the stability and can increase the factor of safety by up to about 15 per cent. Thus, a dump situated on 20 to 25 degree slopes may have adequate stability if the layout takes advantage of the wedging effect of gullies.

Dump stability can be enhanced if the dump layout and the direction of advance is optimized with respect to the available topography within the available dumping areas. A useful planning task is the development of isopachs of topographic slope. During dumping operations the supervising engineers should have a clear idea of the slope of the current area that is providing support to the toe region of the dump. This appreciation should influence dump management in terms of loading rate or of direction of advance.

*Weak Deep Foundations* - The analysis of dump stability on relatively deep deposits of weak fine-grained alluvium can be performed simply using undrained shear strength parameters derived from in situ and/or laboratory testing.

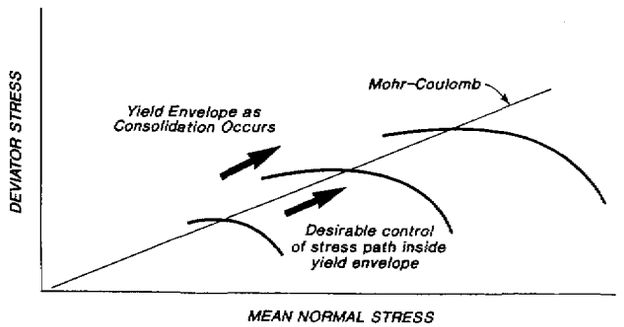



**Figure 34** Stress path failure envelopes for weak foundations.

Considerable conservatism may be introduced as the result of sample disturbance and failure to detect drainage layers within the deposit. Field trials are advisable. Foundation drainage measures such as wick drains may be effective. More sophisticated laboratory testing and analyses, as outlined by Folkes and Crooks (1985) may provide a more theoretically sound model of the stress paths followed during dump construction. The objective is to maintain a small but consistent margin of strength inside the failure envelope which shifts position as consolidation takes place, as illustrated in Figure 34.

Typically a thin dump lift will fail in a translational mode pushing a bow wave out. If the height of the dump is relatively large compared to the depth of weak material the failure will be deep-seated and quasi-circular. If foundation deposits are very weak virtually complete displacement may be practicable. This allows subsequent construction of additional stable lifts. The success of initial displacement of weak foundation soils should be verified.

*Dump Internal Failure* - Dump slides such as investigated by Bishop (1973) resulted from the collapse of loose partially or nearly saturated mine waste. Eckersley (1990) modeled a similar phenomenon in coal mine stockpiles. Dawson and Morgenstern, et al., (1993) have proposed that static liquefaction may have caused several mountain spoil slides. If saturation of portions of a dump containing loose silts, sands and fine gravels occurs a rapid collapse and contraction of the particulate structure may be triggered. Such collapse may result in highly mobile slide debris. The designer must be assured that this condition will not occur, i.e., that significant saturation will not occur within the dump material. However, the mobility of potential dump failure debris appears to be affected more by the topography of the runout path and its soil mantle.

*Methods of Analysis* - Two main types of analysis may be considered for the theoretical prediction of the performance of a proposed dumping scheme. Given the operating conditions and constraints described earlier, and the analytical problems discussed below, the practical designer must exercise considerable judgement, based on the observational approach, in order to provide cost effective dump development plans.

*Limit Equilibrium Analyses* - The principles of limit equilibrium are used commonly to identify potential sliding surfaces which result in the lowest calculated factors of safety. Realistic analyses rely upon the engineer to propose hypothetical trial sliding surfaces on the basis of his intuition, observation, and experience. Conventionally, the stability of trial sliding surfaces is assessed in terms of the overall ratio of resisting forces

to driving forces acting on the mechanism as a whole.

In reality the stress-strain characteristics of the loose waste rock and the dump foundation soils will be different. The observed deformations of dump faces suggest that the behavior of a pile of loose waste rock on a sloping foundation is analogous to a retaining wall with granular backfill. Wall deflection by about one tenth of one per cent of the wall height is sufficient to fully mobilize the available strength of the backfill. The toe region of a waste dump can be analyzed as a structure which retains the upper portion of the dump. Thus, a stability analysis should assume that most, if not all, of the strength of the waste rock is fully mobilized for the portion of the trial failure surface within the dump. An appropriate definition of the factor of safety is the ratio of resisting to driving forces acting on the toe region of the dump. Conventional stability analyses should be modified to find the strength mobilized along the dump foundation contact by iteratively reducing the input foundation strength until a factor of safety of 1.0 is calculated. The factor of safety against foundation shear beneath the toe region of the dump can then be computed.

The program D-Wedge (Golder, 1992b) searches for the critical double wedge mechanism varying the position and inclination of wedge sides. The mobilized strength on the base of the toe wedge is computed. A power function may be used to simulate non-linear waste rock strength.

*Stress-strain analyses* - Stress-strain analyses compute distributions of compatible stress and strain in response to imposed loads. For mine dumps the absolute values of deformation are relatively unimportant. However, the pattern of internal strains and the orientation of principal stresses may indicate critical failure zones.

*The practical application of finite element codes to* the analysis of mine dump designs is not commonplace but continued research into the application of suitable programs is encouraged. The results of such research may provide further insight into observed patterns of deformation. It is not yet clear that stress-strain analyses will result in designs that are better than those resulting from the use of the modified methods of limiting equilibrium of analyses discussed above. Practical application must be linked to field observation programs, which should include assessments of rock quality. Although modern computer programs and hardware are now relatively cheap to use, the tasks of mesh generation and parameter selection continue to require considerable experience and engineering judgement. An example of the mesh used to simulate the advance of dump across a mountain slope is shown on Figure 35. Various zones of the mesh can be switched on as the toe of the dump advances along the mountain side.

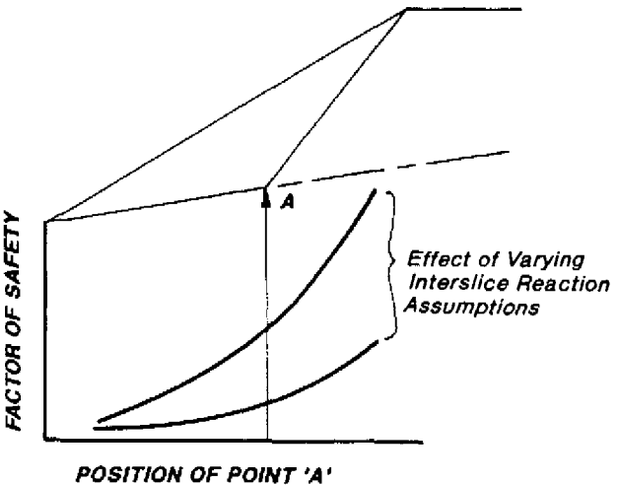



**Figure 35** Example of finite element mesh for mountain mine dump.

A recent upgrade of the FLAC (Itasca, 1993) code permits broad flexibility in material property definition, including simultaneous dissipation of pore water pressure as loading proceeds. However, caution is advised in the interpretation of such analyses without field scale verification.

*Parameter Selection*-In general, the assumption of the angle of internal friction for the mine waste rock equal to the observed angle of repose is considered to be conservative. More precise characterization of the non-linear strength of the mine rock may be worthwhile in certain situations, including some high dumps. Slope stability programs assuming a double-wedge mechanism and non-linear function to describe maximum available shear strength in terms of the waste rock of applied normal stress can be set up readily. Searches for the most critical double wedge can calculate the frictional strength that must be mobilized on the base of the toe region for limiting equilibrium. Selection of a power function can be based on the data assembled for the shear strength of the waste rock in terms of overburden stress by Leps (1970). Alternatively, the adaptation of strength relationships for jointed rock masses to rockfill by Barton and Kjaernsli (1981) is rational and useful. In addition, a comprehensive database of test data for a wide variety of rockfill types is available(Uhle, 1986).

Overall, the engineer must temper theoretical assumptions with the experience garnered through past observations. Of particular importance, are the assumptions regarding pore water pressures. As noted earlier, pore pressure monitoring data is difficult to obtain and thus virtually non-existent. Stability is believed to be affected to a significant degree by excess pore pressure generated in the foundation. Pore water

pressures may rise to critical levels, resulting in instability if shear strains are occurring in a saturated fine grained foundation, and if the rate of generation exceeds the rate of dissipation. The rate of pore water pressure generation is also a function of the foundation slope which in turn affects the rate of foundation strain. Ongoing foundation strain will continue to generate pore water pressure after cessation of dumping. The current state-of-practice in such situations is to recognize the possibility and likelihood of pore water pressure generation and to assess the associated risks of failure. In the absence of reliable pore water pressure prediction, pro-active measures to ensure effective drainage, selective removal of foundation material, or control of mine rock quality and placement rate may be considered. Alternatively, a risk assessment should be performed.

*Three-dimensional Stability* - As noted earlier, advancing dumps over steep terrain within the confines of gullies is beneficial to stability. Complex three-dimensional stability analysis software is available, but relatively simple three-dimensional wedge analyses are often adequate. For failure modes involving foundation sliding, the indicated factor of safety may be increased by up to 15 per cent as the result of three-dimensional effects.

*Factors of Safety* - It is important that factors of safety be evaluated for all sliding surfaces. Assessment of the adequacy of calculated factors of safety should be judged on the basis of the consequences of failure, the sensitivity of the computation to likely ranges of assumed geotechnical parameters, and confidence in the method of analysis based on past precedent. Also, the period of planned existence of the situation under analysis should be considered

### 8.6.3.3 Reclamation

Reclamation strategies incorporated into long-range plans are likely to save money and result in more effective outcomes.

If practicable, dumps should be constructed as a series of wrap-arounds which ultimately form a relatively flat overall face amenable to effective and economical reclamation. Golder (1987) prepared a useful review of the effort required to reslope dump faces. Horizontal cuts are more cost-effective than long downslope pushes. The effort expended for horizontal cuts is proportional to the square of the height of the face. Clearly, a series of terraces require less effort than a single slope with the same overall height.

### 8.6.3.4 Impact prediction

The prediction of the impact of possible failure mechanisms in terms of runout distance, and the environmental, public, and operational consequences are key components of risk assessment. Golder(1994) have developed empirical and analytical methods to predict runout distance. Golder (1993) compiled a database of the environmental, public, and operational consequences of past dump failures. Thus, methods and data are available to conduct risk assessments. Generally, the impacts of past major dump slides have been fairly well controlled and managed. The purpose of objectively documenting past events is to provide a basis for qualitative project risk assessments. Often mine waste slide debris quickly stabilizes and long-term erosion of fines is relatively minor and easily controlled by sedimentation facilities.

*Failure Runout* - Golder (1987, 1993) document the behavior and consequences of the sliding debris from some 40 major dump failures. Failures involving up to about 2 million cubic meters of waste have travelled up to 2.5 km. Mobility is exacerbated mostly by weak or saturated soil within the runout path, and by tightly confined runout paths. Mobility may be affected by dynamic effects within the sliding mass. Precise back-analyses of past events is complicated by the foregoing factors. However, selective comparison with relevant cases is useful.

Figure 36 shows a conceptual plot of the cotangent of the runout angle with height of the dump face. The runout angle is the angle subtended between the dump crest, prior to failure, and the distal toe of the slide debris. The dashed lines are possible trends for predicting runout on the basis of expected conditions.

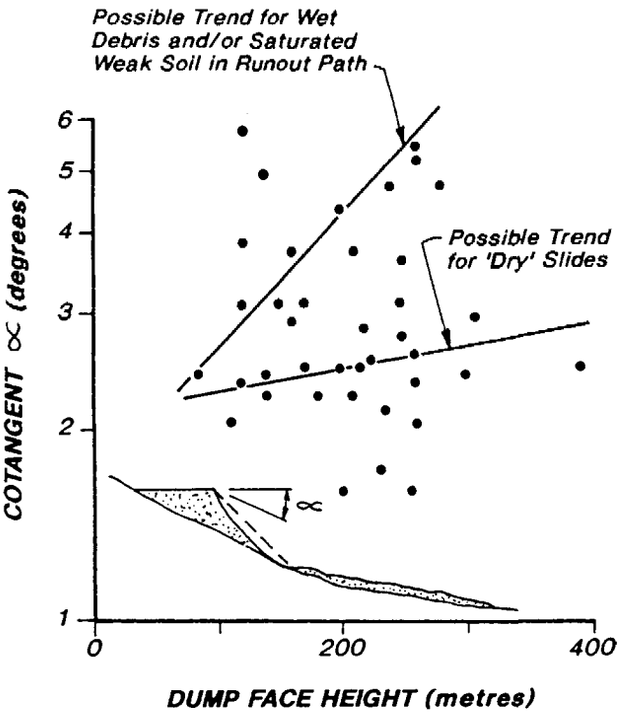



**Figure 36** Dump failure runout angle with dump height.

In addition, the principle of energy conservation can be applied as a general framework for assessing potential runout paths and distances, and the mitigative measures that may be appropriate. Comparison with the runout of major natural mountain rockslides is helpful. Thurber and BC Hydro (1992) have compiled a database of these events. Golder (1994) developed empirical and analytical analyses of selected case histories of dump failure runouts. The results confirmed the importance of the topographic confinement of the runout paths, and indicated two principal categories of mobility. Normal failure runout events exhibited overall base sliding friction angles of about 20 degrees. Highly mobile events, where the runout path was mantled by thick saturated organic soils, exhibited base friction angles of 5 to 10 degrees.

*Rolling Rock* - Occasionally, large competent particles of waste rock may bounce and roll in the course of transit down the dump face. Such boulders may come to rest at considerable distances beyond the dump toe. The maximum distance travelled by such boulders has been observed at many dumps. In the coal mines of eastern B.C. the flattest angle between the dump crest and the furthest rock rollout is about 23 degrees. Elsewhere, slightly steeper rollout angles in the range of 25 to 28 degrees have been observed. The program CRSP, described by Pfeiffer and Higgins (1990) is a useful tool for assessing boulder roll, in conjunction with relevant field observations.

### 8.6.3.5 Mitigation Measures

Various mining operations have developed strategies for dumping short and pushing onto the face if the rates of deformation of the dump crest are higher than a predetermined limit or render the outer portion of the platform untrafficable. In general, concentrated dumping should be avoided. Poor quality waste material should be consigned to non-critical portions of dumps. Limited quantities of poor quality waste may be mixed with good quality material.

*Operational Monitoring* - The use of simple wireline extensometers, as illustrated in Figure 28, has been proven over some 20 years to provide ample warning of impending failures. Intermittent evaluations of other methods of monitoring by engineers and mine operators have not yet found any other methods as practical or effective. A promising modification is the automation of the wireline extensometers which are linked to radio transmission systems used for haulage control.

However, experience shows that continued visual inspection of the platforms of high dumps on steep terrain is essential. Equally important is the training of operations personnel in the significance of the monitoring procedures, and in the implementation of dump closure when threshold rates of movement are exceeded.

The merits of attempting to monitor foundation pore water pressures and deformations have often been debated. The design engineer must consider very carefully the likelihood that his proposed foundation instrumentation would: i) detect the most critical levels present; ii) survive the attendant deformations, particularly if the foundation is steeply inclined; and, iii) permit reliable control of dumping so as to preclude failure. The current state of practice, both analytically and operationally, does not satisfy some or all of these requirements adequately. Field programs which include such monitoring should be regarded as experimental, and not as proven techniques for controlling stability and preventing failures. In critical situations where failure would have unacceptable consequences the design must pro-actively minimize or eliminate those factors that are likely to result in instability. In such cases a high level of effort in the installation and the extent of foundation instrumentation may be justified.

*Instrumentation and Monitoring* - As discussed in the foregoing examples, simple monitoring and visual inspection provides the means for safe operations. Implicitly, or explicitly, mine operators and regulators in some cases have accepted the worst case scenarios of operationally safe failures. Attempts to apply more sophisticated monitoring of parameters including foundation pore water pressures and foundation strains probably would not be practicable or cost-effective as an operational procedure. The practicality of achieving reliable measurements is questionable, although the information potentially available through such monitoring is very attractive to the geotechnical analyst.

Automated wireline extensometers may reduce the cost of reading and maintenance. Nevertheless, continued vigilance by mine operations personnel is very important. The data provided by monitoring should be used promptly to support the judgement of operations staff.

A number of mine operations have conducted programs aimed at relating operational factors, such as dumping rate, to dump performance. Other factors such as material quality and terrain have been evaluated. By tracking these types of information, mine engineers have developed site-specific assessments of acceptable operating constraints. Mine operators should maintain records such as shown on Figure 37.

## 8.7 HEAP AND DUMP LEACH DESIGN

**by M. E. Henderson**

This section introduces the basic concepts of dump and

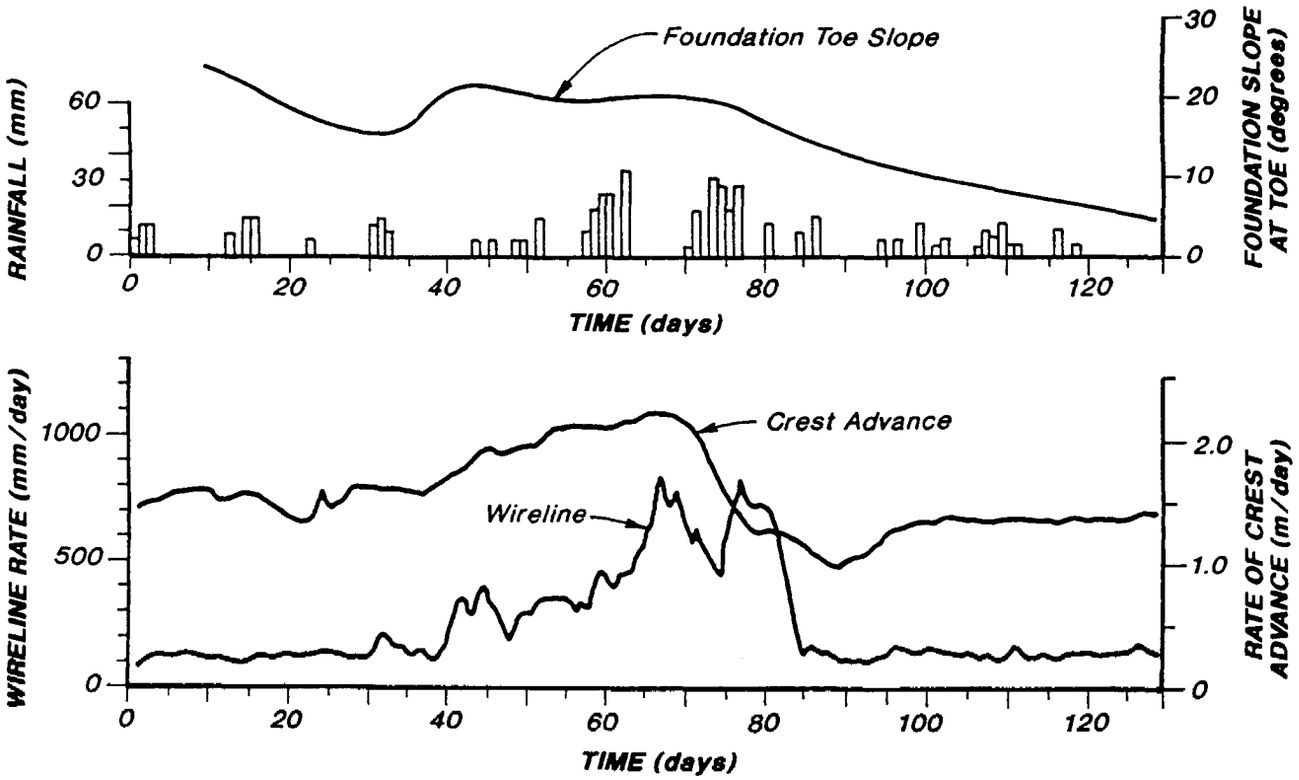



**Figure 37** Typical performance monitoring record.

heap leach design. These design concepts are based upon engineering principles backed up by experience developed during the past several years, during which leaching has become a major mineral processing technique.

## 8.7.1 INTRODUCTION

Heap and dump leaching is the term given to the hydrometallurgical technique of extracting metals by passing a solution through a *pile* of ore. The leachate reacts chemically with the ore, dissolving metals out of the host material, producing a "pregnant" solution. After the solution has passed through the pile, it is collected and transported to a recovery plant where the valuable metals are removed from the solution. This "barren" solution is chemically adjusted and returned to the top of the pile for another cycle.

The leaching process has been used for centuries as an economical method of extracting valuable minerals from the host ore. In more modern times, leaching technology has been commonly used to recover copper, gold, uranium, as well as a wide variety of industrial minerals such as iodine. Heap leaching for the recovery of gold was developed by Heinen, Lindstrom, and others at the U. S. Bureau of Mines during the late 1960's and early 1970's, as an economic recovery method for low grade ores. The first full-scale application of the heap leaching technology was at the Carlin Mine in 1970, followed by facilities at the Cortez and Smoky Valley operations in the late 1970's.

The mining industry has dramatically increased the use of leaching technology since the early 1980's, primarily in gold processing. This increase was in direct response to dramatically rising gold values, following the end of the dollar - gold conversion in the 1970's. Several technological advances were combined during this period, leading to rapid advances in the overall state of the art. These technological advances include an increased ability to economically mine very large quantities of material, developments in the cyanidation and agglomeration processes, and development of effective physical containment systems.

Historic methods of mining and mineral processing involving gravity separation, amalgamation, or flotation circuits and/or carbon-in-pulp (CIP) have been associated with higher grade deposits where the relatively high cost of ore processing is offset by the higher value of the ore. Conventional milling processes often have high mineral recovery efficiencies, with up to 95 percent recovery seen in some mills.

Expansion in the use of leaching technology in the mining industry during the 1980's and into the 1990's has been driven by the exploration and development of large, low grade mineral deposits, reprocessing of existing "waste" material, and a desire to more efficiently extract the available minerals from existing and new ore

bodies. The western U. S. has seen the majority of this development, with dozens of large operations gaining their start during this period. Utilization of leaching technology has been carried to other regions of the world which have similar ore depositional environments. These large, low grade deposits often surround a higher grade mineralized zone, resulting in a combination of milling to process the higher grade ore and leaching facilities to process the ore material which has a grade which falls between that which is economic to process with leach technology up to that which can be economically milled - known as the mill "cut off grade".

The primary difference between selecting milling versus leaching relates to economics. Milling normally is much more expensive, both on a per ton operational basis as well as for capital (construction) costs. Typical mill construction cost to process a 10 million ton oxide (gold) ore body would range from 10 to 30 million dollars, and up. Capital costs for the same size heap leach facility would be in the range of 2 to 5 million dollars (1993 dollars). In contrast, as noted, milling can be expected to recover up to 95 percent of the available mineral, whereas leaching typically accounts for recovery of 50 to 80 percent of the available mineral. Thus, economics dictate which process is selected for a given grade of ore.

*Dump Leach Facilities* - Dump leaching is generally considered the practice of leaching copper from large piles of material that often resemble waste rock dumps, although other minerals may also be recoverable with the technology. These dumps often extend several hundred feet in height, and can contain hundreds of millions of tons of low grade material. In practice, unprocessed ("run of mine") material, or crushed leach-grade material which is below the mill cut off grade, is placed in large dumps which are constructed using truck end-dumping practices. Under current environmental regulations, these dumps are typically constructed on a lined surface, although a few states allow for unlined dump leaching facilities to be constructed, providing that alternate methods of solution containment be available - for example, geologic structures which provide a barrier to solution migration.

Once constructed, the dumps are irrigated with a process solution, typically dilute sulfuric acid in the case of copper dump leach facilities. The solution percolates through the dump, replacing copper ions with ferric ions, until the leachate reaches the solution recovery system. The pregnant or "PLS" solution is collected and routed to a lined interim surge (PLS) pond before processing.

The mineral recovery circuit for copper generally involves an electrowinning circuit wherein the copper in solution is electrically plated onto steel wool, removing the mineral from the solution. The copper is removed from the steel wool in an electric furnace.

Barren solution from the recovery circuit, known as "raffinate", is pumped to a lined storage pond prior to reapplication to the dump. Figure 38 is a schematic diagram for a typical dump leach system.

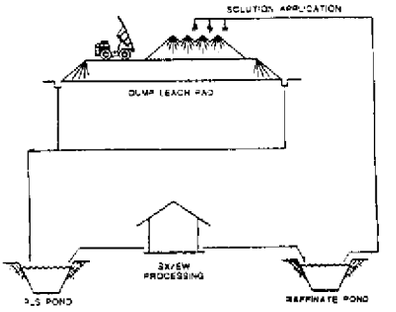



**Figure 38** Schematic typical dump leach system.

*Heap Leach Pads* - Heap leach pads are basically a refinement of the dump leach technology, where the refinement is to provide additional effort to process the ore and to contain the solution. As before, ore which is sub-mill grade but economical to process with heap leaching techniques is segregated and placed on a lined surface. This heap leach ore may or may not be crushed, depending on the optimization of the economics associated with increasing crushing costs and increased recovery rates. Generally, smaller-sized ore has higher and faster recovery rates, but with increasing processing costs.

Generally, there are two types of leach pads: flat pads and valley fills.

Flat pads are relatively flat facilities constructed with shallow grades typically between 1 and 8 percent. The ore is placed on these pads in layers, producing at least 2 freestanding outer slopes. Flat pads are the most common type used for their many advantages over valley fill pads. Advantages include relatively low heights, uniformity of material thickness, better solution control, and relatively high recovery rates. The primary disadvantage is that a naturally level area is required to economically construct such facilities without excessive earthwork costs.

Flat pads may be either single- (dedicated) or multiple-use (reusable) facilities. A dedicated heap leach pad provides the location for the processing and subsequent detoxification and closure on the pad. A reusable pad allows for processing and detoxification on the lined facility, after which the material is removed and disposed of in an unlined, on-site area. Following removal of the spent ore, the reusable pad is available to batch-process another cycle of fresh ore.

Valley fills are constructed in hill or mountain terrain that does not allow for flat pad construction. A valley is selected which has sides not steeper than about 3

(horizontal) to 1 (vertical). The heap leach ore is placed in the valley in individual layers, contacting both sides of the valley for structural support. The downstream face may be free standing (exposed ore) or may be supported with a full or partial height buttress. Valley fills have always been single use facilities, wherein the low grade material is processed, detoxified, and closed in-place.

### 8.7.2 SITING

The siting of heap and dump leach facilities must carefully consider both economic and environmental aspects, optimizing the cost of the facility while minimizing the potential for environmental impact. This economic and environmental view of the siting process must be performed from a long-term prospective, considering the operational life of the facility as well as closure and post-closure issues. In short, every proposed facility must be located and designed with closure in mind.

*Siting*, as defined herein, is the logical, systematic, and defensible methodology which is used to evaluate a number of possible locations for a facility, resulting in the "best" site. The *best* site is then defined as the location which properly balances technical issues, economics, social (political) issues, and environment impacts.

The process of siting involves identification of potential sites for the given processing requirements, identification of the site selection criteria, evaluation of each site against the selection criteria, and ranking of each site.

*Identifying Candidate Sites* - Potential sites are selected in the area surrounding the ore body(s). It is important to note that the location of the ore body is always fixed; a fact that is sometimes not fully understood by the public. Generally speaking, the area which should be evaluated for potential sites extends out from the ore body, to a distance at which haulage costs make the project uneconomic; e.g. below the minimum rate of return as defined by the investors.

As an example, assume that a mining company has found a 10 million ton low-grade gold deposit which has a recoverable grade of 0.08 oz/ton. Assuming that the price of gold for purposes of feasibility studies is $350 per oz, this material is worth $28 per ton. Capital, operating, and development costs are estimated by the company to be in the range of $275 per oz ($22 per ton), resulting in an available "profit" of $6 per ton. With a minimum rate of return on the investment of 15 percent, the required profit per ton mined is $3.30. This leaves $2.70 per ton available for a "cushion" or contingency factor; unanticipated cost overruns in construction, operations, downturn in metals prices, etc. Assuming that the owner requires $2 per ton to cover the unexpected costs corresponding to a contingency factor of 9 percent, $0.70 per ton is available as incremental ore haulage costs. At an incremental haulage cost of $0.15 per ton-mile, the largest economic radius for potential pad sites is about 5 miles. This radius assumes that the terrain is approximately equal in all directions and that the haulage road construction and operational costs are not significantly high (i.e., relatively flat terrain).

When selecting a site, any critical flaws can be used to remove the site from further consideration. Critical flaws are those physical attributes that will preclude development of the desired facilities. Examples of critical flaws are site characteristics which are precluded by law such as being in a flood plain, near surface groundwater, etc., and physical attributes such as inadequate size, active earthquake faults, landslides, areas prone to liquefaction, and historic underground structures that may collapse under load.

The initial selection of potential sites should be limited only by technical feasibility and the economic haulage distance, without disregarding potential sites because of preconceived ideas. Too often, potential sites are prematurely eliminated because of property ownership, environmental issues, and construction costs, without fully evaluating the site. This pre- evaluation elimination of potential sites can result in discarding a site which would have resulted in the lowest overall impact and optimal cost, if subjected to the full site evaluation process. For example, if land ownership is used to limit sites, the final site selected may be located at some distance from the ore body, resulting in a corresponding increase in total costs due to the increased haulage. This total cost can easily exceed property acquisition costs for a given site. Utilizing the data from the previous example, each mile of increased haulage results in an increased cost of $1.5 million, which could be used to acquire a significant amount of property. Similarly, prematurely utilizing environmental impacts as a limiting factor can result in avoiding a close site which is seen to cause an undesired impact (wetlands for example) in favor of a more distant site which has a less significant site impact but results in greater total impacts because of the increased areal extent of the operation.

*Site Selection Criteria* - Site selection criteria are those parameters which are used to individually evaluate sites for each project. These parameters can include site characteristics which are common to each site in addition to unique characteristics; however, it should be noted that it will be the unique characteristics which are ultimately used to compare and rank each individual site.

The most common method of evaluating each site is to subdivide the site characteristics into those dealing with technical, environmental, and social or political issues. These groups of parameters are generally not combined during the site selection process to result in a

single, combined relative ranking score, but are maintained as individual groups. The reason for maintaining this separation is that it is difficult to combine or compare economic impacts to environmental or social impacts which cannot easily be assessed in economic terms. This separation into broad classifications is expected to become less common, as methodology for evaluating the economic impact to environmental issues becomes more accepted, mostly driven by the emerging area of the federal natural resource damage assessment (NRDA) law.

Typical site selection criteria for the technical classification may include:

- Site capacity
- Site grades
- Ability of the site to be expanded
- Construction costs
- Haulage costs (distance and elevation)
- Difficulty in seasonal operation
- Infrastructure requirements
- Closure and reclamation costs

Similarly, site selection criteria for the environmental classification may include such issues as:

- Proximity to wilderness areas, or wilderness study areas
- Presence of wetlands
- Potential for impact to flora and fauna
- Sensitive, threatened or endangered species
- Visual impacts
- Impact to surface and subsurface water resources
- Environmental consequences of system failure
- Cultural resources impacts
- Difficulty in permitting

Finally, the site selection criteria for the social/political classification includes:

- Perception of the project by local people and/or regulators
- Chance for the project to run into opposition from environmental groups
- Recreational land use for the project site (i.e., hunting, fishing, camping, etc.)
- Recreational land use of individual sites
- Visual impacts
- Perceived environmental impacts, or risk of impacts
- Socioeconomic impact to the local/regional area
- Post-mining land use value of each site

Once the criteria for each classification have been identified, a relative weighting factor is assigned to each criteria within each classification. These weighting factors are generally established through coordination between various technical specialists, particularly regarding the environmental classification. For example, assuming that a 1 to 10 scale is used, a particular project may weight impacts to wetlands as 5 (mitigatable), impacts to fisheries as a 9, impacts to elk calving areas as a 6, and visual impacts as a 3.

*Ranking* - Once the potential sites within a reasonable radius of the ore body have been identified and the site evaluation criteria have been identified and agreed upon, the site ranking process is performed. First, each site is evaluated against the given criteria. Relative scores are assigned for each site in each criteria, often based on a scale of 0 to 10, with 0 corresponding to no impact or problem and 10 corresponding to unavoidable, major, and non-mitigatable impacts or significant economic impacts.

The technical classification may be ranked by cost, with a pre-feasibility level design conducted for each site. This ability to rank sites solely on economic factors is unique to the technical arena; the environmental and social impacts do not generally lend themselves to economic impact analysis - at least any that would be agreeable to the public.

The criteria ranking and the weighting of each criteria are utilized to provide a numerical summary of each site, in each broad classification. The overall site rating is determined by multiplying the criteria weight by the site rating for that criteria and adding each sum. More specifically, if $w_i$ is the weight for criteria $i$ and $x_{ij}$ is the rating for criteria $i$ for site $S_j$, then the site ranking $r(S_j)$ for $S_j$ is calculated from:

$$r(S_j) = \sum_i w_i x_{ij} \qquad (8.7.2\text{-}7)$$

This site ranking can easily be set up in a computer spreadsheet format, which allows for easy ranking of the sites and for the use of sensitivity analyses. In terms of ranking, the site with the lowest overall score is presumed to be the "best" site. Often, sites will rank differently between the three classifications. In this case, sound technical judgement is balanced with input from regulatory agencies and the public to select the optimal site.

The next step in the ranking process is to conduct a sensitivity analysis of both the relative weight given for each criteria and the site specific score that each site received for that particular criteria. The sensitivity analysis is conducted by varying the numerical weight or score between the highest and lowest probable values, and investigating the resulting impact to the overall site ranking. This analysis is used to evaluate the potential for altering the site selection process depending on the input parameters. Any weights or site evaluation score which dramatically impact the final site ranking should

be reevaluated carefully to ensure that the proper site was selected.

This type of site selection is very conducive to a risk-based approach, as described in detail in Section 8.6.3. For a risk- based site selection process, the weighting factors and the site specific scores can be statistically varied, resulting in the best statistically selected site. A variation on this overall approach is to utilize Bayesian decision theory, wherein each site is assigned an individual probability of success (or failure). Additional information on utilizing decision theory for site evaluation is contained in Benjamin and Cornell, (1970) and Howard and Matheson, (1983). Additional information and a more rigorous treatment of the siting process is available in Keeney, (1980).

### 8.7.3 ENGINEERING DESIGN

Heap and dump leach facilities are always designed to protect the environment while processing ore in a reliable and economic manner. All such facilities are designed as *zero-discharge*, which means that the entire system which can potentially contain process wastes (liquid or solid) is adequately separated from the environment via engineered structures.

Zero discharge facilities are regulated under federal and state regulations, are based upon the federal Clean Water Act (CWA). Under the CWA, waste facilities are regulated if they have the potential to degrade or contaminate jurisdictional waters. Jurisdictional waters are typically taken to include surface and ground water, thus encompassing nearly all mining facilities. In the past, arguments have been made that dump and heap leach facilities should be exempt from these regulations since they are material processing facilities and not waste disposal facilities. These arguments have been discarded since most dump and heap leach facilities become the final repository of the spend or processed waste in-situ, thus becoming waste disposal facilities at some point in their life. The desire to make this distinction between processing facilities and waste disposal facilities can be traced to the Resource Conservation and Recovery Act (RCRA), and the mining exception from regulation under RCRA via the Bevill Amendment.

The design of dump and heap leach facilities follows two basic engineering philosophies: design by *function*, and design by *regulation*.

In the design by function mode, each element of the facility is designed to meet site- and project-specific requirements. For the design by function, each element of a facility is engineered to remain functional under an expected service or "loading" condition. This philosophy carries to every aspect of a facility design, both on an individual and systems basis. For example, if a slope is required to be stable under static and earthquake loading conditions, for the given material properties, an engineer performs an assessment to determine the maximum stable outer slope. The slope can be further flattened to incorporate uncertainty in the material properties, actual static or earthquake loading conditions, or the analysis methodology itself. This allowance to account for uncertainties is reflected in a *Factor of Safety*, in deterministic analyses.

A more mathematically rigorous and technically correct method of analysis is based upon a statistical assessment of any or all potentially variable or uncertain conditions. This design method is known as *risk analysis*, wherein each element (or system) is designed to produce a required likelihood of acceptable performance - noted as *reliability*.

The design requirements can be deterministic or risk-based, depending upon the level of flexibility available for the facility design. Often, risk-based decisions are made by design engineers, owners, or regulatory personnel without being consciously aware of the basis for a decision. For example, a more rigorous liner system is often required or designed when groundwater is near-surface, without necessarily evaluating the potential for contamination to occur.

Design by regulation occurs when regulatory bodies attempt to set minimum performance standards. By the very nature of setting standards, rigid design criteria or requirements must be established for the worst case which can be expected (or envisioned). This means that facilities, for example solid waste disposal facilities which are regulated under Subtitle D of RCRA, in downtown San Francisco (California), Fairbanks, Alaska, and Beatty, Nevada would be designed to the same prescriptive standards. Clearly, each project site has unique problems and characteristics that should be addressed, to result in a final facility design that meets the environmental desires of owners and regulators alike, without becoming exceedingly expensive.

The regulatory trend today is to set performance standards which provide for public safety and environmental protection, while allowing engineers to earn their pay - designing unique, site-specific facilities. This approach has the added benefit of placing liability with those responsible for facility performance - as it should be. These performance standards typically consist of general facility goals plus minimum performance criteria.

For example, all leach facilities are to be designed to not allow release of process solutions to the environment. The conditions for which a release must not occur include normal operating conditions and extreme events. The design "return period" for the extreme occurrences are defined, and are typically taken as a 1 in 100 year event, corresponding to an annual risk of exeedance of 1 percent. Events larger that the design event are considered "Acts of God", and are acceptable from a regulatory viewpoint.

*Facilities Layout* - Proper design of dump or heap leach facilities incorporates natural or existing topographic features into the final configuration. In difficult terrain, the basic facility type may be dictated from the available area - for example, a steep site may result in a valley construction technique, where otherwise a flat pad may have been more desirable.

The first step in the physical layout of a facility involves determining the size required for a given tonnage of material to be processed. As an example, assume that a mine owner had determined through exploration drilling that the proven and probable ore tonnage was 10 million tons (short). At a somewhat typical in-place ore density of 90 pounds per cubic foot (pcf), the required volume for processing is 222 million cubic feet. For an estimated heap height of 200 feet, the average square side dimension is approximately 1,100 feet, after factoring the volume required by 10 percent to allow for side slope inefficiencies.

The maximum heights of either dump or heap leach facilities is determined primarily from the ore chemistry and physical properties during leaching. A durable ore which does not degrade during leaching can obviously be stacked to greater heights that an agglomerated ore which tends to become less permeable with increasing heights, sometimes to the point where recovery is adversely affected. Over the past decade or so, leach heights have steadily increased, as the industry gains confidence in the performance of the liner system and in the ore recovery rates. Ten years ago a 100-high lined facility was the typical limit of confidence; now heights of 300 feet are common and several are in the planning and design phase which approach 700 feet.

The critical assumption in this computation is the dry density of the ore which is resident on the pad area. Typical values range from 70 to 110 pcf, depending on material type and agglomeration, if any. A reasonable approach is to estimate the ore density during the preliminary or feasibility-level design stages, and refine the estimate with the use of column tests during the final design.

A refinement in the calculation of pad size requirements and associate layout configurations is to evaluate the potential for a phased approach to construction. If a facility is to process ore from a mine over a period of several years, it makes little economic and technical sense to fully construct the facility. A more common approach is to manage capital expense outlays, wherein an incrementally-constructed facility is built. The duration or length between construction cycles varies, depending primarily on mobilization and/or demobilization costs, with 2 years being somewhat typical. Less than two years severely constrains operators to a rigid schedule; more than two years represents the outlay of a significant amount of capital before it is needed.

Civil layout of the project facilities includes the pad area and ancillary facilities, including diversion structures, roads, and solution containment ponds. Efficient design of the entire facility strives for minimizing construction costs, usually resulting from construction volumes and costs.

A flat pad type design should be constrained by available slopes on which to construct the pad area. Typical slopes range from 1 percent to about 8 percent in overall grades. Less than 1 percent begins to present quality control problems for the construction contractor, and can result in inadvertent ponds being left in the pad interior. Slopes greater than 8 percent often result in slope instability, unless other mitigating measures are undertaken such as buttressing, flattening the toe area or the outer slope, or increasing the frictional strength of the liner system in the downstream toe area.

Both valley fill and pad type designs should be limited to maximum interior slopes of 3 to 1 (horizontal to vertical), unless special construction techniques are used. This limit of 3 to 1 has been established to allow for proper installation of a geomembrane liner, without causing undue problems with subgrade construction or placement of the geomembrane.

*Liner System Design* - As noted elsewhere in this handbook, the proper design of the liner system is critical to the performance of a dump or heap leach facility. Failure of the liner system represents the compound potential effect of serious environmental degradation and the potential loss of valuable solutions. Thus, it is in everyones' interest to provide a liner system which functions as desired - fully containing solutions, while maintaining it's functionality under the expected range or operating conditions and useful life.

The approach used herein is based upon a systems analysis - indeed the function of a containment barrier is dependent upon each piece of the system working as designed. This systems approach incorporates the cover material, hydraulic head reduction layer, primary and secondary liner, leak detection layers, and underdrains as a single, working system.

Most, if not all current regulations require the use of a geomembrane liner as part of the liner system. As noted under the previous discussion on risk, the redundancy or reliability of a liner system typically includes some value judgements by the regulatory agencies who are dictating the minimum, acceptable design technology.

Current, "best available control technology" or BACT incorporates the use of composite liner systems, where a geomembrane liner is in direct and intimate contact with an underlying, low permeability soil liner. This composite liner has been shown to reduce expected leakage by about five order of magnitude (10,000 times) as compared to a geomembrane liner overlying a sand

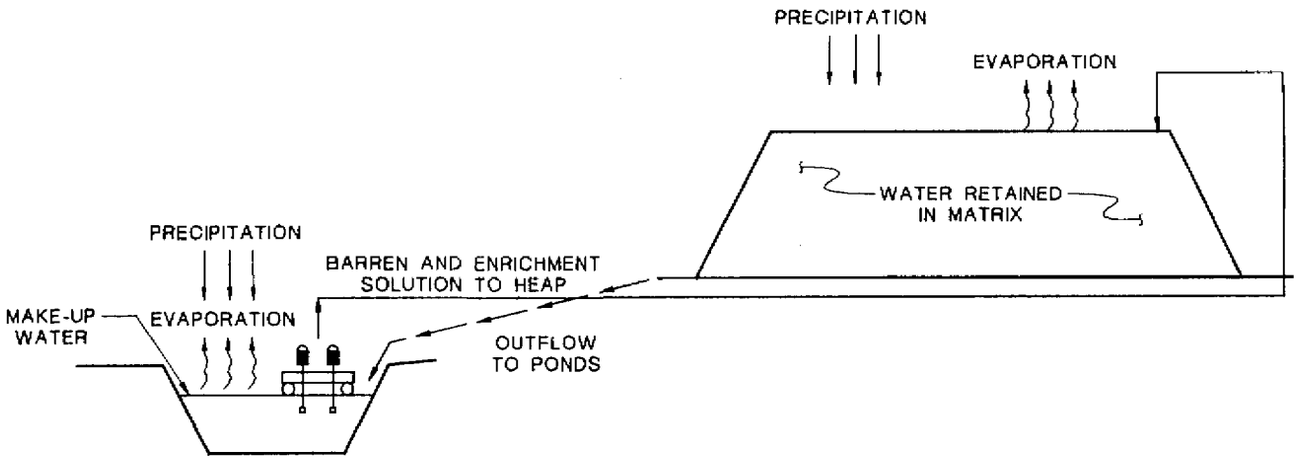



**Figure 39** Schematic water hydrological cycle.

leak detection layer or permeable subgrade.

The cover material which is placed between the upper geomembrane liner and the ore to be processed is critical to the success of constructing the liner without damage, while minimizing hydraulic head on the underlying liner. The type and thickness of the cover layer is determined by the size and angularity of the material to be used for cover construction, geomembrane type, and the type of construction equipment to be used in placing the cover material. Typical thicknesses are 24 inches for minus 1 inch cover material placed by dozers on 60-mil high density polyethylene (HDPE). Full scale field tests are generally recommended to prove or disprove a cover material placement prior to usage over the entire facility.

One of the key issues in a liner design is selection of a geomembrane type and associated thickness. Many technical papers are available to guide engineers on the selection of geomembranes.

The basic guide for selection of a geomembrane type should be to match the material properties to the project requirements. No single liner type exists which will be the best possible geomembrane under all conditions. The most common geomembrane types are high density polyethylene (HDPE), low density polyethylene (VLDPE, and others), and poly vinyl chloride (PVC). HDPE is generally considered the most resistance geomembrane to sunlight and chemical exposure. HDPE is less flexible that VLDPE and PVC, making it less puncture resistant and more susceptible to sliding. Conversely, PVC and VLDPE have been found to degrade rapidly in exposed conditions, requiring special treatment or allowance for exposed surfaces.

Monitoring the performance of the composite liner system can be accomplished with a variety of techniques including underlying leak detection layers and the associated secondary liners, monitoring wells, lysimeters, hydrogen cyanide gas meters, and electrical techniques.

*Water Balance* - Proper modeling of the water balance is critical for environmentally acceptable operation of a dump and heap leach facility. As noted, all such facilities are designed to operate under normal and extreme events without discharging to the environment. These zero discharge facilities must fully contain normal and excess solutions which result from extreme events.

Since most facilities are exposed to the elements, care must be taken to "balance" the amount of water needed in the process with the amount of water that enters or leaves the system. Makeup water may be required in dry regions where the net evaporation exceeds precipitation and creates a deficit water balance.

Conversely, a surplus water balance may occur in wet regions or climates where a significant portion of the year's precipitation or snowmelt is concentrated in one season or isolated storms. Particularly in the case of surplus situations, strategic planning must address fluid management measures which avoid building up excess solutions to the point at which emergency storage is lost or an uncontrolled release occurs.

Figure 39 is a schematic diagram of the water hydrological cycle which is typical for leach facilities.

Computer models are typically used to predict deficit or surplus water balances on annual and life of facility bases. These models use a realistic systems approach to water balance calculations and are set up to allow the engineer or operator to calibrate the model with actual system responses during operations, allowing the model to be the "best" possible fluid management tool, forecasting future system responses and allowing operational measures to be undertaken before the situation becomes critical.

The water balance models predict statistical climatological influences and material variability on the

containment facilities based upon historic data from the region or site and operational projections. This helps the client determine how much water (if any) will be needed for the process, and will produce flow predictions for control measures such as storage, enhanced evaporation, and treatment and discharge.

The basic equation for setting up a water balance model is based upon maximum lined process and pond areas for each phase, quantifying the probable water gained by precipitation, water lost to evaporation, and water retained in the material matrix. The equation is:

$$S_{in} + P + OM_{del} = S_{out} + E + OM_{fc} + \Delta S \qquad (8.7.2.b)$$

where:

- $S_{in}$ = the solution inflow applied during the primary or secondary processing (includes makeup water)
- P = the precipitation that falls directly onto the lined areas
- $OM_{del}$ = the moisture content of the material delivered to the lined areas
- $S_{out}$ = the solution outflow expected to return from the leach area (leachate)
- E = evaporation and evapotranspiration losses from the active and inactive processing areas and from the ponds
- $OM_{fc}$ = the moisture content of the material at field capacity after processing (the difference between OMdel and OMfc is the net consumptive loss)
- $\Delta S$ = changes in storage volume

Two analytical techniques are available for water balance predictions: deterministic (fixed parameter) and probabilistic (variable parameter).

The deterministic models incorporate monthly and operational conditions such as:

Changes in material disposal rates, incoming moisture content, and material type.

Actual monthly evaporation conditions (inactive) and active waste and pond surfaces.

Actual monthly precipitation conditions (rainfall, snowfall, snowpack, rain on snow).

Phased construction additions to the lined containment areas.

Changes in surface sprinkler application rates and wetted surface areas.

Adjustments in spray sprinkler or drip emitter applications for enhanced or reduced evaporation losses.

Observed, computed, or measured infiltration/retardation of precipitation and solutions flows through the waste material.

Time frames for inactive, rinsed, reclaimed, or closed waste management units.

The probabilistic approach provides for a more advances simulation, compared with the deterministic approach, and is valuable for improving predictions of the effects of average as well as extreme wet and dry climatic conditions for operations and closure.

The statistical variability of climatic conditions for precipitations and evaporation is based upon probability distribution functions of the meteorological date in the vicinity of the site. This model can more accurately predict maximum makeup water requirements for the facility and can verify required design storm pond storage capacities for worst-case analyses such as rain on snow during a wet year cycle.

In addition to monthly climatic variations, the probabilistic approach can account for variabilities in the projected waste material properties.

Leach facilities generally operate by applying solution to the top of the facility, collecting gravity drainage or "leachate" in underlying piping which transfers the leachate to lined collection ponds or sumps. These ponds are designed to contain the normal operating volume, plus an allowance for upset conditions such as a power loss, plus a storm allowance.

The normal operating volume consists of a range of depths over which the pumps can operate, combined with the expected daily, monthly, and seasonal variation. For example, large facilities often require leachate storage ponds which are designed for an accumulation of solutions which peak several years in the future.

Volume allowances for power outages provide for emergency storage in case that the incoming electrical supply is disrupted or a mechanical failure of the pumping system occurs. This volume is typically quite large, given the solution flowrates that exit the leach area. For example, if the upset conditions is expected to last less than 24 hours for a 2,500 gpm flowrate, the required emergency storage volume is nearly 500,000 cubic feet. It should be noted that the emergency storage volume is in addition to storm storage volume requirements - given that power outages often occur during intense storms.

The extreme event or storm storage requirements are generally based upon a 100-year, 24-hour storm event. This return period is equivalent to an annual risk of exceedance of 1 percent, and is consistent with the

reliability of other parts of the facility. The source of estimates for this storm is either general regional maps such as those available from NOAA (National Oceanographic and Atmospheric Administration), or a site specific analysis based upon nearby meteorological gaging stations.

Precipitation from storm events impacts the solution conveyance and storage systems via two mechanisms - runoff and infiltration. Runoff from precipitation generally ranges from 10 to 30 percent of the total precipitation for leach areas, and results in a relatively quick impact to the system. The balance of the precipitation is infiltration, which flows downward through the leach material, exiting at a later date. The flow from infiltration is significantly attenuated, resulting in higher flows over a long period of time. Conventional wisdom suggests buffering times ranging from 1 to 3 weeks or more per 100 feet (vertical) of leach material. The actual buffering time, which is the lag between the peak runoff and the peak leachate flow, is dependent on material type, size, field moisture conditions, permeability, and layering. Generally, companies develop estimate of the buffering time from site specific conditions during operations, although several computer models are available assist in refining the estimate.

The advantage of interim solution storage in the heap as a result of infiltration is that the storm storage volume can be significantly reduced, if fluid management techniques are in place to anticipate and deal with the pending storm surge. For example, surplus pumping capacity can be used to apply excess solutions to inactive leach areas until the system is again in balance, or solutions can be moved to other containment systems such as tailings ponds until a system balance is achieved.

*Diversion Structures* - All containment facilities are required to incorporate upstream diversion structures which will divert runoff around the facility. This diversion is generally required to maintain a reasonable and controllable water balance within the zero-discharge boundaries.

Diversion structures, generally consisting of ditch or canal systems, are designed to divert flows resulting from specified storm events. These design storm events are typically specified by the regulatory agencies, and can range from a 25-year, 24- hour storm event to the probable maximum flood - indeed a wide range of possibilities. This wide range reflects as general disagreement among regulators as to reasonable approaches to be used in hydrological design. A reasonable technical approach would be to select a return period or reliability level which is used for all portions of the facility design - for example, the 100- year event that is used for water balance and solution containment models and for the design earthquake event.

All diversion structures should be designed to be stable, avoiding erosion which will lead to either maintenance or failure. Erosional stability is largely a function of water velocity, geomorphology, and the variation between average and peak flows. A good approach to diversion structure design is to select a ditch section and grade which minimizes erosion during design storm events. This ditch section is expect to experience some sedimentation during average events, but will be self cleaning during the higher flows. This approach to design is especially critical if the structure is to provide long term diversion after the facility is closed.

*Foundation Settlement* - Dump and heap leach facilities normally impose static loads on the foundation or subgrade which exceed historic or geologic loads. The only case where this would not normally be the case would be in areas that were covered by glaciers at some point.

The result of these new static loads is that the soils underlying the leach facility compress, in a manner synonymous to a spring compressing. In soil mechanics, this compression is called "consolidation". Even areas that have been previously loaded will experience some consolidation, because of the rebounding that occurred when the load was removed; i.e., glacier melting.

In areas where the foundation subgrade is homogenous in the lateral direction, the settlement will be uniform, varying from nearly zero in the toe area, to a maximum approximately beneath the crest of the fill, at the point of the maximum vertical load.

Analysis of the amount of settlement which can be expected is based upon laboratory testing of the consolidation response of each soil horizon in the foundation. Various equations are available to predict this settlement, depending on the soil type encountered. Permeable soils such as sands and gravels experience settlements immediately upon loading, denoted as "primary settlement" in soil mechanics. Clays and other less permeable soils experience settlement rates which depend largely upon the permeability of the material - thus, the consolidation is controlled by how fast the moisture in the soil matrix can move away as the soil particles try to move closer together. For a more complete reference on consolidation theory the reader is referred to Lambe and Whitman, (1969).

For the basic literally homogeneous strata, settlement is usually not an issue. The two relatively minor topics to evaluate are will the slope from the toe to the crest reverse gradient to the point where solutions are permanently ponded under the leach material, and will the differential settlement between the toe and the crest be sufficiently high so as to exceed the elastic properties of the geomembrane liner. If the outer, downgradient slope is maintained at a minimum of 1 percent, it is difficult to improbable for a reversal to occur. This assumes of

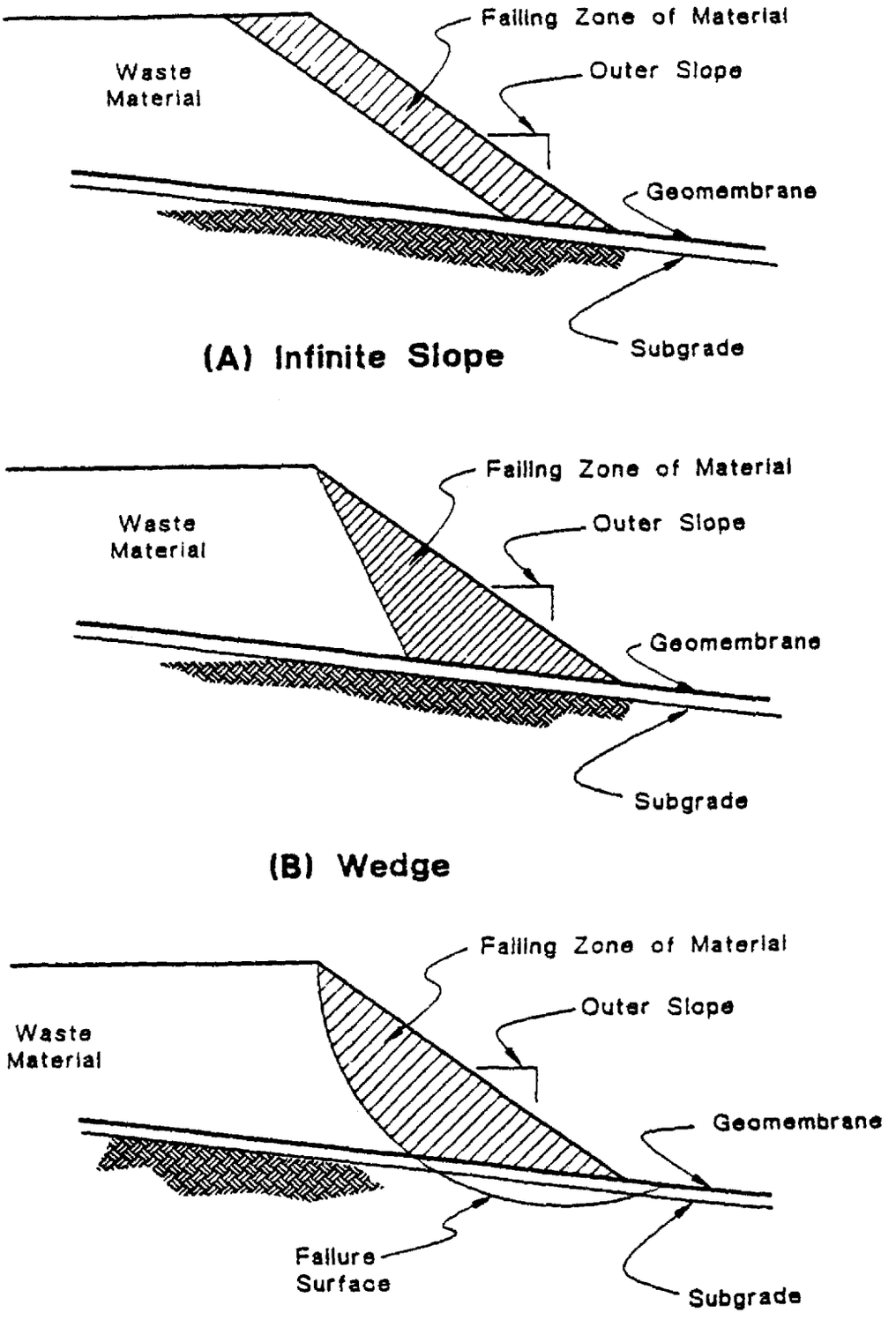



**Figure 40** Failure planes: infinite slope, circular, wedge.

course, that the foundation is relatively competent, as will be required for slope stability purposes. Similarly, the elongation from the zero settlement area to the maximum settlement is improbably with any type of geomembrane, since the incremental elongation along the entire length is trivial.

Settlement becomes more important when non-homogeneous conditions exist under the loaded area. Conditions which can result in rapidly varying settlement conditions under short distances include crossing a fault structure, collapsible soils, and eolian deposits. Each of these conditions can result in serious differential settlements which can lead to liner failure, and should be carefully investigated and evaluated. The techniques for evaluating differential settlement follow the basics as described above.

*Slope Stability* - During the physical layout and design of leach facilities, engineers must select stable outer slopes. This becomes even more critical when using geomembrane materials as a liner, because the geomembrane material has detrimental effects on the overall stability of the slope, and since slope movement will rupture a geomembrane material leading to containment failure.

In order to be stable, slopes must have material strengths of sufficient magnitude to resist movement of the outer face for the selected geometry, under both static and earthquake loading conditions.

Slope instability can manifest itself in many forms, ranging from simple raveling, and near surface sliding (infinite slope failure) to larger and more serious deep-seated movements (circular, non-circular, wedge). Raveling of outer slopes is normally acceptable in an active operations such as a heap or dump leach, but is unacceptable once a final and presumably stable configuration is reached. The more serious slope failure mechanisms are unacceptable, since they represent a major failure or breach in the containment system and often material is transported outside the facility limits.

Figure 40 shows the failure planes for infinite slope, circular, and wedge mechanisms. In each case, failure occurs when the overall driving force exceeds the ability of the structure to resist movement. The factor of safety (FS) is defined as the ration of the resisting forces to the driving forces, with the critical FS equalling unity.

Slope failures are often related to facility operator errors, where a slope is built under conditions not anticipated by the designer. Common examples are where a lined facility is loaded (material placed) in a downhill direction, at or near the angle of repose, and where modifications to the design are made in the field without consulting the original design engineer.

Regulations and common sense dictate that a minimum FS above 1 should be used to design structures involving slopes, in an attempt to provide safe and serviceable facilities over a predetermined lifetime and under various loading and utilizations criteria. Common minimum factors of safety for leach facilities are 1.3 for static loading conditions and 1.0 for earthquake conditions (Harper, 1987). The static case is where the force causing, or trying to cause, slope movement is attributable to the weight of the material being mobilized. The dynamic or earthquake case is where the slope is subjected to a cyclic horizontal and/or vertical acceleration.

Most stability problems associated with geomembranes fall into either the infinite slope or wedge type failure mode, because the failure plane partially follows the geomembrane. The geomembrane represents a weak discontinuity in the mass of the structure, and can have exceedingly low friction angles.

Common slope failures are also limited to infinite slope or wedge modes, because stability problems associated with weak and/or saturated foundations (below the geomembrane) are typically avoided, due to the presence of the geomembrane. Additionally, in a typical operation, hydraulic heads directly on the liner are minimized, and the influence of a phreatic surface on the slope material is avoided.

In general, slope stability analyses involving dump and heap leach facilities are a function of:

Ore material characteristics (friction, cohesion, unit weight, height)
Shear strength of the soil/geomembrane interface
Foundation material properties
Slope of the natural ground
Slope of the outer face
Location of the phreatic surface
Loading conditions (static, earthquake)

This list of stability input parameters can be reduced by not including foundation soil properties, and by assuming that the phreatic surface near the pad outer slope is negligible, especially where hydraulic head drainage layers are included in the design.

A final simplifying assumptions is that the ore material has little or no cohesive characteristics. This assumption is quite reasonable, since most ore is granular, loosely consolidated, and has a relatively small fraction of clay material.

With these simplifying assumptions, the list of input parameters is:

Ore material characteristics (friction, cohesion, unit weight, height)
Shear strength of the soil/geomembrane interface
Slope of the natural ground
Slope of the outer face
Loading conditions (static, earthquake)

**Table 8** Summary of Shear Strength Tests

| Interface | | Direct Shear Tests | | | | |
|---|---|---|---|---|---|---|
| Geomembrane | Interface | Friction Angle | | (avg) | Wet/Dry | Mat'l. FA |
| | | (min) | (max) | | | |
| Geotextile | Clay | 10 | 14 | 12 | Dry | |
| Geotextile | Geonet | | | 20 | Wet | |
| HDPE | Clay | | | 13 | Wet | 25 |
| HDPE | Clay | | | 12 | Wet | 35 |
| HDPE | Clay | 14 | 25 | 19.5 | | 20 |
| HDPE | Clay | 11 | 14 | 12.5 | Dry | |
| HDPE | Clay | 9 | 11 | 10 | Wet | |
| HDPE | Clay | | | 9 | Wet | 28 |
| HDPE | Geonet | 5 | 8 | 6.5 | Wet | |
| HDPE | Geotextile | | | 30.5 | | |
| HDPE | Geotextile | | | 32 | | |
| HDPE | Geotextile | 8 | 10 | 9 | Wet | |
| HDPE | Geotextile | 9.5 | 12.5 | 11 | Dry | |
| HDPE | Geotextile | | | 9 | Wet | |
| HDPE | Gravel | | | 22 | | 36 |
| HDPE | Gravel | | | 21 | Wet | |
| HDPE | Gravel | | | 14 | Wet | |
| HDPE | Gravel | | | 16 | Wet | 31 |
| HDPE | HDPE | 6 | 13 | 9.5 | Dry | |
| HDPE | HDPE | 6 | 11 | 8.5 | Wet | |
| HDPE | Sand | | | 6.5 | | |
| HDPE | Sand | 17 | 18 | 17.5 | Wet | 26 |
| HDPE | Sand | 18 | 25 | 21.5 | Wet | |
| HDPE | Sand | 19 | 27 | 23 | | 38 |
| PVC | Clay | 19 | 23 | 21 | | 20 |
| PVC | Clay | | | 35 | Wet | 33.5 |
| PVC | Geotextile | | | 24.5 | | |
| PVC | Gravel | | | 25 | | 36 |
| PVC | Gravel | | | 20 | Wet | 31 |
| PVC | Gravel | | | 38 | | |
| PVC | Sand | 26 | 33 | 29.5 | | 38 |
| PVC | Sand | | | 38 | Wet | 39 |
| PVC | Sand | | | 19 | Wet | |
| PVC | Sand | | | 33 | | 30 |
| PVC | Sand | 32.5 | 35.5 | 34 | Wet | |
| PVC | Sand | 21 | 27 | 24 | Wet | 26 |
| PVC | Sand | | | 38.5 | Dry | 39 |
| PVC | Silt | | | 30 | Wet | 29 |
| VLDPE | Sand | | | 28 | Wet | |
| VLDPE | Sand | | | 34 | Wet | 30 |
| VLDPE | Sand | | | 28 | Wet | |
| VLDPE | Sand | | | 24 | Dry | |
| VLDPE | Silt | | | 30 | Wet | 29 |

Each of these stability parameters is site specific - and can either be tested in laboratory devices or is a function of the site properties. The key and non-typical parameter in this list is the interface friction of the synthetic liner system. This friction can range from a low of 4 degrees to a high of 20 degrees (+/-), depending on the system being used and the surrounding material properties. Table 8 is a summary of geomembrane shear strengths for various types of materials. Broad license has been used to group the materials into general classifications; specifically test methods, and material types (clays, sands, gravel).

Several conclusions can be drawn from this data. It is apparent that the more flexible membranes result in higher shear strengths, probably due to deformation into the granular material during shearing. Second, and most importantly, the variability of test results is extremely broad, even between similar material types. For example, the HDPE/sand interfacial friction varied between 6 and 27 degrees, depending largely upon the investigator. The primary conclusion from this summary is that for critical structures, the actual interface friction angle should be tested.

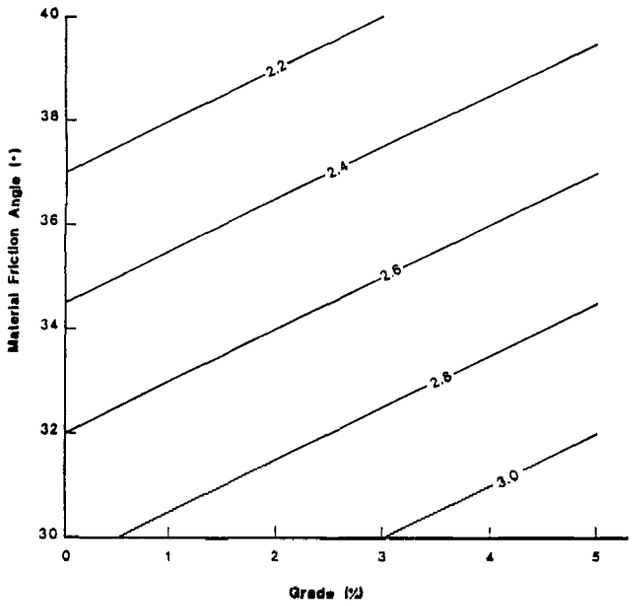



**Figure 41** Slope stability nomograph (HDPE-Clay).

Figure 41 is a generalized slope stability nomograph for a HDPE-clay case. The horizontal axis represents the grade or slope of the subgrade, which is the angle over which slinging on the geomembrane occurs. The vertical axis is the friction angle of the ore material which overlies the geomembrane. The friction angle for the geomembrane interface is assumed to be 13 degrees. The sloped lines on the graph represent various outer face slopes which are considered stable under a minimum FS of 1.3, with increasingly steeper acceptable slopes upward and to the left. Thus for a material where the ore has an overall friction angle of 36 degrees, on a 4 percent slope, the maximum outer slope is 2.6 to 1 (horizontal to vertical).

Figure 42 is a similar nomograph, for the HDPE-sand case, where an average interface friction angle is 17 degrees. In this more stable case, for the assumed conditions as noted above paragraph, the outer slope is

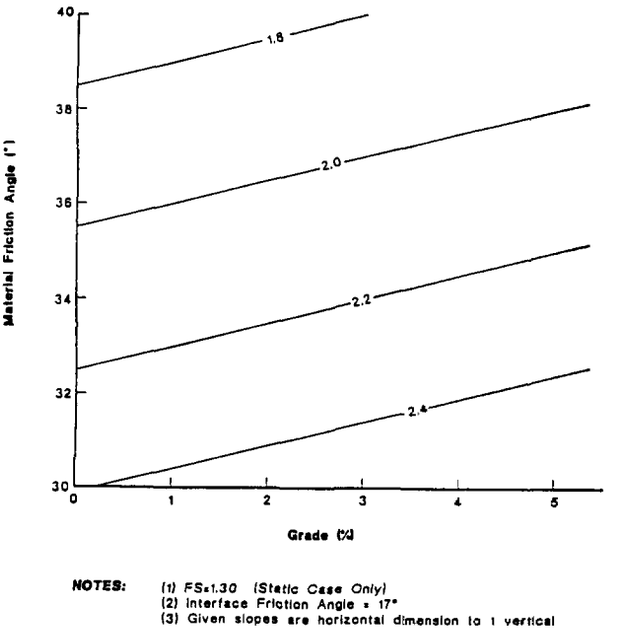



**Figure 42** Slope stability nomograph (HDPE-Sand).

stable at 2.1 to 1.

These nomographs have been provided to illustrate the effect of friction angles on the final outer slope of a geomembrane- lined containment facility. They are not intended to replace a comprehensive geotechnical program, but may be used for feasibility purposes.

## 8.8 WATER BALANCE EVALUATIONS

**by M. L. Brown**

### 8.8.1 INTRODUCTION

#### 8.8.1.1 General

A project water balance is the evaluation of the flow of water from external sources to project elements, from project elements to the environment, and between project elements. A water balance can also be done for individual project elements. It is an accounting of water volume using a selected time step, which can vary from a few minutes to a year in length, depending on the specific objectives of the analysis. A water balance can be a simple manual summation of mean annual values, or it may be a computer model employing complex mathematical relationships. It can be done to evaluate normal conditions, or to determine the behavior of the system under extremely wet or dry conditions. The appropriate type of water balance being performed depends on the specific objectives.

Any water balance is based on the conservation of mass, and can be summarized by the relation:

$$\sum I - \sum O = \Delta S \qquad (8.8.1.1\text{-}8)$$

where:

$\Sigma I$ = the sum of all inflows over the time period;
$\Sigma O$ = the sum of all outflows over the time period; and,
$\Delta S$ = the change in storage over the time period.

This simple relation is made more complex and therefore more useful by subdividing each of the elements, by including various other relationships, and by extending the water balance to many time steps. These refinements are discussed later.

### 8.8.1.2 Objectives

A project water balance is evaluated at several stages during project design. Each evaluation has slightly different objectives.

Early in project design it is important to develop a general understanding of the overall water balance because the results often determine the critical project elements. For example, make-up water supply may be a critical project element because water is in short supply at the project site and significant make-up water is required in order to operate the system; or conversely, excess water in the circuit may be a continuing problem. It is important to understand the magnitude and frequency of water excesses and shortages early in the design process. Water balance problems can be mitigated by appropriate siting of project features and by altering design details.

Later in the project design, a water balance evaluation is performed to determine the size of various project solution conveyance and storage facilities which are necessary in order to meet the criteria for containment. The focus is usually on tailings ponds and heap leach pads, although it is applicable to other project features as well, such as water supply sources. In a typical project design, the water balance provides guidance on the sizing and design of many project features; however, the analysis usually tends to focus on one critical objective. For heap leach pads the water balance must determine the volume of solution storage which must be provided. For tailings ponds, the water balance must address the solution storage and freeboard requirements. Using the water balance as a tool the necessary storage volumes can be determined by comparison of the results to the established design criteria.

### 8.8.1.3 Design Criteria

The criteria used in design are frequently established and published by the regulatory agency having jurisdiction. Less frequently the criteria are selected by the designer and negotiated with the regulatory agency. The criteria are selected in order to control the risk to public health and safety, and the potential for environmental degradation. At present there is general trend away from criteria which specify detailed design requirements, and toward risk based criteria, which require a balance between the consequences of failure and the probability of failure. Detailed criteria might specify the type of liner system for containment of pregnant solutions. Another detailed criterion might involve a specific return period for all solution impoundments. Detailed criteria are relatively inflexible; they do not accommodate innovation, nor do they recognize the importance of performance data for many installations. Conversely, probability based criteria are more general. They might specify, for example, the design storm for a dam's spillway by specifying a relationship between the amount of damage and death due to failure, and the return period of the design flood. For example, if over-topping of the dam could be expected to result in major damage but no deaths, the design flood should have a return period of at least 1000 years. In such cases the design can be made more conservative by either reducing the consequences of failure (less damage) or by reducing the probability of failure (bigger design flood). Probability based criteria mandate levels of risk to be associated with certain consequences. This approach is flexible and can easily accommodate new design approaches and new data from existing systems.

Regardless of the general approach to specifying design criteria, certain expectations regarding risk and consequences tend to be generally held as accepted practice. In industrialized countries the standards tend to be more stringent than in developing countries; however, the differences are diminishing with time. The principal criteria used for tailings dams and heap leach pads in North America are summarized as follows:

*Zero Discharge* - For any facility which contains a solution which is considered toxic to humans or to the environment, there should be essentially zero discharge (including leakage) of solution under normal operating conditions. Cyanide is considered toxic as are many metals in very low concentrations. Solution water can be released if it is treated such that it is no longer toxic. One exception involves dam safety considerations as explained below.

*Dam Safety* - The design event or inflow design flood (IDF) for an embankment or impoundment is frequently proscribed in a probabilistic manner. Dams which would result in major loss of life are frequently designed for the probable maximum flood (PMF). Dams for which failure is very minor are often designed for a flood with a 100 year return period. These are the two extremes; most

IDF's lie between these events.

Recognizing the fundamental conflict between a zero discharge facility and a spillway discharge, design engineers and regulatory agencies often define two floods: the first is the zero discharge flood and the second is the IDF or dam safety flood. The zero discharge flood is one which, if it occurs, will not produce any contaminated discharge or release to the environment. This is usually accomplished by storing all runoff resulting from the flood in a dedicated volume which is maintained between the operating water surface and the spillway crest elevation. The zero discharge flood is usually moderate in size, normally in the range of the 100 year to 500 year event. By comparison the IDF is permitted to result in spillway discharge. The IDF is selected to prevent the sudden and catastrophic release of the contents of the facility. Typically these events have return periods from 1,000 years to 100,000 years.

*Diversions* - Diversion ditches are commonly used to control run-on, or divert uncontaminated flow from neighboring areas. These are typically modest sized, unsophisticated ditches without elaborate erosions protection or high capacities. This is done in high precipitation areas to prevent unwanted water from entering the contaminated circuit, and minimizing treatment costs. For the purposes of computing design flood events, both the zero discharge event and the IDF, these ditches are usually assumed to fail. If special provisions are made in the design of the ditches, this assumption could be altered.

*Normal Operations* - Operation of the facilities under *normal* conditions must be demonstrated. Normal operations must be shown to meet the design criteria. This usually means monthly operations over the life of the facility. Normal conditions must include a range of climatic conditions, from expected wet events to droughts, sequenced in all reasonable manners. The return period of the most extreme events being addressed should be selected to be in the range of the expected life of the project. For example, if the life of the project is 10 years, the water balance simulation should include a month or year of flows (both wet and dry) with a 10 year recurrence interval, but not a 1000 year storm event which will be addressed separately.

*Draindown* - For heap leach pads, the draindown of the solution in the pad must be considered as part of the design event. Draindown occurs in two ways: first, normal operations result in draindown. As leaching moves from high heaps with large volumes of stored solution to low heaps with small volumes, excess solution appears in the storage ponds. Second, uncontrolled draindown occurs following power failure when recirculation stops.

*Storm Runoff* - Runoff resulting from the design flood, or design precipitation event, must be included in the water balance evaluation. This is an extreme event, either an IDF or a zero discharge flood, which occurs over a relatively short duration (hours or days). The runoff resulting from this event is superimposed on the normal runoff used in the water balance analysis

*Snowmelt* - The potential for rapid snowmelt must be considered in determining the maximum draindown volume for a heap leach pad. Similarly, a tailings facility should be capable of accommodating the runoff resulting from an unusually deep snowpack.

*Power Failure* - A heap leach storage pond must be capable of storing all the solution which will draindown if the power to the recirculation pumps is interrupted for an extended period.

*Suspended Operations* - The project design must include contingency plans in the event mining is forced to cease operations for an extended period for any reason. Poor commodity prices or labor conflicts are the most common reasons for suspension of operations.

## 8.8.2 LOCAL HYDROLOGY

### 8.8.2.1 General

Any comprehensive water balance must begin with good site hydrological information, because most elements of the water balance are based on hydrology. This includes estimates of direct precipitation, expected discharges from streams as well as runoff resulting from design storms, snowmelt and overland flow resulting from precipitation on both disturbed and undisturbed areas.

### 8.8.2.2 Streamflow Data

Discharge data for streams near the project site are the ideal data for use in evaluating the site hydrology; however, the available data are rarely adequate because data must be collected at one or more specific locations over a relatively long period of time. Discharge data provides a basis for estimating the expected runoff from various portions of the project area if the basin conditions in the gaged basin and in the project basin are hydrologically similar. Discharge data is sometimes available for undisturbed areas and can be applied to similar areas. At operating mines, discharge data is sometimes available for disturbed areas and/or hydrologically unique areas such as heap leach pads.

Data sources in the North America include the United States Geological Survey (USGS) and (CANMET). Federal agencies are typically responsible for collecting, compiling and distributing discharge data, although state

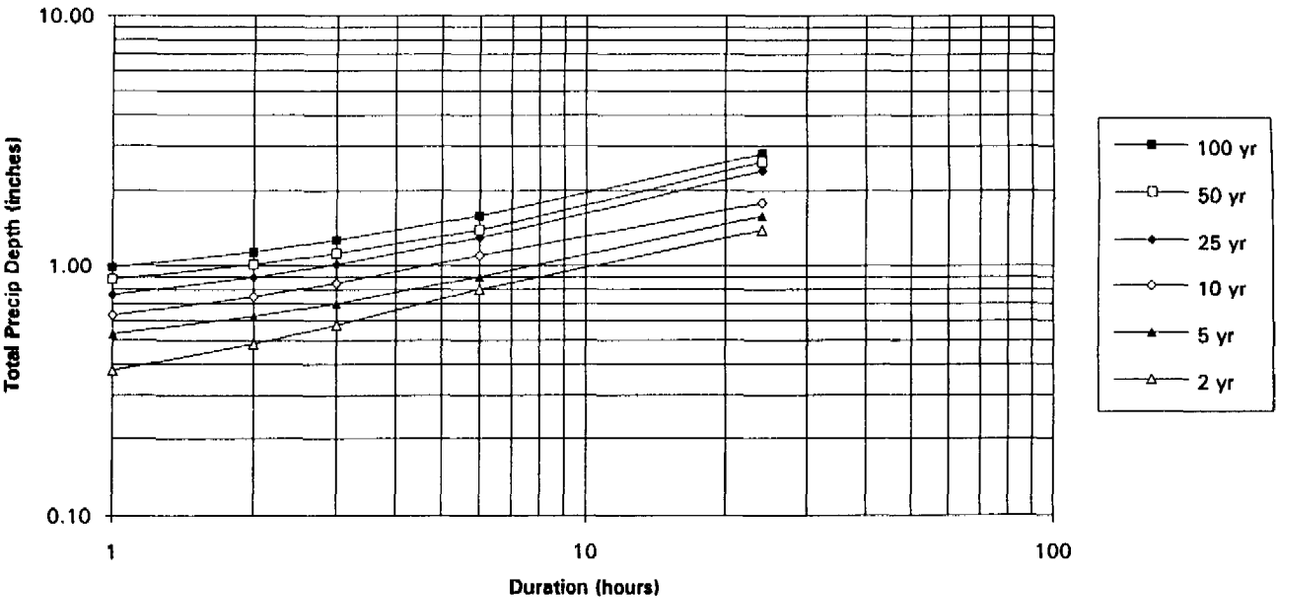



**Figure 43** Storm precipitation depth-duration.

and municipal agencies sometime possess data not available elsewhere. Recently commercial organizations have begun selling discharge data on CD- ROM. This is an ideal method for identifying and collecting relevant data, because the CD-ROM data can be searched by one or more of the station parameters including data type, stream name, longitude, latitude, and period of record.

The most common type of discharge data is mean daily discharge, expressed as volume per unit time. This data is more than adequate for most water balance analyses since volume is the primary concern. Ideally the period of record for the data will be of sufficient duration that it includes both wet and dry years. In order to be useful the data must include, at a minimum, one complete hydrologic cycle (one year).

Stream discharge data can also be used to evaluate peak discharge or storm events. In fact, using discharge data is the ideal method. However, the data must be long-term and the data must contain instantaneous peak discharges, not mean daily values. In a small basin, storm discharge can vary widely over the course of a day, resulting in a large difference between the mean daily discharge and the peak daily discharge. For evaluation of flood frequencies only the annual maximum values are required; however, the period of record must be approximately equivalent to the greatest frequency of the event being estimated. For example, if the period of record for a gage is 4 years, the error in estimating the 5 or 10 year peak flow will be reasonable; however, the error in estimating the 100 or 1000 year peak flows will be so large that alternative methods of estimating flood flows will be attractive. The drainage area for the gage must be similar to (within one order of magnitude) the project basins being estimated in order to allow a reliable adjustment of flood frequency data. For example, if a gaged basin is 10 sq km, the resulting flood frequency can probably be used to reliably estimate the flood frequency of hydrologically similar basins ranging in size from 5 to 50 sq km. The peak flood flows for a given frequency are generally proportional to the square root of the drainage area.

A common difficulty occurs when high quality peak discharge data with a long period of record is available for a large drainage basin, while the project areas are very small, often two or three orders of magnitude smaller. In these cases the peak discharge data from the large basin should not be used to estimate the flood frequency of the smaller basin because there is no reliable method of adjusting the results for the size of the basin. Alternative methods (precipitation based) are available which produce more reliable results. One exception to this involves snowmelt, which can be applied over a much larger range of basin sizes than precipitation based floods.

Another common difficulty occurs when discharge data is available for only undisturbed areas, while the project area of interest will have major disturbance. In such cases the flow data must be modified to be reflect the impact of the disturbance and there is little basis for the adjustments. Modifications can appear arbitrary without basis for calibration. In such cases alternative methods of estimating runoff and peak discharge should be used.

### 8.8.2.3 Precipitation Data

*Normal Precipitation* - The normal precipitation for the project site must be estimated in order to evaluate the site hydrology. The data of interest is the mean annual

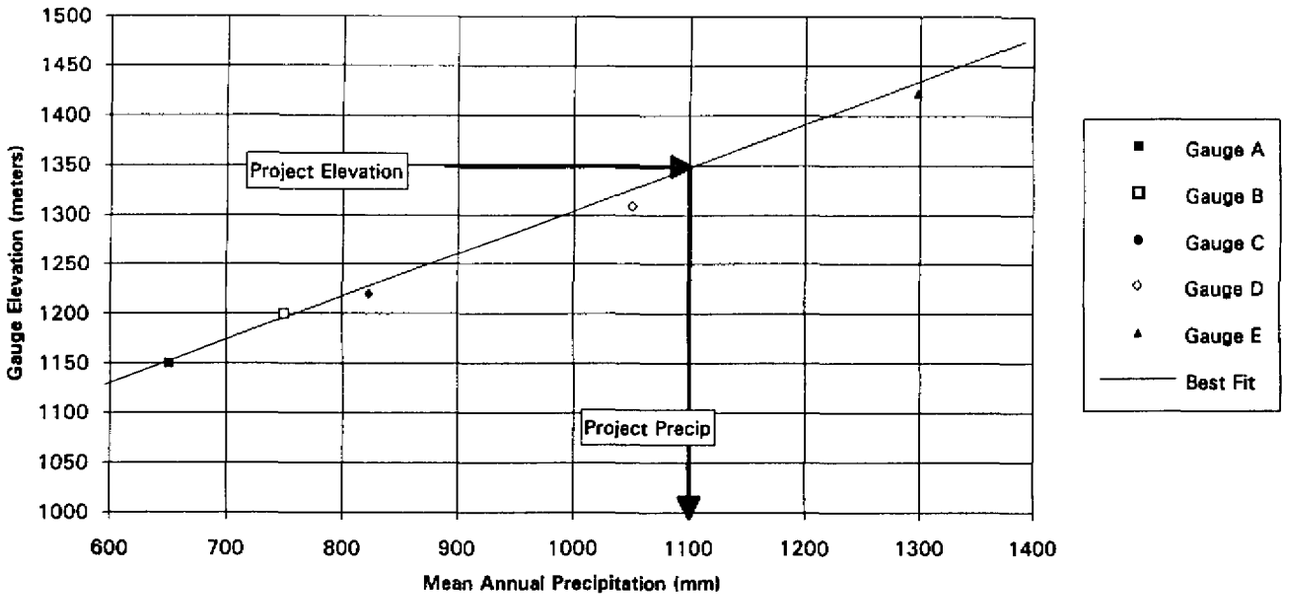



**Figure 44** Precipitation correlated with gauge elevation.

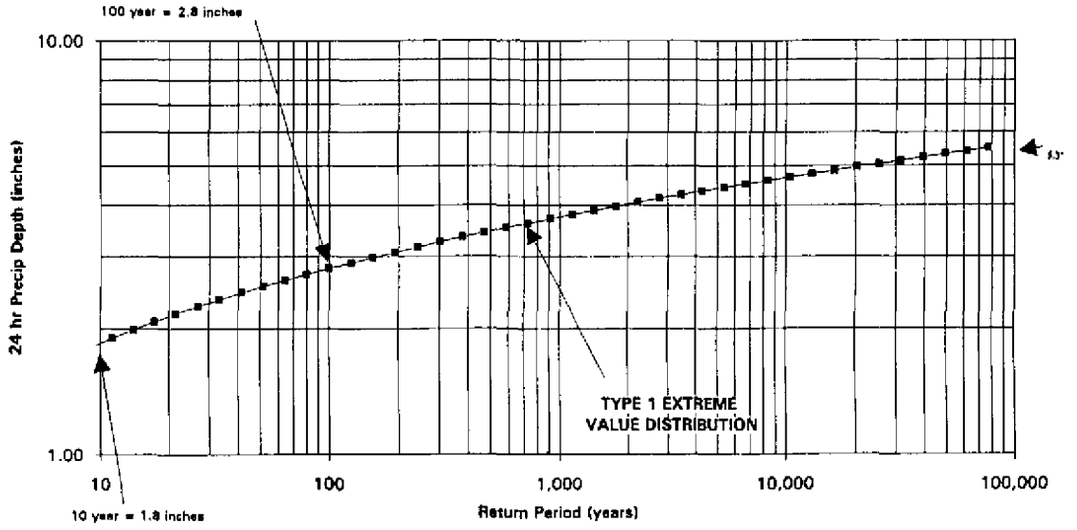



**Figure 45** Extreme value precipitation frequency distributions.

precipitation depth, as well as the mean monthly depths. Daily precipitation is sometimes useful. The estimate is usually developed on the basis of available precipitation data collected by others at a nearby site(s). Government agencies are the primary sources of information although many private organizations collect data. In the U.S. precipitation data is available from the National Weather Service which publishes many data in many different forms. In Canada data is available from Environment Canada. Precipitation data for North America is also available on CD-ROM from commercial vendors.

Because the project site is often distant from the nearest precipitation station, the available data must be adjusted to reflect the differences in the location. Data from several stations may be necessary in order to establish the correlation between a parameter and the precipitation depth of interest. For example, mean annual precipitation is usually strongly correlated to gage elevation. Using several gages over a range of elevations the mean annual precipitation can be correlated to elevation, which provides support for estimating the mean annual precipitation at the project site. This is shown in Figure 43. Other parameters which may produce a significant variation in the precipitation include the longitude, latitude and rain shadow effects. When correlating between gages use caution if the periods of record are not the same. Adjustment for variations in the period of record may be necessary.

*Storm Events* - Extreme value precipitation resulting from short-term storm events is collected, processed and compiled separately from normal long-term precipitation. Storm precipitation for a particular location is expressed as a function of duration and frequency. Although raw data is available from various sources, including CD-ROM, the most common method of establishing extreme value precipitation is to use existing processed data. In the Western U.S. extreme value precipitation depths are published in the NOAA Atlases, one for each of the 17 western states. Similar data is available for Canada (Environment Canada, 1985). These atlases provide maps showing the expected precipitation depths for a range of durations from 2 hours to 24 hours, and for a range of frequencies from 2 year to 100 year. Additional guidance is provided to allow interpolation and extrapolation of the data. Using these atlases, the data for a single site can be summarized graphically as shown on Figure 44.

Estimates of precipitation depths for very low probability storm events, for example the 10,000 year event, require additional analyses. Using an assumed extreme value distribution, the available extreme value data is used as a basis for extrapolating the data to very low probabilities. The methods used to evaluate the magnitudes of these rare events are just now coming into common use. Consult references such as Linsley, et al., 1982 and Schaefer, 198? for detailed information on methods of estimating precipitation depth for return period of 200 years and beyond. These methods use different types of extreme value distribution; the process is illustrated on Figure 45.

For projects with critical elements which would cause major loss of life if they failed, the Probable Maximum Flood (PMF) is often the required Inflow Design Flood (IDF). The PMF results from the Probable Maximum Precipitation (PMP). By definition the PMP is the maximum precipitation depth which could occur but never be exceeded. In the U.S. the methods used to estimate the PMP are based on historical extreme events and on the physical capacity of the atmosphere to produce rain. The estimates are not statistical. For this reason PMP values are often extremely large, sometimes 10 times greater than the 100 year event. In the U.S., PMP values can be estimated using the Hydrometeorological Reports (HMR's) prepared for each region by the National Weather Service or NOAA (National Weather Service, 1973) Where HMR's or similar publications are not available, PMP's can sometimes be estimated using site-specific hydrology studies prepared for large dam projects.

In Canada, unlike the U.S., the PMP is most often based on a statistical evaluation of precipitation data. Environment Canada publishes maps of the mean and standard deviation (X and S) of extreme value precipitation for the entire country. The PMP is computed as:

$$PMP = \overline{X} + K * S \qquad (8.8.2.3\text{-}9)$$

where:

$PMP$ = the 24-hour PMP
$X$ = the mean annual max 24 hour precip depths
$S$ = the standard deviation of the maximums
$K$ = the frequency factor

The frequency factor is computed using an equation which is based on mean annual extreme 24 hour precipitation.

*Snow* - Snow depth and snow water-equivalent data are collected in North America in those locations where water supplies depend on snowmelt. In the U.S. the Soil Conservation Service (SCS) developed snow courses to predict irrigation and water flows in the spring and summer based on snow course data from the preceding winter and early spring. The actual snow water equivalents in the snowpacks are never used directly to estimate runoff; the data is always correlated to a stream gage. Because a correlation must be established a new snow course is not considered reliable until 5 years of data are available for correlation of the snowwater depths to the resulting peak flows and flow volumes at a given gage. The problem with direct use of the data arises because snow drifts when it falls, producing large variations within one watershed. Further, the complex heat dynamics of snowmelt and sublimation make reliable detailed modeling the snowmelt process extremely difficult, if not impossible.

If the watershed of interest is small and snowwater equivalent data can be collected over the entire water shed, the data may be somewhat useful in establishing an upper bound to potential snowmelt runoff; however, a substantial portion of the peak snow water equivalent is lost to sublimation during the snowmelt period which can make this estimate unrealistically high (conservative).

The best method for predicting snowmelt runoff involves the use of stream discharge data. To the extent that the gaged basin is similar to the project basin, stream discharge data eliminates the need to address the issues and uncertainties associated with drifting and melting snow. Using daily discharge records the peak snowmelt flow can be identified and the total runoff volume associated with snowmelt can be estimated. By repeating this over several years data can be assembled for statistical analyses.

### 8.8.2.4 Evaporation and Evapotranspiration

A complete water balance often requires an estimate of

losses from wet, partially wet, vegetated and free water surfaces. In the U.S. data is available from the U.S. Evaporation Atlas (U.S. National Weather Service, 1982) which provides a map showing lines of equal evaporation. Basic evaporation data is available in most areas; this is Class A Pan evaporation data. To estimate losses from free water surfaces the Pan data must be adjusted downward because the pan is warmer than a large water body and evaporation is greater. Typically the adjustment factor is approximately 0.75. Remember that these evaporation values are total potential values; to get the actual net evaporation the local precipitation must be subtracted.

Evapotranspiration or ET, which is the combined loss of water due to soil evaporation and to plant transpiration, is more difficult to estimate. One useful tool is the EPA's computer model: Hydrologic Evaluation of Landfill Performance (HELP) version 2. This model is a one dimensional simulation of the daily movement of water in the near surface soils. The model is data intensive but provides a large data base for the U.S. as part of the input generation. The model can be used to estimate the daily evapotranspiration losses from a surface using assumed vegetative covers, or unvegetated surfaces. The precipitation data for the project site can be used, or synthetic data simulating heap leach solution application rates can be used. The model input data can be adjusted to specified ambient temperatures if the project site elevation is significantly different from the data base station. Typically a 5 year simulation is performed and mean monthly values are developed for the project site.

Agricultural engineers have developed many sophisticated techniques for estimating the ET from various crops. This is done in order to evaluate irrigation water requirements. Under special circumstances these techniques might be useful in estimating ET for a mine water balance; however, other techniques are usually more appropriate.

In general evaporation and ET values vary seasonally but the variation from year to year is relatively small. The mean monthly values of potential ET can safely be applied each year in a simulation. Actual ET may be substantially lower than potential ET when there is deficiency of water. For example, wet tailings may have a high ET loss while dry tailings will be much lower.

### 8.8.2.5 Runoff

*Normal Runoff* - In order to perform a mine water balance the normal (non-storm) runoff from the various tributary areas must be estimated. Estimates from undisturbed areas are usually made on the basis of regional stream discharge data. The unit discharges, $m^3/sec/km^2$ or simply cm, are used to normalize the data. Adjustments are made for elevation, vegetation and aspect as necessary. Similar methods are used to estimate runoff from slightly disturbed areas by using additional adjustment.

For highly disturbed areas including heaps, lined areas, tailings surfaces and similar areas which have major variations from undisturbed surfaces, the runoff is best estimated by computing it as the applied precipitation less losses from ET and infiltration. In the absence of actual site discharge data from disturbed areas which can be used for calibration, the direct use of streamflow data to estimate runoff would require adjustments that would be arbitrary and unsupportable. However, by using precipitation, infiltration and ET values a rational estimate of runoff can be developed which is logical and defensible.

*Flood Discharge*

*Discharge Data* - The magnitude of flood flows in streams within the project area should be estimated using data from a local or regional stream gage or gages, if available. This is the best type of data available since it is a direct measure of the parameter of interest. The data must be instantaneous peak flows, not mean daily discharge, as are normally reported. Like extreme precipitation data, the period of record must be approximately the same length as the return period of the event being estimated. For example, a ten year period of record can be used to estimate a 10 year peak discharge event, or perhaps a 25 year event, but the data are insufficient to reliably estimate the 1,000 year event. If instantaneous peak discharge data is available for a sufficient period of record, the data can be analyzed using the methods outlined in Linsley, et al., 1982.

Unfortunately, this type of discharge data is rarely available, or the discharge data is not applicable because of changed conditions. In such cases flood discharges must be estimated based on precipitation.

*Precipitation* - Several methods are available for estimating flood hydrographs based on precipitation. All of these methods assume that the flood discharge frequency is the same as the precipitation frequency which is driving it, i.e., the 100 year precipitation results in the 100 year peak flow. This is not necessarily the case because of variations in precipitation sequencing and in basin conditions prior to the storm (antecedent moisture conditions). Nevertheless the assumption is used because there is usually no better alternative.

All of the hydrograph generation procedures require information about the drainage basin. At a minimum the basin characteristics needed include the drainage area, time of concentration, and the curve number. The drainage area can be estimated using the project mapping. The time of concentration, abbreviated $T_c$, is the time required for a drop of water to travel from the most

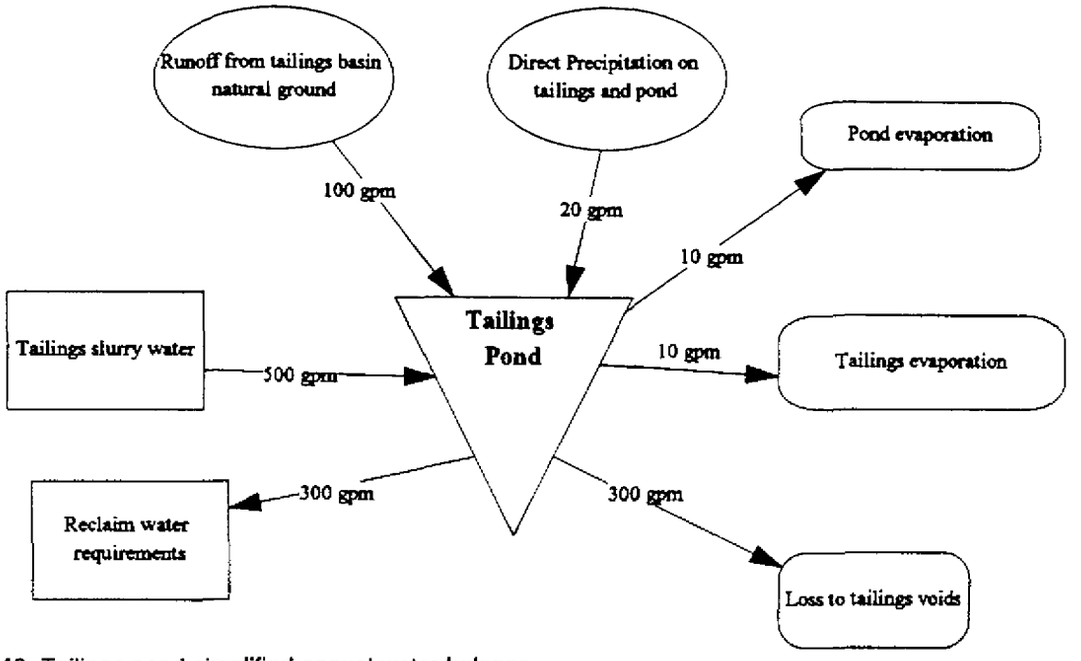



**Figure 46** Tailings pond simplified annual water balance.

distant part of the basin to the outlet or discharge point for which the hydrograph is being estimated. The $T_c$ can be estimated directly by estimating flow velocities and required travel distances. In a typical small basin 90 percent or more of the travel time is spent in overland flow between the basin boundary and the first defined channel. Travel velocities can be estimated using the chart shown in Figure 46. Many alternative methods exist for estimating $T_c$ including the Kirpich Formula and others described in USBR, (1973) and Linsley, et al. (1982).

The time of concentration for a basin can sometimes be less than 10 minutes. However, it is not useful to prepare estimates which are less than 10 minutes because precipitation duration data typically stops at 10 minutes requiring the use of the 10 minute values

The curve number (*CN*) is a value which reflects the imperviousness and water retention capability of the surface soils in the basin. Hydrologic methods using the *CN* were developed in the U.S. by the SCS; thus curve numbers are sometimes referred to as SCS-*CN*'s. A curve number ranges from 0 to 100; soils with *CN*'s of 0 have infinite water retention capacity and never generate runoff. Since such soils do not exist actual minimum *CN*'s are in the range of 30 to 40 for deep gravelly soils. A *CN* of 100 represents a smooth, perfectly impervious surface like glass. Asphalt and concrete parking lots are often modeled using a *CN* of 98. *CN*'s for other surfaces lie between these extremes. Estimates of appropriate *CN*'s can be made by evaluating the soil type and consulting the tables in USBR 1973, Appendix A. If the local soils are not identified the local SCS can be consulted to assist in selecting an appropriate value. Outside the U.S. the *CN* can be selected based on vegetation type using the tables in USBR 1973, Appendix A.

$$Q = \frac{(P - 0.2S)^2}{(P + 0.8S)} \qquad (8.8.2.5\text{-}10)$$

where:

$Q$ = Accumulated runoff depth (inches)
$P$ = Accumulated precipitation depth (inches)

$$S = \frac{1000}{CN} + 10 \qquad (8.8.2.5\text{-}11)$$

The *CN* provides a relationship between precipitation and runoff expressed in Equations 11 and 12.

The *CN* for a specific surface varies with its antecedent moisture condition (AMC). The SCS recognizes three AMC's designated as I, II, and III. The selection of a *CN* is based on average conditions represented by AMC II. While the SCS provides conversions of *CN*'s from AMC II to AMC I (dry conditions) and AMC III (wet conditions), these values should not be used in the estimating of flood discharges. If AMC III is assumed, resulting in a much higher *CN*,

and the flood hydrograph is generated using, say, the 100 year precipitation, the recurrence interval of the resulting hydrograph is much greater than 100 years because it has been combined with an infrequently occurring AMC III. In order to generate a 100 year flood discharge from a 100 year precipitation event, average basin conditions must be assumed.

*Rational Method* - The simplest form of rainfall-runoff model is known as the Rational Method. For small basins it is reasonable to assume that all the precipitation falling on the drainage basin of interest arrives essentially instantaneously at the discharge point, i.e., there is no storage of precipitation in the basin, which is referred to as *routing effects*. The limiting area for application of the Rational Formula is determined by the time of concentration ($T_c$) of the drainage basin; if the $T_c$ is less than approximately 30 minutes, the Rational Formula can be applied. Limitations on the maximum drainage area in which the Rational Formula can be applied have been described by various practitioners as lying in the range from 10 to 200 acres.

$$Q = CiA \qquad (8.8.2.5\text{-}12)$$

where:

$Q$ = Peak discharge (cfs)
$C$ = Runoff coefficient for the drainage basin (0 to 1)
$i$ = Precipitation intensity (inches/hour)
$A$ = Drainage basin area (acres)

The simplest form of the Rational Formula is expressed as Equation 13. This equation takes advantage of the numerical coincidence that 1 inch-acre/hour is very close to 1 cubic foot per second (cfs). The coefficient $C$ used in the equation is based on the type of ground surface in the basin and is analogous to the *CN*. The method, as it was originally developed, used a simple peak precipitation rate based on charts and other generalized sources. This was combined with a runoff coefficient ($C$) which was based on the ground cover and land use. More recently, the improved data sources allow an improved approach to the original methods. Precipitation is selected using rainfall frequency atlases and the duration is selected based on the behavior of the basin. The precipitation intensity used in the equation should be selected for a duration which is equivalent to the $T_c$ of the basin. For example, if the $T_c$ of the basin is 20 minutes the 10 year peak precipitation intensity can be selected from a graph similar to that shown in Figure 43 using a 20 minute duration and the 10 year frequency curve. The reduction in runoff due to the basin absorption can be estimated by using Equations 11 and 12 to determine the ratio of runoff to precipitation resulting from the storm. The value should be estimated at the midpoint of the storm, not the beginning and not the end. For example, if the 100 year precipitation is approximately 10 inches, the incremental runoff should be determined for, say, the precipitation from 4.5 inches to 5.5 inches. If this 1.0 inch of precipitation results in 0.6 inches of runoff as determined by Equations 11 and 12, then the value of $C$ used in the Rational Formula should be 0.6.

*Unit Hydrograph Methods* - When the drainage area of the basin of interest is larger than 200 acres or when there is some storage in the basin which makes the volume of the runoff significant, a unit hydrograph procedure should be used to estimate runoff. There are many procedures available; all of the useful procedures are available as computer programs which vary over a wide range of complexity and cost. Several of the popular programs are listed include HEC1 from the U.S. Army Corps of Engineers (COE) Hydraulic Engineering Center (HEC), TR55 and TR20 from the U.S. Soil Conservation Service, Santa Barbara Urban Hydrograph Method which is available in various programs, Colorado Unit Hydrograph Procedure from Denver's Urban Drainage and Flood Control Agency, SEDCAD from the University of Kentucky and PONDPACK from Haestad Methods. Many others are available commercially. Of these HEC1 is the most universally used and recognized, although it may not be the easiest program to learn or use. All of these methods use a precipitation hydrograph (specified precipitation time-depth sequence) generated from the precipitation depth-duration information and combine it with a unit hydrograph generated from the basin characteristics to produce a flood hydrograph. Several of the programs will route the resulting hydrograph through a reservoir, or down a channel and/or combine hydrographs from different basins.

### 8.8.2.6 Groundwater Inflow

Tailings impoundment inflows from groundwater sources must be accounted for in a water balance analysis. Similarly, groundwater losses from the pond should be addressed, although generally the design objectives are to minimize these losses. Typically the quantities of groundwater involved are not significant to the system water balance; however, there is a potential for these flows to be large under the right circumstances. For this reason groundwater should be addressed. Specific methods used to estimate groundwater inflows and losses are beyond the scope of this chapter.

## 8.8.3 MATERIALS CHARACTERIZATION

### 8.8.3.1 General

To perform a project water balance, the configuration of the system must be defined, as well as the behavior of

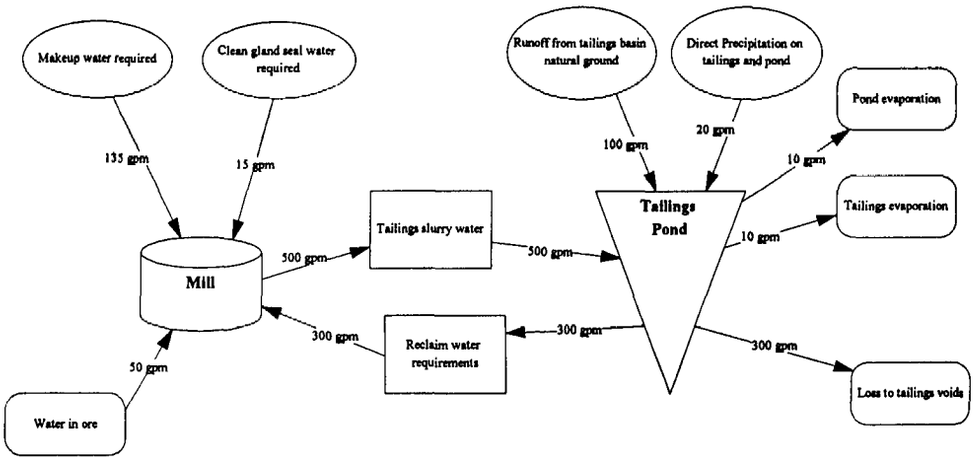



**Figure 47** Heap leach test draindown results.

the basic materials. Because mining projects are dynamic, the configuration changes throughout the life of the project and must be defined at selected intervals during its life. The development of the configurations is an iterative part of the design process. The physical characteristics of the waste materials with respect to water absorption and retention are also very significant to the water balance. These characteristics must be estimated using laboratory testing or by comparison to similar projects.

### 8.8.3.2 Tailings

In a typical mill/tailings water balance, the largest single water flow is in the slurry used to convey the tailings to the disposal site. The second largest flow is usually the reclaim water from the tailings pond. Because these flow are so large, even small errors in the estimates of the flows will have significant impacts on the results. For this reason the characteristics of the tailings, and tailings slurry should be examined carefully

The tailings slurry water content is usually dictated by the mill designer, based on the economic considerations. Typical mills include tailings thickeners which produce a slurry density of approximately 50 percent solids by weight, which is a pulp density which can be comfortably transported by pipeline at modest slopes. Without thickeners the pulp density is only 20 to 30 percent solids, and requires the recirculation of very large quantities of water. It is usually less costly to install thickeners than to pay for the water recirculation.

One of the largest water losses in a mill circuit is usually the water which ultimately fills the voids between the tailings particles. The voids loss rate is a function of the tailings production rate, tailings density, specific gravity, deposition scheme, permeability and consolidation characteristics. Typically the near-surface tailings are low density and correspondingly high water content. As tailings are covered by new tailings, the overburden load will cause consolidation and the release of water. The consolidation process is enhanced by more permeable tailings, by downward drainage and by deposition in thin layers allowing direct evaporation to increase the soil suction thus providing consolidation pressure (subaerial deposition).

The analytical evaluation of the tailings water loss rate is difficult to model with accuracy because of the many unknowns. The best estimating method involves using data from a representative existing tailings pond where the volume and tonnage are known. The average water content can be estimate using the laboratory specific gravity of the tailings together with the net bulk density computed from the known volume and dry tonnage. If this information is not available gravity settling of tailings samples in the laboratory will provide baseline information. When no information is available, use typical values. For most tailings ponds the water in the tailings is 30 percent by weight of the dry weight of the solids; i.e., 100 kg of ore (nearly dry) will consume (retain) 30 kg of water after it is processed and placed in the tailings pond.

### 8.8.3.3 Heap Leach Ore

The hydraulic characteristics of ore in the heap can have a major impact on the water balance and on the size of the resulting pond volume requirements. The significant characteristics are the moisture content during leaching, the residual moisture content following draindown (field capacity) and, to a lesser extent, the time required for draindown to occur. These parameters influence the quantity and timing of solution draindown, which has a major influence on the size of the solution storage ponds.

The hydraulic characteristics of the ore should be evaluated in laboratory column tests, performed in

**Table 9** Average Water Balance

| Flow Source/Destination | | Units | Net Flow $m^2$ |
|---|---|---|---|
| **System Inflows** | | | |
| Annual Precipitation Depth | 400 | mm | |
| Pond Area | 10,000 | $m^2$ | |
| Heap Area | 200,000 | $m^3$ | |
| Precipitation Volume | 84,000 | $m^3$ | 84,000 |
| Annual Runoff | 125 | mm | |
| Undeveloped Heap Area | 50,000 | $m^2$ | |
| Other Tributary Areas | 100,000 | $m^3$ | |
| Runoff Volume | 18,750 | $m^3$ | 18,750 |
| Total Inflow | | | 102,750 |
| **System Outflows** | | | |
| Free Water Surface Evap. | 1,050 | mm | |
| Depth Pond Area | 10,000 | $m^2$ | |
| Average Wetted Heap Area | 50,000 | $m^3$ | |
| FWS Evaporation Volume | 63,000 | $m^3$ | 63,000 |
| Ore Production | 2,000,000 | tonnes | |
| In-Heap Bulk Density | 1.4 | $t/m^3$ | |
| Ore Volume | 1,428,571 | $m^3$ | |
| Net Water Retention | 3.4% | vol/vol % | |
| Loss to Heap Retention | | $m^3$ | 48,571 |
| Total Outflow | | | 111,571 |
| **NET OUTFLOW** | | | 8,821 |
| Make-up Water Required | | | 8,821 |

conjunction with the leach testing. Beginning with a column at natural oisture content, apply solution (water) at the design rate (usually about 0.004 gpm/sq ft). Monitor the discharge rate at the base. Once equilibrium is reached (inflow=outflow) compute the stored water and the change in heap water content (uptake). Cease the application of solution and continue to monitor the discharge. Once drainage is complete, compute the volume or discharge which occurred since the termination of leaching: this is the draindown to a water content referred to as field capacity, which is smaller than the uptake. Once this test is completed sample the ore in the column and determine its water content.

Analytical models are available for the evaluation of the unsaturated flow characteristics of soils. These models are only useful in evaluating heap leach performance in special cases because the models are data intensive, requiring much more information than is typically available for a new ore. Laboratory testing is a preferred method of evaluation. Since column leach testing is almost always done to evaluate the heap leach process, the incremental costs of testing are small. The

results of a typical column test for the evaluation of heap drainage is shown on Figure 47.

### 8.8.3.4 Waste Dumps

The hydraulic characteristics of waste dumps are significant with respect to runoff, both long-term runoff and stormwater runoff. The typical issues are the impact of the waste dump on the net runoff from the dump area, during both construction and following reclamation; and, the impact of the waste dump on stormwater discharge from the affected areas. These characteristics are influenced by grain size, slopes, benches, aspect, snow accumulation and similar characteristics and parameters. The previous section provides a discussion of methods for estimating runoff from these areas.

### 8.8.3.5 Other Surfaces

Runoff from roads, benches, parking lots, etc, which contribute runoff to the water balance must be addressed. The areas must be identified and the volume of runoff must be quantified. Previous section provide discussion of methods for estimating runoff from these areas.

## 8.8.4 WATER BALANCE - DETERMINISTIC ANALYSES

### 8.8.4.1 Average Water Balance

The initial water balance for a project typically involves a computation of average conditions. The average annual flows to and from all the major project elements are computed. Average water requirements are computed from this analysis. To address the variability of weather conditions, the initial average water balance is repeated but, wet conditions and dry conditions replace average conditions. Similarly the variations in the physical layout of the mine over its life can be addressed by doing an annual water balance for startup, mid-life and full development. These analyses can be completed quickly and the results will provided insight into the elements of the project and environmental conditions which have the greatest impact on the water balance. Once the project design is advanced, a more complete water balance is prepared to provide more detailed information on storage requirements and flow capacity requirements. The average annual water balance evaluations assist in establishing which project elements require additional modeling detail.

Typically the water balance (mass balance) is computed at specific nodes or storage locations. For example the free water storage volume in a pond is computed or the inflows and outflows to the mill are balanced to produce an inflow equal to the outflow. Once this is completed for each of the nodes in the system, the flows between nodes are balanced.

An example of an average water balance for a heap leach pad is provided in Table 9. This simplified example shows average climatic conditions in year three of operation. The results show a modest water requirement for average conditions; however, no information is provided regarding the water requirements under wet or dry conditions, or at start-up or shut-down. To provide additional information, the *average* water balance could be repeated using precipitation, runoff and evaporation values for wet years and dry years. Similarly the water balance could be done for areas and production rates which will exist at startup or at the end of operations. These additional water balance tables (not shown) would indicate if storage is needed for excess water, and the likely range of maximum annual make-up water requirements. However, little information is provided regarding the normal monthly operation of the system, and the volume of needed seasonal storage, nor the maximum solution storage necessary. In order to investigate these aspects of the design, more detailed studies are necessary.

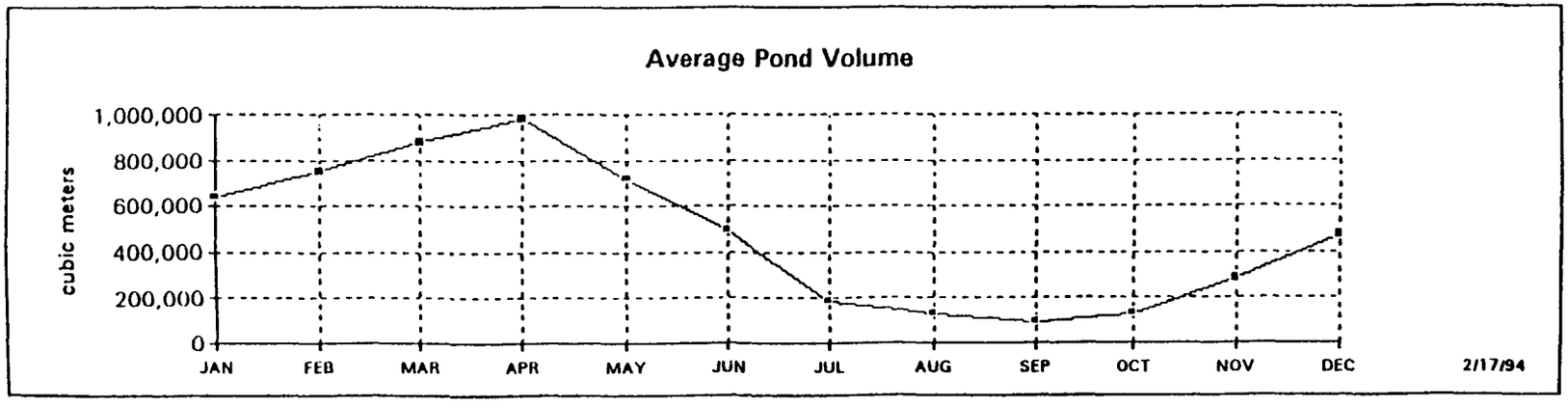
*Development Sequence* - The detailed water balance requires that the size and configuration of all major elements be defined on a monthly basis over the life of the project. This is especially true of heap leach operations which must be defined by a specifically proposed lift placement and leaching schedule. A mine-life monthly table of areas and ore volumes is necessary which itemizes: 1) the total pad area draining to the solution storage ponds; 2) the area of constructed but unused liner; and, 3) the total area of the heap, including active and inactive portions, and 4) the area and volume of ore being leached. A similar table must be developed for mine facilities involving open pits and tailings ponds. If waste dump areas, pit areas, and tailings ponds areas are changing throughout the life of the mine, the schedules of area versus time must be estimated.

*Twelve Month Annual Water Balance* - The twelve month annual water balance consists of a monthly computation of the facilities water balance over the period of one year. An example of a twelve month annual water balance for a simplified tailings disposal facility is presented in Table 10. Month-to-month carry-over storage is permitted in facilities which can accommodate it; however, the end-of-year storage must be the same as the beginning-of-year storage. The initial evaluation should address average conditions. Evaluating the water balance in an average year is the basic determination of performance. Because this is an average situation, there can be no net change in storage over the course of the year and the sum of all inflows must equal the sum of all outflows. An important first step is to define precisely what is included within the water balance and what is external to it. It is generally wise to consider

**Table 10** Twelve Month Annual Water Balance

| | | |
|---|---|---|
| TAILINGS POND CATCHMENT AREA = | 4.00 | sq km |
| FREE WATER SURFACE AREA = | 1.73 | sq km <== from function based on volume |
| TAILINGS SURFACE AREA = | 2.27 | sq km <== remainder |
| TAILINGS SLURRY INFLOW RATE = | 100,000 | m3/month |
| RECLAIM WITHDRAWAL RATE = | 79,000 | m3/month |
| TAILS EVAP/FREE WATER EVAP = | 0.10 | ratio |

| | PRECIPITATION (mm) | FREE WATER SURFACE EVAPORATION (mm) | BASIN INFLOWS | | BASIN OUTFLOWS | | | | NET FLOW | POND VOL | POND AREA | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Precip cu meters | Slurry cu meters | Pond Evap cu meters | Tails Evap cu meters | Reclaim cu meters | Tails Voids cu meters | cu meters | 468,434 | 1.73 | <== last pond volume |
| JAN | 44 | 0 | 174,523 | 100,000 | 0 | 0 | 79,000 | 30,000 | 165,523 | 633,957 | 2.41 | |
| FEB | 33 | 0 | 131,724 | 100,000 | 0 | 0 | 79,000 | 30,000 | 122,724 | 756,681 | 2.93 | |
| MAR | 33 | 0 | 132,740 | 100,000 | 0 | 0 | 79,000 | 30,000 | 123,740 | 880,421 | 3.46 | |
| APR | 28 | 0 | 111,430 | 100,000 | 0 | 0 | 79,000 | 30,000 | 102,429 | 982,851 | 3.91 | |
| MAY | 37 | 102 | 146,990 | 100,000 | 396,853 | 955 | 79,000 | 30,000 | -259,818 | 723,032 | 2.79 | |
| JUN | 36 | 127 | 142,494 | 100,000 | 353,897 | 15,410 | 79,000 | 30,000 | -235,814 | 487,219 | 1.81 | |
| JUL | 30 | 203 | 119,278 | 100,000 | 366,792 | 44,601 | 79,000 | 30,000 | -301,115 | 186,104 | 0.70 | |
| AUG | 27 | 152 | 108,179 | 100,000 | 106,680 | 50,292 | 79,000 | 30,000 | -57,793 | 128,311 | 0.70 | |
| SEP | 20 | 102 | 81,534 | 100,000 | 71,120 | 33,528 | 79,000 | 30,000 | -32,114 | 96,197 | 0.70 | |
| OCT | 23 | 51 | 91,973 | 100,000 | 35,560 | 16,764 | 79,000 | 30,000 | 30,649 | 126,846 | 0.70 | |
| NOV | 41 | 0 | 165,913 | 100,000 | 0 | 0 | 79,000 | 30,000 | 156,913 | 283,759 | 1.00 | |
| DEC | 48 | 0 | 193,675 | 100,000 | 0 | 0 | 79,000 | 30,000 | 184,675 | 468,434 | 1.73 | |
| ANNUAL | 400 | 737 | 1,600,454 | 1,200,000 | 1,330,904 | 161,550 | 948,000 | 360,000 | 0 | 982,851 | <== Annual Maximums | |



all flows as external (inflow or outflow) except for flow between nodes within the system being considered. In this computation all the values except one are assumed and/or estimated (independent variables) using various methods. The last value is computed in the water balance (dependent variable) is usually something that can be adjusted: commonly make-up water required, or excess solution to be treated and discharged.

*Monthly Water Balance* - While the twelve month annual water balance values provide insight into which elements of the project will have water problems, a detailed modeling of the design sequence is necessary in order to evaluate water storage requirements and the probability of spilling solution. One of the first steps in development of a detailed water balance is selection of the time step. A detailed water balance is usually done on a monthly basis, because this is generally adequate and monthly data is usually available. Shorter time steps may be required under special circumstances, especially in cases involving small basins, snowmelt and water rights.

A monthly water balance is similar to the twelve month annual water balance, with certain exceptions: 1) the simulation extends over the entire life of the mine and, therefore, includes the detailed development sequence for all the areas; 2) the simulations allows carry-over storage from year to year, in the tailings ponds, reservoirs and solution storage ponds, as the case may be; and 3) the schedule of precipitation and streamflow usually has some type of variability included, such as an actual precipitation and/or streamflow sequence. The order of the monthly precipitation is usually varied in order to determine the sensitivity of the results to such variations (wet sequence at start-up, mid-life or shut-down). The deterministic monthly analysis is most useful in identifying critical periods in the life of the mine; for example, the period of maximum draindown from a heap, or the time required before enlarging the tailings disposal facility.

Where little or no actual precipitation or streamflow data exists, the monthly water balance can be computed using average monthly values repeated each year over the life of the mine. This is little different from an annual water balance, repeated for different years in the life of the facility. No knowledge is gained regarding the performance of the system under modestly wet and dry conditions

### 8.8.4.2 Tailings Ponds

A simple example for a tailings pond might be as shown in Figure 46. In this example the flow rates of all the inflows and outflows would be computed from average areas and known data, except for the reclaim water which would be a result of the computation. The reclaim water rate computed would be compared with the tailings water requirement at the mill to determine whether the make-up water is required or the excess water must be treated for release.

An alternative approach to the water balance analysis shown in Figure 46 would include the mill in the water balance. The added detail provided by including the mill allows the make-up water requirements to be computed directly. This is shown on Figure 46. The process can be repeated using wet runoff conditions and dry conditions, as well as, areas which reflect the size of the tailings pond at startup, mid-life and full development. This water balance is an average water balance, as shown in Table 9, except the flow between nodes is expressed as an average rate, rather than an annual volume.

A twelve month annual water balance for a tailings pond is presented in Table 10. For ease of presentation this water balance is somewhat simplified from the water balance shown on Figure 46. Like the average water balance, the twelve month water balance can be repeated using various combinations of climate data and development conditions. While this analysis shows the tailings pond volume changing, a more detailed analysis is needed in order to properly select the minimum freeboard requirements and the schedule for dam enlargement.

An example of a detailed monthly water balance analysis is presented in Table 10. This analysis includes a monthly computation of most of the major flows within a system, for an eleven year period, beginning with construction of the tailings facility, extending through 7.5 years of operation and continuing for two years of reclamation. The precipitation data is actual monthly totals from a regional gage, adjusted for site conditions. The principal output parameters of interest are summarized graphically on the last page of the table. This example, which has been simplified to permit presentation, indicates that the tailings disposal facility has negative water balance during operation and will require 25 to 35 acre-feet of make-up water each month. The tailings pond is not expected to fill during normal operation. However, the output also indicates that there is a surplus of water when the mill is not in operation, because the demand caused by the generation of tailings voids is eliminated when the mill shuts down. This is indicated by the rise in tailings pond volume in startup and shutdown. During these planned shutdown periods the excess water can be accommodated; however, the analysis shows that the design should include provisions for accommodating this excess water if the mill shuts down unexpectedly midway through the mine life.

### 8.8.4.3 Heap Leach Pads

The water balance analysis of a heap leach pad is similar to the water balance analysis for a tailings facility. Both analyses require the development of estimates for precipitation, runoff and the physical parameters

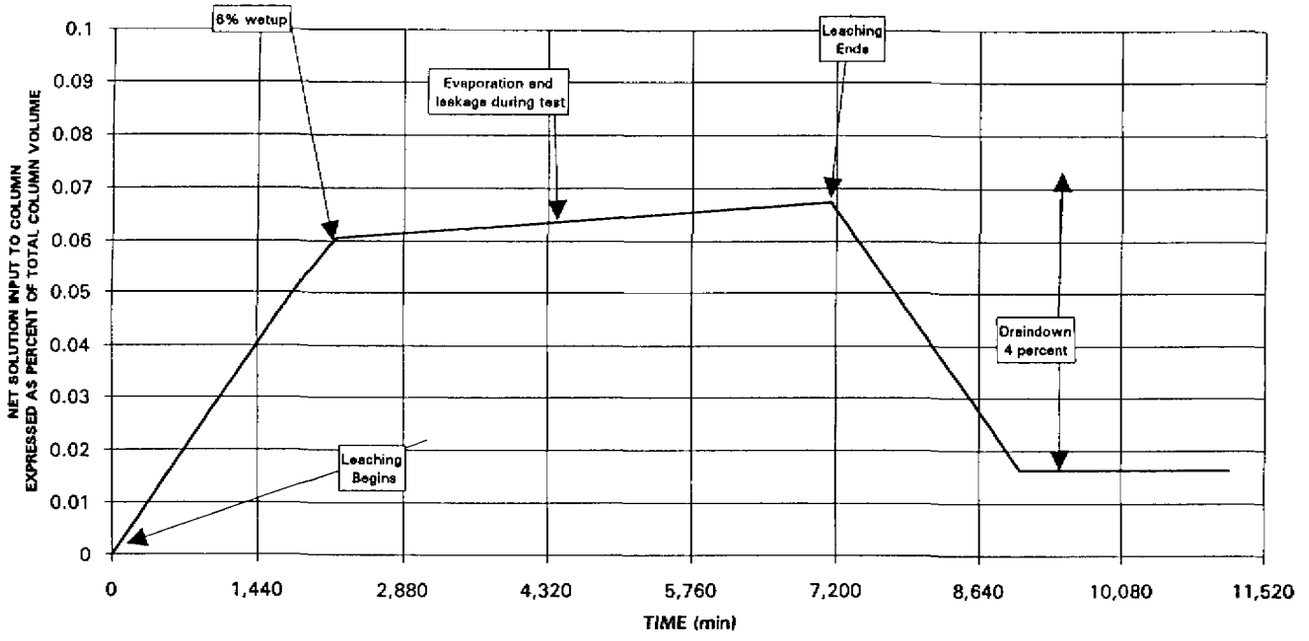



**Figure 48** Tailings pond probabilistic water balance.

describing the facilities configuration and the characteristics of the ore. Water balance analyses of heap leach pad operations in relatively wet areas are typically most sensitive to estimates of precipitation, snowmelt and draindown volumes, since excess water and solution storage requirements are the major issues. In a valley fill heap operation, the tributary drainage area and the capacity and reliability of diversion facilities can also be major issues. In drier climates, water supply issues can dominate the analyses. The short-term water supply requirements may be controlled by the wet-up requirements at the maximum heap height, which may also dictate the sizing of the solution storage ponds

Because of the complexity of a heap leach pad water balance analysis, a detailed monthly water balance analysis is almost always necessary in order to adequately access the potential for water balance problems. These analyses can also show when and why the critical design condition occurs, allowing the designer to take appropriate measures to reduce design requirements if possible.

## 8.8.5 WATER BALANCE – PROBABILISTIC APPROACHES

### 8.8.5.1 General

Probabilistic methods are the preferred approach to the evaluation of risk and adequacy of designs for systems because they allow the application of criteria which are more rational than are possible with deterministic methods. In addition, the process of developing the probabilistic model produces substantial insight into the operation of the system including an appreciation for which parameters have the most impact on the results. The probabilistic models can sometimes reveal weaknesses in a design which are not apparent when the evaluation in limited to deterministic methods. Probabilistic methods result in better designs.

*Available Methods* - Probabilistic computations are done using computer spreadsheets in a manner similar to deterministic methods. Probabilistic computations are numerically intensive. Fortunately two spreadsheet add-ons are available which make the computation relatively quick and painless. These add-ons are @RISK and Crystal Ball; others may exist.

The probabilistic add-ons allow the spreadsheet to be computed over a large number of iterations. In each iteration (re-computation) the input data, which is fixed in a deterministic analysis, is sampled from its probability distribution. The inputs are used to compute the outputs according to the relationships established in the spreadsheet. The output is also expressed as a probability distribution.

### 8.8.5.2 Tailings Ponds

A typical tailings water balance problem might involve establishing the minimum flood storage volume which must be maintained above the tailings in order to produce an acceptably low probability of spilling when the flood occurs. Assume that the regulatory agency has specified that the annual probability of spilling reclaim water must be 0.005 or less (a 1 in 200 years event). Further, assume that configuration of the tailings pond is

TAILINGS POND CATCHMENT AREA = 4.00 sq km

FREE WATER SURFACE AREA = 1.76 sq km <== from function based on volume

TAILINGS SURFACE AREA = 2.24 sq km <== remainder

TAILINGS SLURRY INFLOW RATE 100,000 m3/month

RECLAIM WITHDRAWAL RATE 79,000 m3/month

TAILS EVAP/FREE WATER EVAP 0.10 ratio

## WATER BALANCE

| | PRECIPITATION | | | FREE WATER SURFACE EVAPORATION | | | BASIN INFLOWS | | | BASIN OUTFLOWS | | | | NET | POND | POND | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MEAN (mm) | STD DEV (mm) | Actual (mm) | MEAN (mm) | STD DEV (mm) | Actual (mm) | Precip cu meters | Slurry cu meters | Pond Evap cu meters | Talls Evap cu meters | Reclaim cu meters | Talls Voids cu meters | FLOW cu meters | VOL 475,539 | AREA 1.76 | <== last pond v |
| JAN | 44 | 24 | 44 | 0 | 0 | 0 | 174,380 | 100,000 | 2 | 0 | 79,000 | 30,000 | 165,378 | 640,917 | 2.44 | |
| FEB | 33 | 19 | 33 | 0 | 0 | 0 | 132,195 | 100,000 | 2 | 0 | 79,000 | 30,000 | 123,192 | 764,109 | 2.96 | |
| MAR | 33 | 12 | 33 | 0 | 0 | 0 | 133,085 | 100,000 | 3 | 0 | 79,000 | 30,000 | 124,081 | 888,190 | 3.49 | |
| APR | 28 | 16 | 28 | 0 | 0 | 0 | 111,900 | 100,000 | 4 | 0 | 79,000 | 30,000 | 102,897 | 991,087 | 3.94 | |
| MAY | 37 | 26 | 36 | 102 | 8 | 102 | 145,992 | 100,000 | 400,465 | 589 | 79,000 | 30,000 | -264,062 | 727,025 | 2.80 | |
| JUN | 36 | 19 | 35 | 127 | 13 | 127 | 141,814 | 100,000 | 355,848 | 15,187 | 79,000 | 30,000 | -238,221 | 488,804 | 1.81 | |
| JUL | 30 | 28 | 30 | 203 | 13 | 203 | 118,449 | 100,000 | 368,227 | 44,484 | 79,000 | 30,000 | -303,263 | 185,541 | 0.70 | |
| AUG | 27 | 24 | 26 | 152 | 10 | 152 | 110,742 | 100,000 | 106,607 | 50,257 | 79,000 | 30,000 | -55,122 | 130,419 | 0.70 | |
| SEP | 20 | 17 | 20 | 102 | 8 | 101 | 81,468 | 100,000 | 71,033 | 33,487 | 79,000 | 30,000 | -32,051 | 98,367 | 0.70 | |
| OCT | 23 | 21 | 25 | 51 | 3 | 51 | 98,853 | 100,000 | 35,589 | 16,778 | 79,000 | 30,000 | 37,486 | 135,854 | 0.70 | |
| NOV | 41 | 29 | 41 | 0 | 0 | 0 | 165,114 | 100,000 | 1 | 0 | 79,000 | 30,000 | 156,113 | 291,967 | 1.03 | |
| DEC | 48 | 26 | 48 | 0 | 0 | 0 | 192,574 | 100,000 | 1 | 0 | 79,000 | 30,000 | 183,572 | 475,539 | 1.76 | |
| NNUA | 400 | 78 | 402 | 737 | 53 | | 1,606,565 | 1,200,000 | 1,337,782 | 160,783 | 948,000 | 360,000 | 0 | | | <==ANNUAL MAXIMUM |

**Figure 49** Heap/dump leach probabilistic water balance.

**MONTHLY WATER BALANCE**
**PROBABALISTIC HEAP/DUMP LEACH WATER BALANCE**

| | area (sq m) | tonnes in dump (x1000) | 1 Jun-94 | 2 Jul-94 | 3 Aug-94 | 4 Sep-94 | 5 Oct-94 | 6 Nov-94 | 7 Dec-94 | 8 Jan-95 | 9 Feb-95 | 10 Mar-95 | 11 Apr-95 | 12 May-95 | Jun-95 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **LEACHING STATUS** | | | | | | | | | | | | | | | |
| FIRST HEAP AREA | | | | | | | | | | | | | | | |
| Area No 1 | 24,000 | 1,150 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 2 | 6,400 | 80 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 3 | 5,100 | 90 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 4 | 11,600 | 250 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 5 | 12,900 | 300 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 6 | 10,100 | 330 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 7 | 32,300 | 1,520 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 8 | 34,300 | 1,730 | | | | | | | | | | | | | |
| Area No 9 | 25,300 | 1,530 | | | | | | | | | | | | | |
| Area No 10 | 23,600 | 1,730 | | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | |
| Area No 11 | 31,900 | 2,200 | | | | | | | | | | | | | |
| Area No 12 | 25,500 | 2,000 | | | | | | | | | | | | | |
| Area No 13 | 7,000 | 490 | | | | | | | | | | | | | |
| DUMP NO. 1380 | | | | | | | | | | | | | | | |
| Area No 1 | 8,188 4 | 1,381 4 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | | |
| Area No 2 | 9,868 | 1,556 3 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | | |
| Area No 3 | 10,468 | 1,561 1 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | | |
| Area No 4 | 9,868 2 | 1,559 5 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | | |
| Area No 5 | 9,479 3 | 1,494 7 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | | |
| Area No 6 | 3,586 9 | 3,586 9 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | 0 40 | | | | | | |
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | |
| **PRECIPITATION** | | | Jun-94 | Jul-94 | Aug-94 | Sep-94 | Oct-94 | Nov-94 | Dec-94 | Jan-95 | Feb-95 | Mar-95 | Apr-95 | May-95 | Jun-95 |
| Mean Monthly Precipitation (mm) | | | 10 29 | 126 10 | 101 09 | 53 34 | 33 53 | 20 57 | 37 59 | 25 48 | 20 32 | 14 73 | 8 09 | 7 11 | |
| Standard Deviation of Precip (mm) | | | 15 24 | 46 48 | 46 01 | 29 21 | 34 01 | 16 26 | 32 00 | 16 76 | 14 99 | 12 76 | 11 94 | 6 86 | |
| Precipitation in Month (mm) | | | 16 57 | 126 30 | 101 16 | 53 28 | 33 99 | 20 55 | 37 46 | 25 45 | 20 48 | 14 64 | 8 80 | 7 10 | |
| **EVAPORATION** | | | | | | | | | | | | | | | |
| Mean Monthly Lake Evaporation (mm) | | | 266 70 | 157 48 | 129 54 | 142 24 | 134 62 | 116 84 | 76 20 | 91 44 | 106 16 | 154 94 | 180 34 | 251 46 | |
| Standard Deviation of Evap (mm) | | | 25 65 | 25 40 | 19 30 | 11 68 | 25 40 | 13 46 | 21 59 | 13 21 | 18 29 | 11 68 | 39 37 | 34 04 | |
| Evaporation in Month (mm) | | | 266 72 | 157 45 | 129 52 | 142 25 | 134 61 | 116 83 | 76 21 | 91 43 | 106 11 | 154 95 | 180 39 | 251 46 | |
| **SUMMARY** | | | | | | | | | | | | | | | |
| Total Area Being Leached (sq m) | | | 51,479 | 177,479 | 177,479 | 177,479 | 177,479 | 177,479 | 177,479 | 126,000 | 0 | 0 | 0 | 0 | |
| Total Tonnage under Leach (Tonnes) | | | 11,140 | 16,590 | 16,590 | 16,590 | 16,590 | 16,590 | 16,590 | 5,450 | 0 | 0 | 0 | 0 | |
| Potential Draindown Volume (cu m) | | | 318,283 | 473,998 | 473,998 | 473,998 | 473,998 | 473,998 | 473,998 | 155,715 | 0 | 0 | 0 | 0 | |
| Wetup Volume (cu m) | | | 445,596 | 218,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| **POND INFLOWS** | | | | | | | | | | | | | | | |
| Total Solution Application Vol (cu m) | | | 889,554 | 3,169,061 | 3,169,061 | 3,066,834 | 3,169,061 | 3,066,834 | 3,169,061 | 2,249,856 | 0 | 0 | 0 | 0 | |
| Operational Draindown Vol (cu m) | | | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 318,283 | 155,715 | 0 | 0 | 0 | |
| Pond Runoff Volume(cu m) | | | 1,130 | 5,295 | 3,302 | 1,736 | 1,045 | 593 | 1,081 | 687 | 859 | 681 | 410 | 351 | |
| Heap Runoff Volume(cu m) | | | 573 | 13,450 | 10,773 | 5,643 | 3,620 | 2,189 | 3,989 | 1,934 | 0 | 0 | 0 | 0 | |
| Natural Ground Runoff Volume(cu m) | | | 32,903 | 2,614 | 3,353 | 3,682 | 3,738 | 3,464 | 2,259 | 7,590 | 20,211 | 29,354 | 34,167 | 46,921 | |
| **POND OUTFLOWS** | | | | | | | | | | | | | | | |
| Total Solution Drainage Rate (cu m) | | | 889,554 | 3,169,061 | 3,169,061 | 3,066,834 | 3,169,061 | 3,066,834 | 3,169,061 | 2,249,856 | 0 | 0 | 0 | 0 | |
| Wetup Volume (cu m) | | | 445,596 | 218,000 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Pond Evap Volume (cu m) | | | 16,230 | 6,600 | 4,227 | 4,642 | 4,140 | 3,373 | 2,200 | 2,468 | 4,344 | 7,212 | 8,396 | 12,423 | |
| Heap Surface Evap Volume (cu m) | | | 13,730 | 27,945 | 22,907 | 25,246 | 23,891 | 20,734 | 13,525 | 13,520 | 0 | 0 | 0 | 0 | |
| Seepage Volume (cu m) | | | 4,331 | 4,476 | 4,476 | 4,331 | 4,476 | 4,331 | 4,476 | 4,476 | 4,042 | 4,476 | 4,331 | 4,476 | |
| **NET POND INFLOWS** | | | | | | | | | | | | | | | |
| Total Inflow minus Outflow (cu m) | | | -445,201 | -235,662 | -14,262 | -23,137 | -24,103 | -22,192 | -12,872 | 310,021 | 168,378 | 18,349 | 21,849 | 30,374 | |
| **POND VOLUME** | | | | | | | | | | | | | | | |
| Pond Volume (cu m) | | | 554,799 | 319,137 | 304,875 | 281,738 | 257,635 | 235,443 | 222,572 | 532,592 | 700,970 | 719,319 | 741,168 | 771,541 | |
| Pond Surface Area (sq m) | | | 41,920 | 32,636 | 32,636 | 30,754 | 28,871 | 28,871 | 26,989 | 41,920 | 46,543 | 46,543 | 49,404 | 49,404 | #N/A |
| **DESIGN VOLUMES** | | | | | | | | | | | | | | | |
| Design 24 hr. Storm (mm) | | | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 | 127 | |
| Design Storm Volume (cu m) | | | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | 605,448 | |
| Potential Draindown Volume (cu m) | | | 318,283 | 473,998 | 473,998 | 473,998 | 473,998 | 473,998 | 473,998 | 155,715 | 0 | 0 | 0 | 0 | |
| Pond + Potential Draindown (cu m) | | | 873,082 | 793,135 | 776,873 | 755,736 | 731,633 | 709,441 | 696,569 | 698,307 | 700,970 | 719,319 | 741,168 | 771,541 | |
| Required Pond Volume (cu m) | | | 1,478,530 | 1,398,583 | 1,384,320 | 1,361,184 | 1,337,081 | 1,314,889 | 1,302,017 | 1,293,754 | 1,306,418 | 1,324,766 | 1,346,615 | 1,376,989 | |

**ASSUMPTIONS**

| | | |
|---|---|---|
| Heap Bulk Density | 1.75 | tonnes/cu m |
| Undrained Area | 0 236 | sq km |
| Starting Pond Vol | 1,000,000 | cu m |
| Starting Pond Area | 60,850 | sq m |
| Total Basin Area | 8,134,613 | sq m |
| MONTHLY RUNOFF COEFFICIENTS | | = the proportion of precip which arrives at the PLS pond |
| Precip on Heap | 0 6 | |
| Precip on Natural Ground | 0 3 | |
| Precip on PLS Pond | 1 00 | |
| STORM RUNOFF COEFFICIENTS | | = the proportion of precip which arrives at the PLS pond |
| CN | 83 | |
| S | 2 50 | based on CN, see eqn 4 |
| Precip on PLS Pond | 1 00 | |
| EVAPORATION COEFFICIENTS | | = the proportion of lake evap which leaves the surface |
| PLS Pond | 1 00 | |
| Heaps Actively Leaching | 1 00 | |
| SEEPAGE LOSSES | | |
| Footprint Seepage | 100 | lpm |
| Main Seepage | 100 | lpm |
| Seepage Bd Dur | 50 | lpm |
| MOISTURE CONTENTS | | |
| Initial Moisture Content | 4 00% | lpm/sq m |
| Wet-up Moisture Req'd | 7 00% | lpm/sq m |
| Drawdown Moisture | 5 00% | |
| APPLICATION RATES | | |
| Leach Rate | 0 4 | |
| Wet-up Rate | 0 4 | |

**POND AREA/VOLUME**

| Elev (m) | AREA (sq m) | VOLUME (cu m) | AREA (sq m) |
|---|---|---|---|
| 1145 | 0 | 0 | 0 |
| 1150 | 1,278 | 3,194 | 1,278 |
| 1155 | 5,110 | 19,161 | 5,110 |
| 1160 | 12,309 | 62,708 | 12,309 |
| 1165 | 23,225 | 151,544 | 23,225 |
| 1166 | 25,107 | 175,710 | 25,107 |
| 1167 | 26,989 | 201,758 | 26,989 |
| 1168 | 28,871 | 229,689 | 28,871 |
| 1169 | 30,754 | 259,501 | 30,754 |
| 1170 | 32,636 | 291,196 | 32,636 |
| 1171 | 34,262 | 324,645 | 34,262 |
| 1172 | 35,887 | 359,719 | 35,887 |
| 1173 | 37,513 | 396,419 | 37,513 |
| 1174 | 39,139 | 434,745 | 39,139 |
| 1175 | 40,765 | 474,697 | 40,765 |
| 1176 | 41,920 | 516,039 | 41,920 |
| 1177 | 43,076 | 558,537 | 43,076 |
| 1178 | 44,232 | 602,191 | 44,232 |
| 1179 | 45,387 | 647,000 | 45,387 |
| 1180 | 46,543 | 692,966 | 46,543 |
| 1181 | 49,404 | 740,939 | 49,404 |
| 1182 | 52,266 | 791,774 | 52,266 |
| 1183 | 55,127 | 845,470 | 55,127 |
| 1184 | 57,988 | 902,028 | 57,988 |
| 1185 | 60,850 | 961,447 | 60,850 |
| 1186 | 62,382 | 1,023,063 | 62,382 |
| 1187 | 63,915 | 1,086,211 | 63,915 |
| 1188 | 65,448 | 1,150,893 | 65,448 |
| 1189 | 66,981 | 1,217,107 | 66,981 |
| 1190 | 68,514 | 1,284,855 | 68,514 |
| 1191 | 71,208 | 1,354,716 | 71,208 |
| 1192 | 73,902 | 1,427,270 | 73,902 |
| 1193 | 76,596 | 1,502,519 | 76,596 |
| 1194 | 79,290 | 1,580,463 | 79,290 |
| 1195 | 81,984 | 1,661,100 | 81,984 |
| 1250 | 288,000 | 9,615,660 | 1,008,000 |

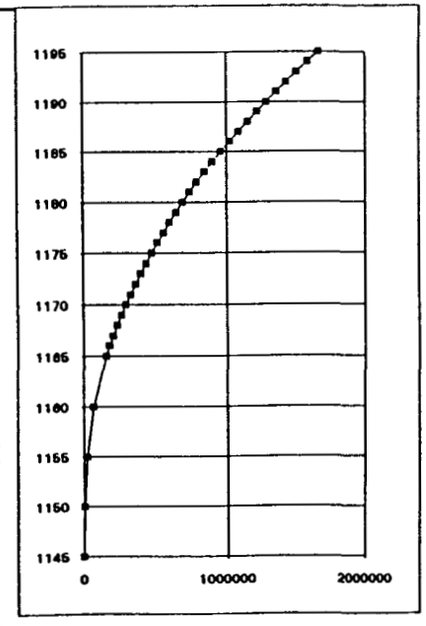



Figure 50 Deterministic heap leach water balance.

relatively constant over the period of concern. The basic water balance network is similar to that shown in Figure 46. The computation is summarized on Figure 48.

### 8.8.5.3 Heap Leach Pads

Like the tailings pond, the probabilistic water balance for a heap leach pad is an extension of the deterministic model, with probability distributions used for parameters which have uncertainty. This is most commonly applied to the detailed monthly water balance, although it can be applied to the twelve month average water balance as well. In addition to the use of probability distributions for precipitation and other climatic parameters, the uncertainty associated with materials characterization and other estimates can be incorporated in the model by using probability distributions.

An example of a probabilistic water balance for a copper heap and dump leach facility is provided in Figure 49. For ease of presentation, the model is limited to 12 months of operation. The assumptions incorporated into the model are presented on the second page of Figure 49. The facility is a valley fill heap and dump leaching operation using a dam to create a reservoir for storage if the pregnant leach solution. A system of diversion ditches surround the heaps and convey normal runoff around the solution storage reservoir, minimizing solution dilution. The leaching operation continues for seven months following initial wet-up. The design criteria for the pond volume requires that the pond accommodate the normal volume plus emergency draindown plus storm runoff such that there is less than a 1 percent chance of spilling solution over the life of the facility.

The spreadsheet as shown in Figure 49 includes the mean values for climatic parameters and estimated heap characteristics. Using these values the results are summarized in Figure 50, which shows the expected pond volume with initial wet-up in the first two months and draindown in the later months. Note the large emergency draindown volume in the early months when leaching is underway. In later months the emergency draindown volume drops to zero as the actual draindown occurs. The allowance for storm runoff is the 100 year storm runoff.

The probabilistic water balance includes variability for the climatic parameters, plus uncertainty in the estimate of the draindown potential and the seepage loss from the pond. The model was run using Crystal Ball, which allow the production of forecast distribution graphs and trend charts attached to a single workbook spreadsheet. The model was run for 1200 iterations. The results are summarized on Figures 51 and 52. Figure 51 shows the variability of the Require Pond Volume and Figure 52 shows the variability of the Actual Pond Volume. Note that the Actual Pond Volume (Fig 51) is quite variable in the latter part of the year because of uncertainty regarding the draindown percentage; however, this variability is not expressed in the Required Pond Volume because there is no corresponding change in variability shown in Figure 51. The top line in Figure 51 is quite variable because it represents the limit of the distribution which was input. In contrast, the 95 percent level is both very smooth and much smaller. When examining the outer limits of a distribution it is necessary to generate many thousands of iterations in order to produce smoothly varying results.

The 100 percent line in Figure 51 represents the maximum values encountered for the Required Pond Volume in 1200 iterations or lifetimes. The single largest value of approximately 2,250,000 $m^3$ has a probability of 1/1200 = 0.08 percent of being exceeded in any one lifetime. In this case one lifetime equals one year, therefore the probability of begin exceeded is also 0.08 percent annually. The smallest value for the upper line is approximately 1,300,000 $m^3$, and this value is exceeded 12 times during the lifetime. Thus the probability 1,300,000 being exceeded is 12/1200 = 1/100 = 1.0 percent. Therefore, a solution pond volume of 1,300,000 $m^3$ is needed in order to provide a probability of spilling solution which is less than 1 percent over the life of the project. Note that this is consistent with the results of the deterministic analysis presented in Figure 50. In Figure 50, the simple addition of a 100 year flood volume to the deterministic simulation of the pond volume produces very similar results. It is only when the life of the project extends beyond one year, or the variability of other parameters is more significant, that the differences between the probabilistic and deterministic results begin to become apparent.

## 8.8.6 PRESENTATION AND EVALUATION OF RESULTS

The presentation of a water balance analysis together with an evaluation of the results is often the most difficult and challenging aspect of the study. If the results cannot be communicated, analysis are not useful because, in today's regulatory environment, project designs are group efforts which include the decisions of diverse and sometime non-technical parties. Water balance analyses are often very complex, involving many areas, assumptions and scenarios. The design criteria are often poorly defined and must be selected and justified. The enormous quantity of data which is generated by a detailed monthly probabilistic analysis requires careful planning and attention to presentation methods which will achieve the objective of communicating the results without unnecessary confusion. An obvious tool is graphical outputs. Graphs of all input and outputs should be made routinely, for purposes of checking the inputs and performance as well as present the results and

| | | | |
|---|---|---|---|
| TAILINGS POND CATCHMENT AREA = | 4.00 | sq km | |
| FREE WATER SURFACE AREA = | 1.02 | sq km | <== from function based on volume |
| TAILINGS SURFACE AREA = | 2.98 | sq km | <== remainder |
| TAILINGS SLURRY INFLOW RATE | 100,000 | m3/month | |
| RECLAIM WITHDRAWAL RATE | 79,000 | m3/month | |
| TAILS EVAP/FREE WATER EVAP | 0.10 | ratio | |

WATER BALANCE

| | PRECIPITATION | | | FREE WATER SURFACE EVAPORATION | | | BASIN INFLOWS | | BASIN OUTFLOWS | | | | NET | POND | POND | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | MEAN | STD DEV | Actual | MEAN | STD DEV | Actual | Precip | Slurry | Pond Evap | Tails Evap | Reclaim | Tails Voids | FLOW | VOL | AREA | |
| | (mm) | (mm) | (mm) | (mm) | (mm) | (mm) | cu meters | cu meters | cu meters | cu meters | cu meters | cu meters | cu meters | 291,113 | 1.02 | <== last pond v |
| JAN | 44 | 24 | 39 | 0 | 0 | 0 | 154,131 | 100,000 | 1 | 0 | 79,000 | 30,000 | 145,130 | 436,243 | 1.60 | |
| FEB | 33 | 19 | 33 | 0 | 0 | 0 | 132,507 | 100,000 | 1 | 0 | 79,000 | 30,000 | 123,506 | 559,748 | 2.10 | |
| MAR | 33 | 12 | 57 | 0 | 0 | 0 | 229,158 | 100,000 | 3 | 0 | 79,000 | 30,000 | 220,155 | 779,904 | 3.03 | |
| APR | 28 | 16 | 22 | 0 | 0 | 0 | 88,781 | 100,000 | 2 | 0 | 79,000 | 30,000 | 79,779 | 859,683 | 3.37 | |
| MAY | 37 | 26 | 24 | 102 | 8 | 111 | 96,319 | 100,000 | 374,271 | 6,982 | 79,000 | 30,000 | -293,935 | 565,748 | 2.13 | |
| JUN | 36 | 19 | 27 | 127 | 13 | 114 | 109,391 | 100,000 | 242,544 | 21,346 | 79,000 | 30,000 | -163,499 | 402,249 | 1.46 | |
| JUL | 30 | 28 | 5 | 203 | 13 | 190 | 19,283 | 100,000 | 277,467 | 48,168 | 79,000 | 30,000 | -315,352 | 86,897 | 0.70 | |
| AUG | 27 | 24 | 6 | 152 | 10 | 161 | 23,324 | 100,000 | 112,851 | 53,201 | 79,000 | 30,000 | -151,728 | 0 | 0.70 | |
| SEP | 20 | 17 | 16 | 102 | 8 | 99 | 73,684 | 100,000 | 69,588 | 32,806 | 79,000 | 30,000 | -37,710 | 0 | 0.70 | |
| OCT | 23 | 21 | 19 | 51 | 3 | 49 | 75,514 | 100,000 | 34,339 | 16,188 | 79,000 | 30,000 | 15,986 | 15,986 | 0.70 | |
| NOV | 41 | 29 | 34 | 0 | 0 | 0 | 136,872 | 100,000 | 0 | 0 | 79,000 | 30,000 | 127,872 | 143,858 | 0.70 | |
| DEC | 48 | 26 | 39 | 0 | 0 | 0 | 156,255 | 100,000 | 0 | 0 | 79,000 | 30,000 | 147,254 | 291,113 | 1.02 | |
| NNUA | 400 | 78 | 324 | 737 | 53 | | 1,295,219 | 1,200,000 | 1,111,068 | 178,693 | 948,000 | 360,000 | -102,542 | 859,683 | | |
| | | | | | | | | | | | | | | ANNUAL | | |
| | | | | | | | | | | | | | | MAXIMUM | | |

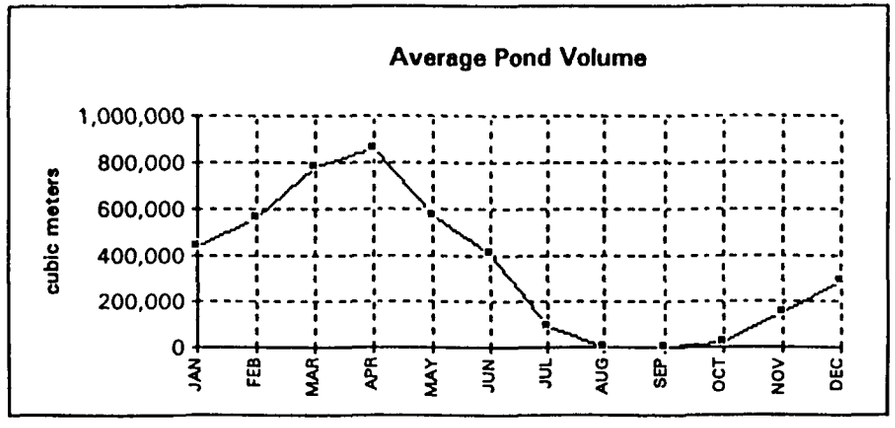



**Figure 51** Probabilistic water balance example.

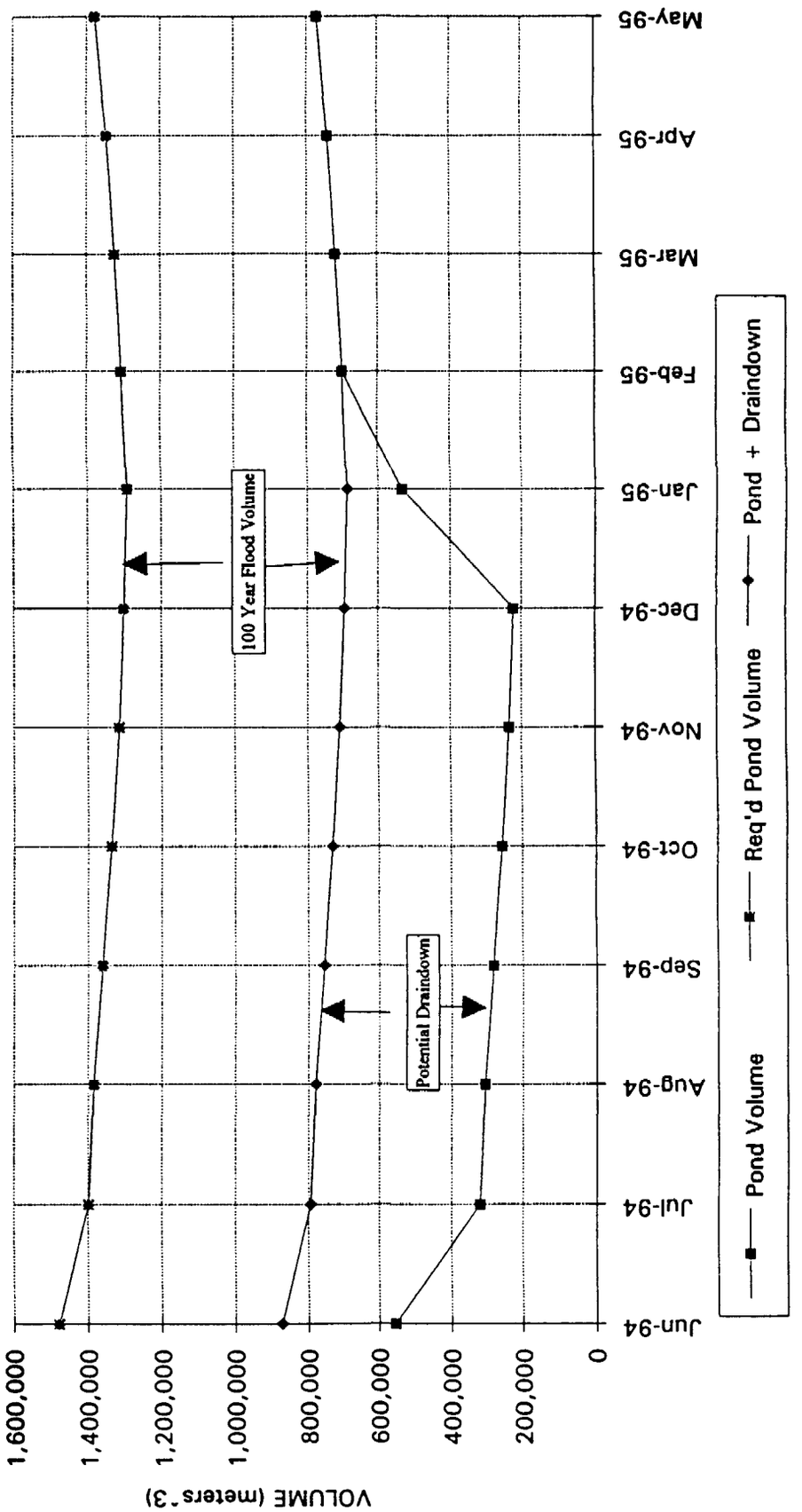



**Figure 52** Water balance results from probabilistic analysis.

conclusions. Graphical results such as those presented in Figure 51 should be used whenever possible, in lieu of tables of data such as Figure 49.

The problem of presentation and communication of the results suggests that models of this type be as simple as possible. Describing even a simple model is difficult; explanation of complex models can become so difficult that the audience attention is lost. Simplicity can be achieved without compromising the validity of the results by eliminating elements which are insignificant to the results, and addressing those elements individually, external to the main model.

One major presentation problem involves the explanation of probabilities of occurrence during the project life, during the a single year and during shorter periods of risk. An excellent tool for generating tables of example data is the Poisson distribution.

#### 8.8.6.1 Poisson Distribution

The problem of computing annual exceedance probabilities for various scenarios and comparing these to probabilities to durations of mine life can be simplified using the poisson distribution. This probability of an unlikely event occurring can be computed as follows:

$$P(x) = (\lambda t)^x \frac{e^{-\lambda t}}{x!} \qquad (8.8.6.1\text{-}13)$$

where:

$P(x)$ = the probability of occurrence
$\lambda$ = the arrival date
$t$ = the duration of exposure
$x$ = the number of occurrences

For example, the probability of a 100-yr flood ($\lambda$=0.01) occurring two times ($x$=2) in a period of 50 years ($t$=50) is $(0.01*50)^2\ e^{-0.01*50}/2 = 0.08$. The equation provides the probability of exactly n occurrences, not n or more. Therefore the probability of no occurrences is 1 minus the probability of 1 and 2 and 3 and 4, etc. However, this equation can also be used to directly compute zero occurrences of the event, such that n equals 0. Remember that 0! equals 1. For example the probability that a 100-yr event will not occur even once ($x$=0) in 50 years is:

$$P(x) = e^{-\lambda t} = e^{-0.01*50} = 0.61 \qquad (8.8.6.1\text{-}14)$$

The equation is an approximation to the theoretically correct results of the binomial. For the most part the equation provides excellent results, however, caution should be used for very short durations and high arrival rates.

## 8.9 CONSTRUCTION QUALITY ASSURANCE/QUALITY CONTROL

**by M. J. Hlinko and M. E. Smith**

*"Quality in any undertaking is never an accident. It is always the result of high intention, sincere effort, intelligent direction and skillful execution: it represents the wise choice of many alternatives."*

- Author unknown

### 8.9.1 INTRODUCTION/GENERAL

#### 8.9.1.1 History and Background

In the past one of the major concerns associated with surface impoundments has been the deterrence associated with groundwater contamination. Chemical solution control is the primary function of properly engineered liner selection, good design and proper installation. Poor performance in any one of these three areas can cause a system to malfunction or even fail. Taking into account the drawn effort applied in the system design to achieve site-specific environmental protection, it is only logical, as well as economical, to implement a "quality control" and "quality assurance" plan prior to construction to ensure regulatory compliance.

In recent years, the trends have proved to identify the importance of quality control and quality assurance when it involves environmental protection. Strict conformance to a well delineated quality control and quality assurance plan for the construction of the surface impoundment has been found through experience to be an important factor in the success of the design. A stringent quality control and quality assurance plan may make the difference between a facility that functions with a minimum of problems throughout its service life and one that falls short of its minimum performance goals. Under the authority of its surface management regulations, in August 1990, the Bureau of Land Management (BLM) established a policy for managing heap leach operations on its land to ensure that these operations do not cause unnecessary or undue degradation. The policy sets out a broad range of principles as a guide including minimum acceptable design criteria such as specific construction practices.

"An observation of six case studies:

*An average of one defect per 10 m (30 ft) of field seam (flexible membrane liners) can be expected without quality assurance by an independent firm and with adequate quality control by the geomembrane installer.*

*An average of one defect per 300 m (1000 ft) of field seam can be expected with reasonably good installation, adequate quality assurance (which implies adequate quality control), and repair of noted defects. (Quality assurance followed by adequate repair drastically decreases the number of seam defects but does not totally eliminate them.)"*

(J.P. Giroud, and R. Bonaparte, 1989 "Leakage Through Liners Constructed With Geomembrane Geotextile and Geomembranes.")

The terminology of quality control and quality assurance is often misconstrued. While there are no standardized definitions for these yet, the industry is undergoing increasing consistency. The following definitions are two that the authors have come to use and seem consistent with what other practitioners are using.

*Quality Control (QC) - Those actions which provide a means to measure and regulate the characteristics of an item or services to contractual and regulatory requirements.*

*Quality Assurance (QA) - A planned and systematic pattern of all means and actions designed to provide adequate confidence that items or services meet contractual requirements* and *will perform satisfactorily in service.*

General practice for earthworks construction is for an engineering firm to provide quality control under contract to either the owner or the contractor. Quality assurance is generally not formally included.

For geomembrane liners the installer generally provides the quality control and the owner contracts with a third-party firm for quality assurance. The third-party firm may be either the designer or a truly unrelated party, depending upon the owner's philosophy on this point. Clay liner construction is treated either as an earthwork component, with no quality assurance, or (preferably) as a liner component with third-party quality assurance.

## 8.9.2 PURPOSE

### 8.9.2.1 Purpose of Quality Control

Quality control is one of the most important of all services that the engineer performs in fulfilling a professional commitment. It involves full-time review of construction, site remediation, or other field work based on plans and specifications. It is far different from the "occasional site visits" that are called for in some model contracts and that seldom are effective.

From a somewhat negative point of view, field observation discourages contractors from cheating on the quality they build into a project, by providing the oversight needed to encourage conformance with plans and specifications and to catch shortcomings, intentional or otherwise. It also should be borne in mind that even the most carefully developed plans and specifications and the most quality-conscience contractors are subject to errors and omissions, among other problems. Through effective quality control, these can be caught before molehills grow into mountains. In this regard, however, it is important to recognize that field observation is best performed by or under the direction of those who developed the plans and specifications. A third-party quality control plan monitors conformity with plans and specifications.

Construction quality control (CQC) used to be provided as a matter of course. It has been relied on less in recent years, due to its cost and because of the liability imposed on the quality control firm. Now, in large measure due to the problems created by lack of observation, many owners see it as a service that saves more than it costs, while design professionals regard it as a service that reduces liability exposure more than it increases it.

### 8.9.2.2 Purpose of Quality Assurance

The purpose for construction quality assurance (CQA) in the general sense, is to provide some assurance that the project is developed as intended. While quality control takes a microscopic approach, focusing on individual test results, quality assurance should be more holistic.

A quality control and quality assurance plan should be implemented as an integral part of the systems designs for site- specific environmental protection. The program should be in-place as early as the preliminary design stages and should be continued through both facility construction and operation to assure the integrity of the facility.

The quality control/quality assurance plan is the owner-operator's site-specific written response to both state and federal regulatory agencies' requirements and may be submitted as part of the permit application. The plan should include a detailed description of all quality control and quality assurance activities that will be performed to manage quality in order to document the owner's approach. In regards to a systems design for site-specific environmental protection an incisive quality control/quality assurance program should be incorporated to properly qualify and quantify the unique geological conditions of the proposed site. The quality control plan and the quality assurance plan should, unto itself, continue as a check and balance during construction and facility operation as well as perpetuate into the closure phase.

Quality control is primarily a testing function, similar to compaction testing in earthworks quality control. For geosynthetics, it is usually provided by the

*manufacturer* in the plant and by the *installer* during construction. On a project which has various types of geosynthetic products, such as polyvinyl chloride (PVC) and high density polyethylene geomembranes, plus geotextiles and geonets, each manufacturer and each installer will conduct separate, discrete quality control programs.

Quality assurance is not primarily a testing function. Rather, it is a much broader scope of services. In earthworks it is analogous to providing engineering observation, borrow pit evaluation, review of the design drawings and specifications, and so forth. The quality assurance personnel have the responsibility for oversight of the quality control testing being performed by the manufacturer and the installer, as well as performing their own observations and testing. It is also the quality control personnel's responsibility to ensure that the quality control programs being conducted by the various suppliers and installers are properly integrated.

#### 8.9.2.3 Benefits and Drawbacks

The benefits and drawbacks of a well organized and implemented CQA plan is non-comparable. It is a perfect example of "pay now or pay later". Historically it has been proven that an arrant CQA program has been cost effective during the project construction as well as the overall dependability of the facility's operations. The engineering and the design have been painstakingly fine tuned to bring the proposed product on-line. To stop the momentum at the drafting table (computer) would be inappropriate. A well established CQA program provides an added measure of insurance for both the owner/operator, the design professional, and the regulatory agencies. The impacted cost of a properly placed CQA plan is relatively small in comparison to show down or shut down of operations and the cost of post-construction repairs.

### 8.9.3 THE CQA PLAN

With the completion of the proposed design, the follow through of an organized CQA plan should be implemented. The CQA plan outline could be boiler-plate and can be employed on other projects. However, the final CQA plan should be site-specific and shall be congruent to the plans and specifications.

A guideline to approach an incisive CQA plan should always include:

- Overview of the plans and specifications, from a constructibility viewpoint.
- Defined methodology of the CQA plan; detailed methods and procedures for construction and required testing.
- Areas of responsibility for each quality control function and how these are to be integrated into the quality assurance program.
- Distinctions between practices during earthworks clay liner and geomembrane liner construction.
- Complete, encompassing, monitoring and documentation throughout the construction phase. This section should include manpower utilization, testing methodologies, test frequencies and summation.
- Submission of final CQA report, shall include all documentation by the monitor, record drawing, test results, surveying data, and submittals by the contractor and the manufacturers.

The CQA plan should be customized to complement a particular design and the specific goals of the owner.

### 8.9.4 IMPLEMENTATION

On small, simple projects the design drawings and construction specifications are all that are needed to execute a functional CQA program. On more complex projects a formal construction quality assurance plan should be developed by a specialist. The plan should be as material-specific as possible, and for that reason it is advisable to wait until the selection of the manufacturer and the installer before the plan is prepared, although "generic"' plans have been used with success.

A typical CQA plan has the following major components:

Definitions
Roles & Responsibilities
Controlling Documents
Documentation
Operations CQA

#### 8.9.4.1 Definitions

All terms unique to the CQA operations, or subject to multiple definitions should be clearly defined. The definitions section should also define any abbreviations, trade names, and jargon which will be used within the Project. A list referencing a site- specific construction project should be placed in the vanguard of both the specifications and the CQA manual.

#### 8.9.4.2 Roles & Responsibilities

The role and responsibility of each participant must be clearly defined. This is especially important with respect to the limits and responsibility for the manufacturer's and installer's quality control, and to delineate between earthworks quality control and geosynthetics CQA. It is also important to delineate the roles of the CQA engineer, the construction manager, and any other

representatives that the owner may have. If outside laboratories are to be used for testing materials then it must be clearly established as to who will be responsible for directing the laboratory's work and reviewing the test results.

Reporting protocols should also be defined in this section. The CQA engineer should not have the authority to "reject" material or "direct" work (to do otherwise would compromise the third-party nature of this assignment). The CQA engineer should report to the designated owner's representative, usually the construction manager, who has these authorities.

### 8.9.4.3 Controlling Documents

Most complex projects have design drawings prepared by the design engineer, the geomembrane and geotechnical consultants, and shop drawings prepared by the geomembrane manufacturer and installer. There may be separate documents for each major component of construction, such as earthworks, earthworks, clay liners, geosynthetics and geomembrane liners. In addition, the construction manager will issue specifications, the geomembrane consultant will issue the CQA plan, and the manufacturer will issue specifications and a quality control manual. The CQA plan must specify the order of control of all of these various documents and the method of resolution in the inevitable case of a conflict.

### 8.9.4.4 Documentation

Any quality control or quality assurance program is only as good as the documentation. And the level of documentation should be determined on a case by case basis. On small projects it may be acceptable to use a simple note book and single page daily reports for all record keeping. But on larger projects separate logs must be maintained for each function: earthworks observation and testing, subgrade acceptance, panel receiving on site, material certificates, deployment, welding, repairs, final acceptance and so forth.

The industry has not settled on a unified set of documents and record keeping. Each consultant develops the paperwork that is best suited to their style of work and types of projects. The authors have experience with consultants who have used as many as 23 different types of forms on a single project, and others who use as few at two. Generally speaking, it takes from 8 to 12 types of forms to properly document the total quality assurance program for a typical mining application, including the manufacturer's and installer's quality control.

### 8.9.4.5 Earthworks Quality Assurance

Engineers designing earthen mining applications prefer a combination of method and performance specifications. The performance must be specified to ensure adequate performance over time. Most design engineers consider some method specifications necessary. Moisture content, density, and compactive effort must be controlled in the field if the specified permeability factors are to be achieved; specification of these parameters helps ensure that this is achieved. Combination method and performance specifications must be very carefully drawn to solve the problem of the specified method that does not yield the specified performance.

Design tolerances are usually present in the specifications and should be included in the CQA plan. Although statistical methods are available for determining design tolerances, most engineers use a "rule of thumb" method based on their experience. A safety factor approach is one approach. Another is to allow a certain percentage of test failures based on experience during construction quality control activities. Generally speaking, earthwork testing has one of two types of pass/fail criteria: minimum single test value, or minimum average value (usually with either a lower minimum value or limits set on deviation). Examples include "all tests must meet or exceed 95 percent compaction" or "the average of all tests taken in a single day (or in a particular work over) must be at least 95 percent, and no single test may be less than 93 percent."

Specifications as well as design drawings should include:

- Facility configuration and size
- Foundation preparation
- Liner material characteristics
- Hydraulic conductivity
- Soil density/moisture content relationships
- Plastic index
- In-place strengths
- Clay/soil liner thickness and permeability requirements
- Slope configuration, if applicable
- Lift thickness
- Scarification between lifts
- Compaction equipment and number of passes

*Earthwork Quality Control*

A significant part of the CQA plan is the evaluation and the qualifications of the proposed constructive lithology. The quality control portion of the CQA program provides for continual checks and balances this criteria of the specified materials during construction. On-site quality control testing as well as laboratory testing would be performed at a pre-determined frequency to verify conformity.

Quality control testing frequencies and test methodologies may differ depending on the application. Table 11 represents two sample construction testing

**Table 11** Subgrade Preparation and Clay Liner Construction Testing Requirements

| **Subgrade Preparation** | |
|---|---|
| Test Description and ASTM Designation | Test Frequency |
| In-Place Moisture Density Nuclear Methods (ASTM D-2911) | 1 test per 10,000 square feet (sf) (929 square meters $m^2$) |
| In-Place Moisture Density Sand Cone Methods (ASTM D-1556) | 1 test per 10 nuclear tests performed adjacent to nuclear density test for correlation |
| Moisture Density Curves (ASTM D-1557) | 1 test per 100,000 sf or per change of material (9290 $m^2$) |

| **Clay Liner** | |
|---|---|
| Test Description and ASTM Designation | Test Frequency |
| In-Place Moisture Density Nuclear Methods (ASTM D-2911) | 1 test per 1,000 cy (765 $m^3$) |
| In-Place Moisture Density Sand Cone Methods (ASTM D-1556) | 1 test per 20,000 cy (15,292 $m^3$) for correlation |
| Moisture Content (ASTM D-2216 | 1 test per 1,000 cy (765 $m^3$) adjacent to every nuclear gauge test location |
| Moisture Density Curve (ASTM D-1557) | 1 test per 10,000 cy (7650 $m^3$) |
| Field Permeability Tests (BAT Permeameter) | 1 test per 2,000 cy (1530 $m^3$) |
| Laboratory Permeability Tests (EPA Method 9100 or ASTM 18.04 Draft No. 6) | 1 test per 2,000 cy (1530 $m^3$) |
| Sieve Analysis (ASTM D-422) | 1 test per 10,000 cy (7650 $m^3$) |
| Atterberg Limits (ASTM D-4318) | 1 test per 10,000 cy (7650 $m^3$) |

requirements.

Testing frequencies and designation may be altered to assure material selection and constructive capabilities state and federal guidelines may also influence the quality control testing requirements involving the proposed application.

### 8.9.4.6 Geosynthetic Quality Assurance

The operations include three major areas: manufacturer's quality control, installer's quality control, and the third party quality assurance. There would typically be a separate QC plan for each manufacturer and installer, all part of the single CQA plan. Items typically specified as part of the operations CQA are:

Contractor's submittals and schedule.
Plant inspection frequency and detail.
Required material certifications
Material conformance testing type, frequency and criteria for acceptance.
Seam testing frequency, type and criteria for acceptance.
Method of repair of rejected areas.

Material testing specifications and criteria for acceptance is an area of much confusion. There are three distinct types of testing: *performance testing, compliance testing* and *conformance testing.*

*Performance tests* are engineering tests used to develop site-specific design criteria. For example, the friction angle and cohesion/adhesion along the interface of the geomembrane and the underlying soils. The engineer must specify the testing method that best models the site conditions, and the engineer must determine whether minimum, maximum, average or typical values are to be used in the analysis. Performance testing cannot be used for specification compliance.

*Compliance tests* are internal tests performed by the manufacturer to verify that their material meets their own specifications. These are the tests that are used to generate published "specifications" for the various materials and are typically performed on a regular interval. The test methods and specifications are not project specific and are not intended for use for acceptance of the material on any particular project.

One word of caution with respect to compliance testing. Manufacturer's published values are usually either "typical" or "average" values. While these are useful in comparing products, these values are inappropriate for use in design.

*Conformance testing* is that group of testing performed by the CQA engineer to verify that the materials provided to the project meet the specifications for that project. The conformance tests should be selected to measure those properties that are important to the project, and the criteria for acceptance should be set as needed by the design parameters. In selecting the conformance tests to adopt in the specifications and CQA plan the engineer must consider:

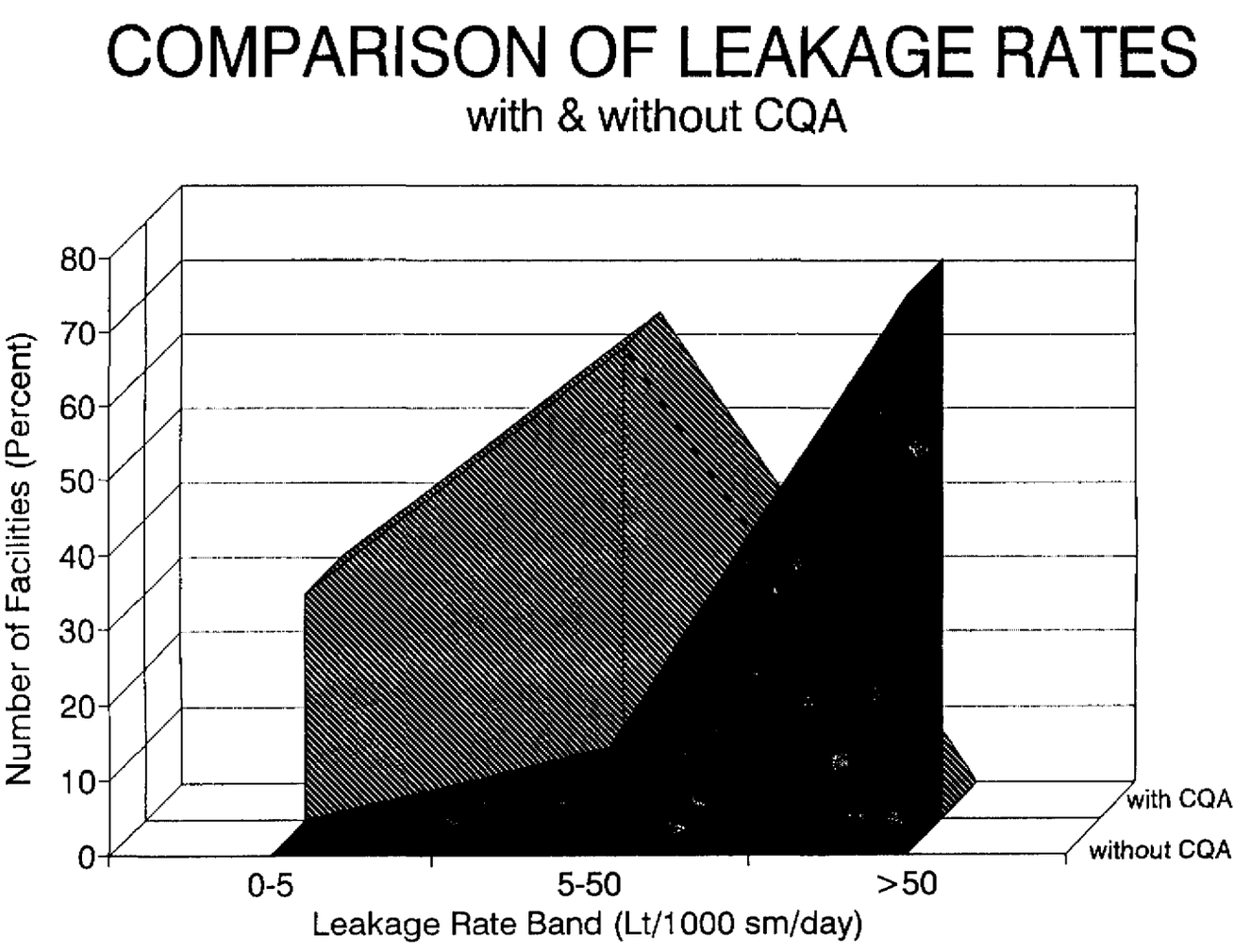



**Figure 53** Results of stud/leakage bands vs. % of facilities studied.

- The type of facility and the anticipated loading conditions.
- Threat to human health and the environment.
- Required level of confidence in the containment system.

Just as important as selecting the types of tests is specifying the criteria for acceptance. While most engineers are well equipped to specify these criteria, an important and often overlooked issue is minimum (or maximum) versus average values.

Certain properties lend themselves to specification of minimum (or maximum) test values, such as carbon black content, while others are more appropriately measured on some average basis. For example, the authors usually specify two different membrane thicknesses: one for the project average and a lower one for individual test minimums. Other properties are best specified on a roll- or lot-average basis. The minimum average roll value method of specifying is especially useful for geotextiles, geonets and geogrids, but not really applicable to geomembranes.

Any design is only as good as its implementation, and geomembrane liners are more susceptible to construction defects than most other engineered components. The nature of the material - a thin, weak membrane - and the fact that the work is often buried as fast as it is deployed, makes for ideal circumstances for construction defects to go unnoticed. But liner systems often represent a major capital investment, are usually the only thing separating a waste from the environment, and in the case of mining must perform well for the operation to be profitable.

"Do I need quality assurance on my project?" Only if you want the facility to work.

### 8.9.5 VALUE OF QUALITY ASSURANCE IN FLEXIBLE MEMBRANE APPLICATIONS

As consultants whose practice specialize in the design and quality assurance of geomembrane liners, the authors are often asked to justify the need for third party quality

assurance. Many consumers of geomembranes believe that the installer's quality control program is adequate to ensure that the installed product will perform satisfactorily. And often this is the case.

However, before making the decision to engage or not engage a quality assurance team, the owner must evaluate the specific application. Examples of projects where quality assurance must be provided include applications where:

- There is a significant threat to human health or the environment.
- The economic value of lost liquids exceeds the cost of quality assurance.
- Repair or replacement of the installation is very costly or not practical.

Beyond this philosophical approach to deciding when CQA is needed, there is quantitative data supporting its value. In 1992, the U.S. Environmental Protection Agency concluded a study of a number of landfills which were constructed with double geomembrane liners with intervening leak detection and collection systems. These facilities were studied specifically to quantify the difference in performance between facilities with and without CQA. Only double geomembrane lined facilities were included because these are the only liner systems where the leakage rates can be reliably measured.

The results of this study are presented in Figure 53 as leakage bands versus the percentage of facilities studied that fell into that band. There was a striking difference between sites with CQA and those without. None of the sites with CQA demonstrated leak rates of greater than 50 liters per 1,000 square meters per day (l/d), and nearly half of the sites reported leaks of less than 5 l/d. Eighty percent of the sites without CQA, however, report leaks of greater than 50 l/d. While the EPA study did not cite the upper range of leakage rates, the author's have experience with sites that have measured leaks of greater than 5,000 l/d.

To put these leakage rates into perspective for the mining community, Table 12 summarizes leakage rates in l/d with corresponding percentage of pregnant leach solution. These relationships were developed using typical solution application rates, leach areas and pad geometries for copper heap leach projects.

**Table 12** Leakage Rates versus PLS Loss

| Leakage Rate (l/d) | Loss of PLS (% of solution) |
|---|---|
| 5 | < 0.003 |
| 20 | 0.01 |
| 500 | 0.2 |
| 2,000 | 0.8 |
| 10,000 | 4.2 |

### 8.9.5.1 The Manufacturer's Quality Control Program

Quality assurance begins at the plant with the manufacturer's internal quality control program. Each manufacturer has their own unique program, and it is the responsibility of the quality assurance team to verify that the manufacturer's QC program meets the needs of the project, and to recommend modifications where it does not.

The manufacturer's quality control begins with inspection, sampling and testing of the resin. Either random or systematic samples from each car load of resin should be obtained and tested for the relevant physical and chemical properties. The results of these tests are then compared with the test certifications supplied by the resin supplier, and if the test results match and the results pass the project specifications, the resin is accepted for use. Otherwise, the resin is rejected.

**Table 13** Typical HDPE Resin Tests

| Test | Designation | Requirement |
|---|---|---|
| Specific Gravity | ASTM D-792-66 Method A | 0.94g/cm$^3$ |
| Melt Index | ASTM D-1238-85 Condition E | 0.1 to 0.3 g per 10 min. |
| Low Temperature Brittleness | ASTM D-746-79 Procedure B | Minus 22 degrees C |

Table 13 presents some typical resin properties for high density polyethylene (HDPE) tested by resin suppliers and the sheet manufacturers. The manufacturer's quality control program also includes monitoring the relevant control points during sheet fabrication, including die temperatures, membrane thickness, resin flow rates, sheet width, and visual inspection. As each panel is fabricated samples of the sheet are obtained and tested for the relevant physical and chemical properties of the sheet. Table 14 presents some typical HDPE sheet properties tested by the manufacturer.

The quality assurance program begins with random inspections of the plant (sometimes called plant audits) during fabrication of the material for the project. The purpose of this is to verify that the manufacturer is performing the specified QC functions and to provide early warning of any problems.

**Table 14** Typical HDPE Sheet Tests

| Property | Test Method |
|---|---|
| Carbon Black Content & Dispersion | ASTM D-1603 & ASTM D-3015 |
| *Fingerprinting (composition % carbon black,* crystallinity, amount of polymer) | ASTM D-4437, as Modified in Appendix A Therman Gravimetric analysis (TGA) |
| Dimensional Stability | ASTM D-1204, to 212°, 15 minutes |
| Hydrostatic Resistance | ASTM D-751, Method A, Procedure 1 |
| Melt Index (sheet, not base polymer) | ASTM D-1238 Condition E (on finished) |
| Water Absorption | ASTM D-570 |
| Specific Gravity | ASTM D-792, Method A |
| Puncture Resistance | ASTM D-101B, Method 2031 |
| Tear Resistance | ASTM D-1004, Die C |
| Environmental Stress Crack | ASTM D-1693, as Modified in Appendix A |
| Tensile Properties:<br>• Modulus of Elasticity<br>• Yield & Break Stress<br>• Break Elongation | ASTM D-638, Type IV Specimens (at two- inch-per-minute extension rate) |
| Thickness | ASTM D-1593, para 9.1.3 pr ASTM 374 |
| Hardness | ASTM D-2240 |
| Volatile Loss | ASTM D-1203, Method 1, Appendix F (after immersion) |
| Resistance to Soil Burial<br>• Tensile Strength at Yield & Break<br>• Elongation at Yield & Break<br>• Modulus of Elasticity | ASTM D3083, as Modified in Appendix A |

*Before* the sheet is shipped to the project the test certificates for both the resin and the sheet must be provided to the CQA engineer to verify that the material meets the project specifications. While this seems an obvious step, it is a common cause of construction delays. A common scenario: sheet is shipped to the site without test certificates, the certificates are delayed and installation must proceed or the job will be delayed. Once the certificates are delivered to the engineer, missing tests or failing results are noted and the owner is left with the unfortunate decision of either delaying the project further or accepting sub-standard material. While this is almost always the result of honest oversights and conflicts in human resource availability, the result is still the same.

### 8.9.5.2 Installer's Quality Control

The installer's quality control program begins with receiving copies of the test certificates from the manufacturer and verify that the material meets specifications. As the sheet is delivered to the site the installer must cross-reference the material certifications to verify that only those panels which have been tested and verified to meet specifications are delivered.

### 8.9.5.3 Subgrade

Before any geomembrane can be deployed, the subgrade must be properly prepared and inspected by the CQA engineer, the installer, and the earthworks contractor. The subgrade should only be accepted for geomembrane deployment when all three parties are satisfied with its preparation.

This is a crucial point and one that is usually overlooked when there is no third party CQA team. As an interface between two technologies, the interaction of the earthworks and the geomembrane is not the responsibility of either of these two trades. But, poor subgrade preparation is one of the leading causes of liner

system failures and can result in large differential settlements, punctured geomembranes and slope failures.

Once liner deployment begins, the quality control program focuses most of its attention on two areas: visual inspection of the sheets for damage and manufacturing flaws, and on the quality of the seams.

### 8.9.5.4 Field Seams

There are two types of field seams: solvent welded seams, commonly called "glued" seams, and heat welded seams. Solvent seams are used for PVC, chlorosulfinated polyethylene (CSPE), more commonly known as Hypalon™, and other similar geomembranes. With solvent welds the success of the seam depends primarily on the proper selection of the type of solvent, weather conditions, and on *hygiene*. Moisture and dust are the primary causes of poor solvent seams. Solvent is applied manually and presents a great opportunity for operator error. Therefore, visual inspection during application of the solvent is the primary quality control tool. On the other hand, solvent seams are typically 100mm in width, compared to about 20mm for heat welds, and offer a greater tolerance for defects.

There are two types of heat welds: extrusion welds and fusion welds. Heat welds are used for polyethylenes: HDPE, very low density polyethylene (VLDPE) and linear low density polyethylene. Extrusion welds are very much like filet welds in steel. A bead of molten polyethylene of the same composition as the sheet material is extruded over the lap of the two sheets. Prior to welding the edges of the areas to be welded must be cleaned and ground or the bead will not stick. And it is very important that grinding occur immediately before welding to avoid dust settling into the freshly ground area. Fusion welds are formed by heating both sheets with a hot wedge, them crimping the sheets together without the addition of extrudate. Either single or double welds can be formed using a solid or a split hot wedge, respectively.

The double weld (split wedge) is the most common and provides a significant quality control advantage over any other type of seam. Between the two welds is an air channel that is used to test the seam for continuity, which is discussed in more detail in the following section.

### 8.9.5.5 Seam Continuity Testing

Seams are tested for continuity, or the ability to prevent leakage, by non-destructive methods. There are three common types of seam continuity testing: air channel pressure testing, vacuum box testing, and air lance testing. The air lance method is used for flexible membranes such as PVC which cannot be tested in a vacuum box (the vacuum draws these membranes up into the box and defeats the test). A small diameter nozzle of air is directed at the seam, with the nozzle perpendicular to the seam and parallel to the ground. As the operator walks along the seam testing it continuously, the sheet opposite the nozzle is observed for movement. Any movement indicates a leak through the seam and that section is marked for repair.

Vacuum box tests are used for rigid sheets such as HDPE and can also be used for VLDPE. This is the first test method developed for HDPE is still the only commonly accepted method for testing extrusion welds. This test uses a clear plastic box with an open, gasketed bottom, typically rectangular in shape. First, a length of seam is cleaned with soapy water, then the box is pressed against the seam and a vacuum is applied. The operator observes the seam for bubbles which would indicate a leak. The box is then advanced about three-quarters of its length and the test repeated.

The vacuum box is a reliable test method, but very labor intensive and subject to operator fatigue and error. For these reasons industry has moved towards the air pressure test. In this test the air channel between the dual weld produced by a split hot wedge is pressurized and monitored with a pressure gauge. If the pressure does not drop below a specified level (an allowance for temperature variations and relaxation of the geomembrane) the seam passes. At the conclusion of the test the end of the air channel opposite the pressure gauge is opened to verify that the entire length of air channel was pressurized.

### 8.9.5.6 Seam Strength Testing

Both solvent and heat welded seams should be tested for strength. The strength of the seams is an indication of its ability to withstand service loads, and as such is a very important parameter. Strength test specimens must be cut from the actual seam, and are usually specified every 150 to 200 meters of seam length. In addition, it is recommended that trial welds be fabricated and tested each morning and each afternoon for each heat welder to verify that the unit is functioning properly. For solvent seams trial welds are not necessary.

Strength testing consists of shear strength and peel strength, and specifications typically require both that the failure occur not along the seam/sheet interface (film tearing bond criteria) and that a minimum force is achieved before failure. For glued seams the minimum force us usually 1.8 kg/cm after the specified curing period. For heat welds the minimum strength is generally specified as a percentage of the tensile strength of the sheet, such as 50 to 60 percent in peel and 80 to 90 percent in shear.

Each coupon is cut into ten samples: five to be tested in peel and five in shear. The specifications must set forth whether all five of each type must pass, or whether

the average value must pass. The specification preferred by the authors is to require that all specimens meet the film tearing bond criteria, that 4 of the 5 specimens pass each of the minimum strength criteria, the average of all specimens pass the strength criteria, and that the minimum value be not less than 80 percent of the specified value regardless of the average.

### 8.9.6 CONSTRUCTION QUALITY ASSURANCE REPORT

Conceivably, the most vital part of an effective quality control and quality assurance plan, depends heavily on the identification of all activities that should be inspected. This includes assigning knowledgeable and experienced personnel to perform the onus of quality control and quality assurance for the inspection of these applications. As a point of clarification, the quality assurance report should be submitted upon the review and acceptance of the quality control report which includes all the test results, manufacturers' submittals, construction reports and as-built drawings.

The quality control report could be submitted by the contracted installer or when referring to earthworks quality control by the engineering firm. Every facet of the construction must be documented and cataloged. The communication channels must remain open between the construction quality assurance engineer, the quality control engineer (may be the same as the quality assurance engineer), and the client as well as the contractor. All documentation should be compiled into a construction quality assurance report and exhibited as evidence that the facility was constructed in accordance with the systems design for site-specific environmental protection. The final report serves the function of a quality audit of the construction and certifies that construction specifications were adhered to during construction.

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# Chapter 9

# OPERATIONS ENVIRONMENTAL MANAGEMENT

edited by C. H. Parrish

## 9.1 INTRODUCTION

Before spending a full chapter discussing operations environmental management, it is appropriate to define the term. As used here, it will mean all the activities necessary to insure that a mining operation is designed, executed, and closed in an environmentally sound and socially acceptable manner. This definition extends beyond actual mining, to all the activities of corporations that conduct mining operations. The field is, for the most part, about 20 years old and more precise definitions have not yet evolved. Indeed, the terms "environmentally sound" and "socially acceptable" are used to reflect the fact that national and community standards are not yet fully developed.

Chapter 2 contains a discussion of the early days of hydraulic mining regulation in California. The first successful regulation came in an 1884 court decision which shut down many of the larger hydraulic mining operations in the western Sierra Nevada (*Woodruff v. North Bloomfield Gravel Mining Co.* (Circuit Ct. D Calif.) 18 F. 753, Jan. 7, 1884). The federal government followed this decision with "An Act to Create the California Debris Commission and Regulate Hydraulic Mining in the State of California" (Act of Mar. 1, 1893, Ch. 183, Stat. 507,). This federal legislation shut down all but the smallest hydraulic mines. These early efforts limited mining environmental impacts by effectively creating prohibitions. It has only been since the 1970s that the current system has evolved. This system limits impacts by imposing a large number of regulatory requirements for environmental protection on operating mines. This system of regulation has propelled the development of the modern practice of mining operations environmental management.

Operations environmental management involves a broad range of technical and non-technical skills. It has recently become axiomatic that political, regulatory, and community relations functions of operations environmental management hold equal footing with technical matters. Simply put, it is no longer adequate for a mining operation to quietly go about its business. It is increasingly important to keep the larger community around a mine site informed about site events, compliance record, and other operational achievements. Otherwise, lacking solid information from a site operator, there may be a tendency for the community to assume the worst about the site.

Owing to the emerging nature of environmental management, as well as the broad range of skills needed, people employed in the field have wide ranging backgrounds. Mining companies employ, as environmental managers, individuals with educational backgrounds in geology, hydrology, animal biology, plant biology, soil science, range science, forestry, archeology, engineering, law and probably several other disciplines. This first generation of operations environmental managers emerged from the ranks of technical people who grew up with the current regulatory scheme. It would be presumptuous to forecast whether the field will stabilize into a specialized discipline in its own right or whether this divergent approach will continue for some time to come. No matter what course the field takes, it will probably continue to reflect outside forces on the industry. Those forces are shifting from requirements for technical compliance with specific regulations to the need to address public and governmental understanding of the modern mining industry and what it contributes to society. The emerging non-technical tasks will take on increasing importance for the environmental manager.

This chapter will discuss the functions of operations environmental management, provide a framework for understanding where and when those functions are performed during the life of a mine, and explain how some companies assign the execution of those functions. It will also highlight some issues of current importance to environmental managers. Technical issues and specific regulatory requirements are addressed elsewhere in this publication.

## 9.2 EVOLUTION OF OPERATIONS ENVIRONMENTAL MANAGEMENT

A brief history of operations environmental management is helpful to understanding how the current model evolved. The United States' mining industry experience is used to illustrate the history for several reasons: 1) the regulatory scheme in the United States is often used as a model for development of regulatory systems in other countries, 2) many companies that operate in the United States have adopted policies of conducting their world-wide operations in accordance with North American standards, unless local standards are more stringent, and 3) mining environmental regulation in the United States generally pre-dates similar regulation in other parts of the world, giving U.S. companies a head start in developing their practices.

The history of operations environmental management can be described in three periods, each of which contributed current practices. The first period will be referred to as the pre-SMCRA period and includes all time up to the enactment of the Surface Mining Control and Reclamation Act ("SMCRA") (30 USC 1201 et. seq., Aug. 3, 1977). The middle period will be called the early SMCRA period and includes the time from 1977 to about 1983, followed by the third, or present period. While some may argue with the selection of 1983 as the start of the present period, the circumstances defining the beginning of this period are largely indisputable.

### 9.2.1 PRE-SMCRA PERIOD

Prior to 1977, the world of mining environmental legislation was either non-existent or just emerging. Some local governments passed ordinances that regulated mining. These ordinances were geographically spotty, loosely enforced, and not very specific in their requirements. In the absence of strict federal regulation of the mining industry, states began to adopt their own regulations. In the early 1970s several states, notably Pennsylvania, Montana and Ohio, passed coal mine environmental control laws. Pennsylvania in the eastern coal mining region, and Montana in the western region, passed what were considered the most stringent of these laws. Some laws had been passed at the U.S. federal level, notably the Clean Air Act ("CAA") (42 USC 7401 et. seq., November 21, 1967), the Clean Water Act ("CWA") (33 USC 1251 et. seq., October 18, 1972), and the National Environmental Policy Act ("NEPA") (42 USC 4321, January 1, 1970). Implementation of these laws was slow. Both the CAA and the CWA contained language to allow for compliance to be phased in over time. NEPA, which largely affects new projects or major expansions of existing projects, was not having much of an effect on the industry because: 1) there was little hard rock mine development on federal lands in the western U.S. during this period, 2) the expansion of the western coal industry had not yet hit full stride, and 3) coal development in the eastern U.S. generally did not require federal decision making, thus completely avoiding NEPA review.

Prior to passage of SMCRA there was a feeling that prescriptive environmental regulation was a fad that would either stabilize or decline very soon. Most mining companies in this period did not have an environmental department. Environmental matters were assigned to staff members on an ad-hoc basis, on par with other project-type work at mine sites. Often the assignment went to a junior engineer or geologist. The era of ad-hoc environmental management came to an abrupt halt in 1977 when Congress passed SMCRA.

### 9.2.2 EARLY SMCRA PERIOD

The early SMCRA period is characterized by a large bubble in the demand for mining environmental management created by the rough coincidence of one of the largest expansions in the history of the U.S. mining industry and the passage of SMCRA. The industry expansion was confined to the coal sector and was driven by a run-up in energy prices.

Despite its name, SMCRA did not address the entire mining industry. Instead, it imposed certain requirements on surface and underground coal mining operations. This was, and remains, the most sweeping act to affect mining operations in the U.S. Among the things SMCRA required were: (1) that all coal mines apply for, receive, and operate in conformance with permits issued under the act, (2) that comprehensive data be collected on virtually all environmental media and supplied to the regulatory agencies in support of such permit applications, (3) that certain prescriptive standards be applied to all coal mining operations, (4) that all permitted operations regularly monitor and report compliance with permit conditions, (5) that agencies issuing permits regularly inspect all permitted operations, (6) that interested parties could complain to permitting agencies about mine site practices and the agencies were obliged to investigate such complaints, (7) that permitted operations must allow access to agency inspectors, and (8) that violations of permit conditions or prescriptive standards were punishable by civil and criminal sanctions. Thus, the basis was established for a command and control system of environmental regulation of mining operations. This model, while widely decried, remains the basis for much of the proposed regulation of mining operations in the U.S.

The almost simultaneous increase in coal mining activity and the enactment of sweeping new regulations had a profound effect on the coal mining industry. Suddenly, the ad-hoc approach to environmental management was inadequate. It was replaced by the need

for specific technical and legal expertise to secure permits for existing and proposed mines and to monitor and report compliance. Many companies responded by creating large, centralized environmental services departments. These departments were staffed by technical professionals with backgrounds in environmental disciplines. Commonly the departments were placed under direction of technical groups, although some were overseen by law departments.

Almost as quickly as the bubble grew, it burst. The work load created by the need to permit older mines subsided as the task was completed. Falling energy prices meant that there were few, if any, new mines. In fact, the industry began to consolidate and some of the less efficient mines were closed and production shifted to larger, more efficient operations.

### 9.2.3 PRESENT PERIOD

As the work load created by the passage of SMCRA and the coincident expansion of the coal industry subsided, coal mining companies realized that the large environmental staffs hired for mine permitting were no longer needed. It wasn't long before companies began to reduce staff levels. For the most part, environmental services groups were eliminated. By this time, however, it was not practical to return to the days of ad-hoc environmental management. Closure of CAA and CWA phase-in periods along with the need for continued SMCRA compliance had raised the floor defining the minimum levels of environmental management activity. Plus, many mining companies had come to realize that there were other reasons to manage environmental matters at levels above the mandated minimums. What emerged, was a move toward a lean in-house staff to attend to every day tasks, supplemented by consultants hired for extraordinary tasks. Consultant tasks are typically large, short term projects, or projects or problems needing special expertise.

While the coal companies were wrestling with down sizing their environmental staffs, other sectors of the mining business were beginning to come under the same types of pressure, albeit under slightly different circumstances, that affected the coal industry in the early SMCRA era. By this time, the CAA and the CWA were fully implemented. In addition, the Endangered Species Act ("ESA") (16 USC 1531 et seq., Dec. 28, 1983) was passed. The ESA would have a profound effect on the mining industry, particularly that portion of the industry that operates on public lands.

The development of heap leach technology, which allowed economic extraction of low grade gold deposits, produced a boom in gold mining in the mid to late 1980s. Most of the new gold mining activity was concentrated on public lands in western states. Drawing from the experience of the coal companies, the gold companies resisted the temptation to create large in-house staffs. By and large they adopted the model that the coal companies developed after the early SMCRA period. It now appears that much of the mining industry, including non-ferrous metals and industrial minerals, has adopted this model.

## 9.3 OPERATIONS ENVIRONMENTAL MANAGEMENT FUNCTIONS

Operations environmental management functions have evolved with time, and discussions among industry practitioners indicate that a rough consensus has developed with regard to where, within an organization, these tasks should be assigned. There are a number of tasks that are generally considered to be corporate tasks, a number of tasks that are generally considered to be project functions, and finally, some tasks that are commonly completed at either or both management levels. The breakdown used here merely represents the most frequent distribution of tasks within organizations. Virtually all organizations will have their own variations, based on their particular circumstances, on how and by whom these tasks are accomplished.

### 9.3.1 CORPORATE TASKS

Environmental management tasks that are generally taken up at the corporate level involve those things that might affect the corporation as a whole, and which may create liability for officers and directors, or which are not directly related to mine project development or operation.

#### 9.3.1.1 Policy Development

Policy development is an area that has become increasingly important in terms of mining company operations environmental management. Many companies have come to recognize the benefits of having written environmental policies. Among these benefits are: 1) policies can provide definitive guidance to company personnel who may not have direct access to senior officers and directors, and therefore need consistent written guidance that explains corporate policy; 2) properly constructed policies can limit both corporate, and officers' and directors' liability for environmental matters, provided that such policies adequately articulate the company's intentions, and are consistently enforced; and 3) policies can serve as public relations tools insofar as they serve as an open statement of the company's position on environmental matters.

Policy development is, by its very nature, a corporate task. Although rank and file company employees need to accept and implement environmental policy, it is incumbent on management to articulate policy. Under a

clearly stated policy, employees can solve problems, safe in the knowledge that so long as their actions are within the policy, they enjoy full management support. Policy development is an ongoing activity because it is necessary and desirable to periodically review such policies. Periodic reviews allow policy adjustments, as necessary, to reflect changing societal expectations and regulatory frameworks.

#### 9.3.1.2 Audit

Regular audits of operating properties have become a fixture of mining operations environmental management. As with financial auditing, reserve auditing, and other similar activities, environmental auditing provides an opportunity to bring fresh minds to bear on environmental compliance at a project site. Audits are an excellent tool to improve site environmental compliance by providing an outside perspective of site activities and compliance matters. Audits can also help corporate officers' and directors' demonstrate diligence in environmental oversight. This function can only be achieved, however, if problems found during an audit are immediately addressed and reported in accordance with applicable regulations. An audit program should only be undertaken when there is a clear will and means to resolve any problems identified as a result of the program. A thorough discussion of the benefits of implementing an audit program can be found in Keppler and Delcour (1994).

Audits must be undertaken with care and clear purpose in mind, because they can be a double-edged sword. There is currently an active public policy debate regarding the discoverability of audit reports. Some argue that audit reports should be confidential and non-discoverable, thereby encouraging companies to audit their operations, discover problems, and resolve those problems without having to be concerned about their own internal investigations being used against them (Goldman, 1994). Opponents of this position argue that allowing such confidentiality can have the effect of allowing companies to hide wrongdoing (Ronald, 1994). The ongoing policy debate has resulted in conflicting practices among regulatory agencies regarding discoverability of audits. The United States Environmental Protection Agency ("EPA") is currently at odds with a number of states that have adopted audit privilege statutes. Because of the double-edged sword that audits represent, and because of this current debate regarding legal protection of audit findings, an audit program should only be undertaken with a full understanding of potential consequences of implementing such a program.

The need for caution extends beyond program development to implementation. Individual site audits must be carefully developed because of the need to assure completeness, accuracy, and appropriateness for the industry and location. A lesson can be taken from the EPA experience with publishing manuals on environmental investigations. In 1989, EPA published a manual on multi-media environmental investigation. The manual contained a checklist of items to be investigated. Being from the EPA, this list was embraced by many practitioners as a guide to complete environmental audit needs. New environmental legislation, changes in interpretations of existing environmental law, and changes in regulations, quickly made the checklist obsolete. When EPA updated the manual in 1992, the checklist was omitted (EPA, 1992).

As things currently stand, because of the overall corporate implications of auditing and protection of audit results, coupled with the need to avoid allowing site personnel to "grade their own papers," audit programs are currently administered by most companies at the corporate level.

#### 9.3.1.3 Due Diligence and Fatal Flaw Analysis

Due diligence work consists of performing an independent environmental review of an acquisition target. These reviews are sometimes known as site assessments. Environmental due diligence work is similar to audit work, although the results of the activities are used solely to assist in project evaluation, and do not have the audit functions of confirming compliance with corporate policies and serving as site management tools. Because most corporations conduct merger and acquisition activities at the corporate level, the environmental due diligence work is likewise conducted at the corporate level.

Due diligence practices are well developed. The American Society for Testing and Materials ("ASTM") has published two protocols for conducting site assessments (ASTM 1993a and 1993b). The protocols were not developed specifically for the mining industry and it is recommended that practitioners modify the activity to address any potential environmental risks particular to the mining industry or the site in question.

Fatal flaw analysis is a process for determining whether a development project has environmental issues that would cause the project to become uneconomic. This type of analysis is similar to a due diligence audit in that it seeks to answer the question of whether additional investment in a particular project is warranted. Fatal flaw analysis can be conducted at either the corporate level or the project level. It is noted here because of its similarity to due diligence work.

It is worth mentioning that the outcome of any due diligence exercise or fatal flaw analysis can, and should, be influenced by the perceived quality of the deposit. A high quality ore deposit can compensate for the risk

associated with purchasing, or developing and operating, a project in an environmentally sensitive location.

#### 9.3.1.4 Lobbying

Lobbying is normally related to policy development and long-term corporate needs for regulatory reform. It is also, all too often, conducted as a defensive measure against proposals for increased regulation of the industry. Lobbying can take place in both the legislative and regulatory venues. Legislative lobbying addresses local, state or federal lawmaking initiatives that would affect mining operations. Regulatory lobbying is aimed at administrative rule making which is also conducted at all three levels of government.

Depending on the regulatory effort in question, companies sometimes hire lobbyists to assist in this task. Another common practice is to lobby as part of a trade organization such as the National Mining Association or one of the regional or state mining associations. Enlisting the support of industry organizations helps to spread the cost of lobbying more evenly throughout the industry. It also serves to let lawmakers and regulators understand that the concerns are not solely the concerns of one company, but represent the views of the industry at large, thereby giving them greater weight. Most companies conduct this activity at the corporate level because individual operations seldom have the personnel available to address these issues.

### 9.3.2 PROJECT FUNCTIONS

Project functions are those activities that normally relate to day-to-day project operations. The need to quickly respond to project operating needs generally means that these activities can be more efficiently completed at the project level.

#### 9.3.2.1 Technical Investigations and Analyses

Technical investigations and analyses are activities that are generally undertaken in response to specific needs. Needs range from baseline data collection for permitting purposes, to impact investigations to help determine compliance, to analytical work to assist in developing final closure or remediation plans. This type of work addresses very specific local problems and is usually the responsibility of project personnel. Often this work requires specialized expertise and is completed by consultants.

#### 9.3.2.2 Permitting

Project permitting continues to grow in importance in the overall life of a mining project. Permit conditions set at the outset of a project will control many of the project activities throughout its life. Also, the level of environmental analysis required by permitting agencies continues to rise and the number of agencies with authority to issue permits to a mining operation also continues to increase. Because of mutual reinforcement between these two phenomena, permitting is consuming an increasing share of corporate environmental resources. Permitting costs do not stop once an operation is approved and begins construction. Most permits today have a finite life attached to them and require regular reapplication and re-permitting exercises.

Permitting is the subject of other chapters in this book, however, it is worth mentioning here that the activity invariably involves numerous agencies and can be very expensive and time consuming. It remains, however, largely a project function and not a corporate function for many organizations because the consequences are normally concentrated at the project in question.

#### 9.3.2.3 Regulatory and Legal Compliance

Much of the regulatory system in place in the United States today relies on self-monitoring and reporting by mining operators. Reasons for this reliance vary, but can be categorized under a few general areas. First, most regulatory agencies do not have adequate staff to perform monitoring at individual mining sites. Second, even if adequate personnel existed, agencies seldom have the in-depth knowledge of site activities that would allow them to properly conduct monitoring, testing or sampling activities. Third, by shifting the sampling and monitoring responsibilities to the operator, regulatory agencies can be assured that the operator remains in constant contact with the effects of the operation. This is most desirable because responsibility for correcting any compliance problems rests solely with the operator. Only by being informed can the operator adequately perform this function.

Once a project is permitted and under construction or operating, it becomes necessary to comply with the multitude of permits issued for the project and various legal and regulatory requirements that may or may not be articulated in the permit documents themselves. This is very much a local activity. It involves not only on-the-ground compliance with permit conditions, but also sampling, testing and monitoring of permit compliance and reporting of results.

##### *9.3.2.3.1 Sampling and Testing*

Virtually all permits issued to mining operations today require some form of sampling, testing, or monitoring, or some combination of these activities. Permits generally describe the media to be monitored, sampled, or tested, the frequency with which the activity is to take

place, and the acceptable ranges within which the results must fall in order for the operation to be considered to be in compliance with its permits. Furthermore, failure to conduct sampling, testing or monitoring is itself often considered to be a violation of permit conditions.

#### *9.3.2.3.2 Reporting*

Keeping in mind that a primary objective of sampling, testing, and monitoring required by mining operating permits is to allow the regulatory agencies to evaluate site compliance, the importance of reporting is self-evident. Most, if not all, permits issued to mining operations today contain requirements for periodic reporting to the regulatory agencies. The reporting can take several forms. Special incident reports are often required to report breakdowns, out of compliance findings, and other non- routine events. Monthly or quarterly reports are quite often required for certain data, and annual summary reports are often used as a way to synthesize the data flowing from an operation. Failure to file reports is often a violation of permit conditions.

### 9.3.2.4 Health and Safety

Health and safety activities and environmental management activities at mine sites are slowly beginning to converge. Originally, health and safety activities were largely related to accident prevention. As the accident prevention portion of worker health and safety regulation matured, regulations moved toward addressing work place environmental hazards. This movement continues today. Increasingly, work place health issues are administered by the same agencies that administer environmental regulations. For example, EPA now administers a number of different regulations related to worker right-to-know and worker exposure to job site hazardous materials. As a result, some companies have begun to place health and safety issues under common direction with environmental management functions at mine sites. Combining these functions is by no means a universal response from the industry, but is a trend that bears watching.

### 9.3.2.5 Reclamation and Remediation

Reclamation and remediation takes in all on-the-ground activities that are undertaken to mitigate the impacts of mining projects on the environment. These activities can range from reclamation activities such as regrading, topsoil replacement and revegetation of disturbed areas, to groundwater contamination cleanup activities. Because reclamation and remediation projects are site specific and site based activities, most companies today assign these responsibilities to local management.

### 9.3.2.6 Employee Training

Today, operating permit compliance often requires individual employee knowledge. For instance, it is common for a mine permit on public lands to contain a stipulation that excludes firearms from the mine site, with the possible exception of allowances for security personnel. Since the employee parking lot is generally considered part of the mine site, this means that employees who might routinely carry firearms in their vehicles could unwittingly expose their employer to a potential notice of violation. While this is only one example, more and more companies are incorporating environmental compliance education into new employee training and annual refresher training mandated by worker health and safety laws.

In addition to providing direct benefits by informing employees of their obligations and duties under certain permit conditions, this has the added benefit of arming employees with knowledge that will help them understand why certain things are required at the mine site and will also help them become the eyes and ears of environmental site compliance. Most often, such employee training programs are developed at the individual mine sites to address specific permit conditions and local training needs.

## 9.3.3 MIXED CORPORATE AND PROJECT FUNCTIONS

The previous sections have been devoted to describing environmental management activities that are generally assigned to either corporate or local personnel. There are, however, a class of environmental management activities that can seldom, if ever, be assigned solely to either the corporate or local management. These activities are public, press, and government relations and education, and risk management.

### 9.3.3.1 Public, Press and Government Relations

It has been said that all business operates only by public consent. If this is true, then it is incumbent on businesses to actively engage the public in conversation. Such conversations are particularly important for businesses that do not have direct contact and interaction with the public. Mining is such a business. It is so far upstream in the product development and manufacturing channel as to be invisible to much of the general public. A prime example of this is found in the electric power industry. While most Americans today probably realize how convenient and cheap electric power is, they probably seldom equate the outlet in their living room with a coal mine. And even if they make that connection, they will probably fall far short of making

any connection to a copper mine. If they think about it at all, they will probably think of the electricity supplier who is their immediate contact.

Environmental activism, combined with historical practices of the mining industry in the United States, has been the driving force behind the changing regulatory climate faced by the mining industry. A considerable portion of current activism affects mining. At least one Washington D.C. lobbying group exist solely for the purpose of promoting increases in mining industry regulation. Many others devote their attention to public land matters that directly affect the mining industry in the western U.S. Still other lobbying groups devote their attentions to air, water, wildlife, and other issues that indirectly affect the mining industry. According to Lawson, (1996) environmentalist groups dedicated to direct action, litigation, lobbying, public relations, and land preservation, had paid staff totalling over 5,600 and combined annual budgets of over $890,000,000 in 1994.

With the public increasingly detached from mining, and well funded and aggressive activism from the many lobbying groups, the time has come for individual mining companies to address the question of public consent for the industry. Mining companies are just beginning the effort to educate the public. Because so many of the public issues faced by the mining industry revolve around environmental questions, environmental managers often lead the effort to address these issues. However, the task is so large, that many companies distribute responsibility for public and community relations throughout the company.

Maintaining relations with federal lawmakers is most often a corporate function. Relations with state lawmakers may be either a corporate or local function, while local elected officials are usually contacted by project personnel. Lawmakers often do not realize the importance of mining to their districts, but can be very receptive to a positive message. Often, the problem is that the only time they hear of mining related issues is when the public gets irate over issues such as expansion of a local gravel pit. If the mining industry wants these important individuals to hear its message, it must contact them.

Similarly, the press will often concentrate on the negative stories about mining. It is up to the mining industry to generate other stories for the press to carry. While it is unlikely that the national press would respond to a local mining story, companies, and environmental managers in particular, should be prepared to respond when a reporter calls. Because many mines are located near smaller communities, it is generally productive to contact the local press when there is a positive story to tell. Local press contacts are almost always made at the project level. The environmental manager should always be prepared to supply information directly to the press, if appropriate, or to the designated spokesman for the operation.

Public relations, especially in communities around mine sites, is very much a local function. Some mining companies have developed community outreach programs designed to provide a consistent source of accurate information to interested locals. This practice is so new that there is little that can be said about standard industry practices. It is an area that is receiving increased attention in the industry, and because many of the issues that concern the public are related to environmental matters, the environmental manager is likely to be involved even when a company has a public relations department.

### 9.3.3.2 Risk Management

Environmental risk management may be assigned to certain individuals within a company, but experience shows that risk management decisions are made at all levels of a company. Consider the questions below.

A mine manager may ask him or herself; "The permitting agency just stopped working on our application to expand one waste rock dump and eliminate another. I understand that they have an emergency to deal with somewhere else, but I need dump space. The expansion project is an unqualified environmental positive when compared to the approved plan and the permitting agency views the project favorably. Should I begin the expansion without approval and run the risk of being cited for being out of compliance with my permits, or should I stay with the approved plan even though it is less environmentally sound?" A senior environmental manager may ask him or herself; "Site Z is nearing closure and we have a number of options for final closure design. The site looks clean today, but the definition of clean may change in 10 years. How much should the company spend today to minimize long term potential liabilities from the site, especially when no problems are apparent?" A company president may ask him or herself; "Company X wants a merger, and it makes good business sense, but their environmental record is less than perfect. The technical reports show current problems and question some past practices but everything looks manageable. The merged entity would be very strong, could clean up their current problems, and could go forward with a clean environmental program, but there is no way to know whether latent liabilities exist. Can I recommend a merger under these conditions?"

Every one of the above questions is an example of environmental risk management. It is probably the most ubiquitous task undertaken by environmental managers at all levels of a company. It is such a pervasive feature of environmental management that it can pass unrecognized in the daily milieu. It varies from traditional risk management because there are no actuarial tables, and there is almost no established guidance. Most people

want to do the right thing, but the "right thing" is not always obvious. The best that can be said in these instances is that the risks must be weighed against the potential outcomes, both favorable and unfavorable, of each action. Decision can then made based on a weighing of the relative merits of the choices. Depending on the magnitude of the decision, it is often helpful to seek input from others during deliberation.

## 9.4 ENVIRONMENTAL MANAGEMENT CYCLE

All mining projects follow a fairly well defined environmental management cycle. Early exploration may require little environmental management and may be performed by one person on a part time basis. This level may increase as exploration becomes more extensive. Once a development decision is made, a mining project enters what is arguably its most intense period of environmental management as baseline data is collected, environmental analysis is performed and permits are obtained. Dozens of people with different expertise may be involved at this stage. Construction and operation of a mine is a sustained period of environmental management that almost always involves at least one full time person, and may involve up to ten full time people depending on the complexity of the project. Many mines go through at least one re-permitting cycle during their productive lives. These episodes increase the management load, but most often do not approach the intensity of the initial permitting effort. It is inevitable that all mines will close, and many will require a final closure plan approval from regulatory agencies. All will require final reclamation. During closure, the level of environmental management once again increases for a short time. This section will briefly describe mining environmental management at each phase of the mine life.

### 9.4.1 EXPLORATION

All mining projects start with exploration. Early stage exploration tools include library research, detailed geologic mapping, interpreting satellite imagery, geochemical soil sampling, trenching, and limited drilling of target areas. Assuming continued exploration success, disturbance will increase as drilling expands. For purposes of this discussion, exploration is deemed to continue until a positive decision is made to begin engineering for a project and apply for operating permits. The environmental management of exploration projects largely involves technical work as part of the site evaluation process. There is also some early stage work with government agencies in exploration permitting.

#### 9.4.1.1 Site Evaluation

Environmental evaluation of exploration projects usually takes place in several discrete stages in the life of a project. The exploration geologist uses environmental evaluations in screening projects for suitability. The most obvious screening tools are proximity to land use restrictions such as designated wilderness or proposed wilderness, national parks, or other uses that are likely to result in increased scrutiny of a project.

As an exploration project progresses, it will probably be screened several more times for environmental fatal flaws. Usually, these more advanced screenings are performed by corporate environmental personnel or by consultants.

#### 9.4.1.2 Exploration Permitting

Permitting needs vary greatly on exploration sites. Things that can affect exploration permitting include:

- Land ownership
- State and local regulation
- The existence of old mining sites
- Presence of threatened, endangered, or special interest species
- Presence of surface waters or wetlands
- Presence of cultural resources
- Land use classification (both on the site and nearby)
- Attitude of local politicians and regulatory personnel
- Proximity to special land management areas such as national parks, wildernesses, etc.

These, and other factors, influence the manner in which the regulatory agency(ies) approaches exploration permitting. These are many of the same factors that influence the regulatory agencies' approach to mine project permitting. At the simplest, the project geologist handles the permitting and reclamation work with little or no assistance. Conversely, it is becoming more common for federal land management agencies to prepare a fairly extensive environmental assessment ("EA") at some stage in the exploration process for projects on public land. As sites grow in environmental complexity, it is increasingly common for the exploration geologist to be assisted by consultants or by specialist personnel from within the corporation.

Two trends will exert greater influence over the cost and difficulty of permitting exploration projects in the future. One of these trends is the increasing desire, on the part of regulatory agency personnel, to perform more complex environmental analysis before approving a project, thereby reducing agency exposure to outside criticism. The other trend is the ongoing shrinkage of agency budgets. Increasingly, user fees fill the budget gaps. In this context, user fees can take the form of direct

reimbursement for agency staff costs as well as reimbursement for the cost of outside consultants to complete the analysis. If these trends continue in the U.S. and certain other countries, they will contribute to the overall cost of finding mineral deposits and may affect where exploration dollars are directed. They will also affect how mining companies approach environmental management of exploration projects.

### 9.4.2 MINE PROJECT DEVELOPMENT

The traditional definition of mine development usually includes late stage ore body definition drilling, design, permitting, and construction. For purposes of this discussion, project development includes only permitting. This narrow definition is chosen simply because, from an environmental management perspective, mine permitting is a unique activity. It is a time when a mine project is especially vulnerable to outside influences because the mine developer controls only a few of the variables affecting a project. Government agencies, environmental groups, neighbors, and local elected bodies all hold significant influence over costs and schedule during this phase of mine development.

Project development is usually the period of most intense environmental management activity. In the U.S. today, this stage of the environmental management cycle seldom takes less than 2 years, and sometimes takes up to 5 or 6 years. The intense activity and long duration combined with financial pressure to bring a mine into production makes for a stressful working environment. The environmental manager needs a strong, dependable team during this critical time.

Both the technical and non-technical aspects of environmental management are critical to success in this stage. Technical issues include baseline data collection, project design, and permit application processing. Non-technical issues include regulatory agency relations, community relations and government relations.

Mine permitting is addressed elsewhere in this book and this section does not seek to duplicate that effort. Instead, it will focus on the environmental management tasks involved in mine permitting.

#### 9.4.2.1 Baseline Data Collection

Baseline data collection usually requires a team of technical experts in environmental disciplines. Current practice is for the mining company to contract with several specialist consultants to complete the actual field work. Historically, these teams were referred to as multi-disciplinary teams. This has been replaced by the term "interdisciplinary team", reflecting the fact that several disciplines may need related or similar data, and therefore should work in concert to develop the field program. This team must be managed to complete the data collection while meeting key objectives of cost effective and timely collection of data adequate to complete the needed environmental analysis.

Data adequacy is usually determined by permitting agency personnel. The need for agency acceptance of the baseline program is complicated by the tendency of some agency personnel to try to use project baseline data collection programs to further unrelated, or loosely related but desirable, agency objectives. Thus, the technical team and the environmental manager must work closely with agency personnel when developing a baseline program. The goals of timeliness and cost effectiveness cannot be achieved if too much unrelated work is allowed to creep into the program. Conversely, agency acceptance of the baseline program is often facilitated by including some extraneous work. It becomes the responsibility of the environmental manager to balance the need to build good relations with agency personnel against the cost and time needed to complete any extraneous work.

#### 9.4.2.2 Project Design

Mining project design is an iterative process involving geologists, engineers, designers, and increasingly, environmental managers. Past practice had the geologists, engineers and designers developing a project design among themselves, using review and feedback loops to refine the design for optimum project efficiency. The environmental manager was then responsible for getting the permits for that design.

For most projects today, the review and feedback loop includes the environmental manager. This insures that the design team understands which portions of the project raise environmental sensitivities, and allows the design team to take those sensitivities into account. It also allows the environmental manager to understand which aspects of the project design are negotiable, and how critical the negotiations are to the technical and economic success of the project. Seldom do environmental considerations drive the entire project design, but they can have significant impacts on design of individual project components. Conversely, most projects contain only a few non-negotiable aspects. This leaves an open field for compromise.

#### 9.4.2.3 Permit Application Processing

Processing of permit applications involves preparing the permit applications and data packages themselves, shepherding those applications through agency review, and facilitating agency environmental analysis. It is important to distinguish between agency review of the application, and the environmental analysis. Application review involves determining whether the application

addresses all facets of the mining operation in sufficient detail to allow the regulatory agency to administer the laws and regulations under its authority. Environmental analysis is the process of determining and disclosing the mine's impact on the environment.

Preparing the permit applications and data packages is the only permit processing activity that remains firmly under the control of the mine developer. Because this activity is under the control of the developer, and because the developer will likely be urging the agencies to complete their work as quickly as possible, it is important that the mine developer use this activity to convey a consistent message of urgency in the permitting process. Agencies will request data or other information as part of the permit application review. If the developer meets all of its commitments to supply information to the agency, the agency will give more credence to requests for timely action. It is up to the environmental manager to see that commitments are appropriate to the need, and are met with timely, accurate information.

Review of permit applications is largely controlled by agency policies, practices, and personnel. While federal agencies usually have the resources necessary to process applications, the trend toward smaller agency budgets may affect permit processing in the future. Local agencies often look to the mine developer to reimburse application review costs. Cost reimbursements can be either in the form of direct payment to agencies or to third party reviewers who answer to the agencies.

Environmental analysis for new mines often involves preparation of an Environmental Impact Statement ("EIS"), the highest level of environmental review under NEPA. In the past, some mining companies urged agencies to use an Environmental Assessment ("EA") to meet their obligations under NEPA. When successful, this avenue can significantly reduce the time and cost involved in environmental analysis. When unsuccessful, this route has led to some notable setbacks to mine development. One gold mine in California, after going through an EA and getting most of their permits, was challenged by environmentalist groups. The permits were withdrawn and an EIS was prepared resulting in several years of delay. A similar series of events transpired at a copper mine in Nevada. Because of these and other limitations to the EA process, mining companies are increasingly urging agencies to use the EIS process for environmental review.

As with most general statements, there are exceptions to the need to prepare an EIS for a mine project. Some exceptions are; small mines, some mines on private lands, some mines that have participated in regional EISs, and mines that are located in states that do not have NEPA type laws and require no federal permits.

The environmental management function is to determine the most appropriate level of environmental review and work with the regulatory agencies to facilitate that review.

#### 9.4.2.4 Regulatory Agency Relations

This discussion focuses on those government groups that hold direct control over project permit decisions. Because of the sway such bodies hold over a project during the permitting stage, a positive working relationship with those agencies is especially important. The relationship should extend from the local regulatory specialist all the way to the top of the agency, if possible. This goes for both federal and state administrative agencies headed by political appointees to local agencies with elected boards.

The practice of developing such relationships may be governed by state or local rules. For instance, California has a particularly strict sunshine act that prohibits meeting with more than two members of some local elected boards unless the meeting is an open, advertised, public meeting. Local counsel is recommended to assure compliance with such measures. Once compliance with such restrictions is assured, the environmental manager should meet periodically with agency managers to update them on project progress and discuss any concerns that develop.

#### 9.4.2.5 Community Relations

The environmental analysis process as laid out under NEPA and similar state laws is designed to encourage public input to agency decision making. This public input can have significant effects on a project. Therefore, it is important to keep the public well informed as a project progresses. The need for community relations varies greatly between communities. Suffice it to say that local judgement must be used in developing a program of community outreach.

#### 9.4.2.6 Governmental Relations

In this context, governmental bodies are those individuals and institutions that hold indirect control over projects. Examples of such bodies would include; state and federal law makers who represent the local area, governors (who may be in the direct line of authority over administrative agencies, but who rarely are directly involved in project level decision making), and board members, mayors or administrators of surrounding local governments whose approval is not needed for the project.

By definition, these people and institutions cannot approve or deny a project. They can, however, exert significant influence over those who do have such authority. This makes it important to contact as many of these individuals as possible early in the permitting

process and educate them about the project.

### 9.4.3 MINE OPERATIONS

Mine development, defined in section 9.4.2, included only the permitting phase. This leaves construction and operation of mines and their associated processing facilities to be addressed under mine operations. While acknowledging that mine construction can be far more hectic than day to day operations, its environmental management functions are much the same as for mine operations.

Environmental management at a mining operations largely involves permit and regulatory compliance assurance through monitoring and reporting, maintaining good relations with regulatory agencies and the local public, and keeping up employee education efforts. Regulatory compliance includes complying with both the specific conditions found in operating permits, and overriding regulations that are not usually the subject of individual site permit conditions. Many sites employ a monitoring and compliance calendar to track all of the specific compliance activities. It is also usually the responsibility of the site environmental manager to track site operations for changes which may require permit amendments or modifications.

The following sections discuss some, but by no means all, of the challenges faced by an operations environmental management team during mine construction and operations. Emphasis is placed on issues outside the every day tasks of site management.

#### 9.4.3.1 Construction Period

Construction is a unique period in the life of a mine. The mine operator is responsible for site environmental compliance during construction, even though the majority of site activities may be under the immediate control of contractors or subcontractors. The challenge of environmental management during construction is found in the constantly changing nature of site activity and the constantly changing cast of characters on the site. These dynamic forces can conspire against sound site management unless properly contained. Experience has shown that site environmental managers can work themselves to a frazzle during construction, and still not be anywhere near the desired environmental compliance levels. Managing construction environmental compliance requires a management system that does not overwhelm compliance personnel. To develop such a system, it is necessary to look at the two variables that make environmental compliance difficult during construction, namely; site activity and cast.

Limiting site activity during construction is one possibility for reducing the risk of environmental exposure. While this technique would reduce confusion, it would also slow down construction. It is doubtful that this solution would be acceptable to most mining companies, especially since other avenues are available.

The changing cast of characters found on a mine site during construction suggests a couple of methods of managing environmental compliance. The first method would be to limit the changes by contracting with one prime contractor. It would then be the responsibility of the site environmental management team to oversee only one contractor. As with the previous solution, this could reduce the daily work load of the environmental manager, but it is not necessarily the best construction approach. Another limitation of this approach is that it would not address subcontractor activity.

Another approach would be to make each contractor responsible for compliance with permit conditions. This approach has proved successful at recent construction projects. Factors in successfully implementing such a program include: 1) each prime contract should contain a clause or clauses firmly establishing that environmental compliance is the responsibility of the contractor, 2) environmental responsibility should flow through to lower tier contractors, 3) each contractor should be responsible only for compliance that is within his or her sphere of influence, 4) each contractor should be supplied with appropriate permit documents and regulatory references, 5) penalties should be established for non-compliance resulting in agency action, 6) contractors should be responsible for remediation costs resulting from their activities, and 7) circumstances outside the scope of a contractor's obligations should trigger force majeure.

This type of construction environmental management system cannot, and should make no pretense of, transferring permit responsibility from the mine operator to construction contractors. What it can do is give contractors an economic interest in environmental compliance matters. There is a cost to asking contractors to shoulder some of the burden of environmental responsibility, but the cost is minimal when the contractor is given control of the risks. The additional cost is easily offset by the risk reduction that comes when all site construction contractors are active partners in environmental management.

#### 9.4.3.2 Operating Period

Mine plans are not static documents, but change based on a myriad of factors. Even when the mine plan is not changing, the physical and chemical character of the mined rock may be changing in ways not foreseen from exploration data. Similarly, process design can change based on technological development or the need to respond to changing feed materials. With each change, the environmental manager must seek the answers to important questions regarding the impact of those

changes. Some of the more significant current questions are:

Will stability of the final pit highwall (or final underground configuration) be affected?

Will waste rock dump stability be affected?

Are there changes in ore or waste chemistry that may change the acid generating or acid neutralizing character of materials in the post mining environment?

Are any changes in water discharge rates expected?

Are changes in water chemistry expected?

Are any changes in air pollutant emissions expected?

Are changes in tailings (or other final processing wastes) expected to affect the closure stability of the disposal area?

Will new process chemicals be brought on site? If so, how will this affect environmental reporting, work place hazards, or employee exposure?

While it is not practical to anticipate all the questions, problems, or changes that may arise during the life of an operation, the environmental manager should look at each new development in light of the following questions: 1) Are any expected changes significant enough to change the offsite environmental impacts of the mine? 2) Are any expected changes significant enough to change the post mining environmental impacts of the mine? 3) Will any expected changes require permit modifications? 4) Would any expected changes affect employee or community disclosure requirements? A "yes" in response to any of these questions indicates a large issue that will affect site management needs.

### 9.4.4 MINE EXPANSION

It is not at all unusual for a mine to go through at least one expansion during its operating life. During this period, the challenge is to keep the existing operation running efficiently while carrying the permitting burden. There is little consensus in the industry as to how such expansions are handled as they are largely dependent on the resources available to the mine operator.

As a permitting exercise, a mine expansion can either be made easier by the existence of the mining operation, or it can be made more difficult. The degree of difficulty encountered during mine expansion permitting efforts is often related to the compliance record of the mine.

### 9.4.5 RECLAMATION AND CLOSURE

Mine reclamation is an activity that normally occurs both concurrent with operations and after operations cease. Depending on the mine geometry, concurrent reclamation may be a large portion of the reclamation activity or a relatively modest portion. Strip coal mines are perhaps the best example of mine projects whose reclamation is dominated by concurrent reclamation. As each cut is backfilled with material from the subsequent cut, reclamation takes place. At the opposite end of the scale is the underground mine with surface facilities that cannot be reclaimed until the mine is completely exhausted.

In terms of the environmental management workload, final closure planning resembles mine expansion permitting and represents a period of increased environmental management activity. This is regardless of how much reclamation could have been, or was done, during the operating life of a mine. One of the principal reasons is the common practice of submitting a final closure plan for regulatory approval prior to actual closure. While the mine permits should provide the basis for the closure plan, the many small changes that arise during mine operations can leave the reclamation plan approved in the mine permitting documents outdated. Some jurisdictions have codified the need for final closure plans approval in their regulations. Others have not, but have consistently found them to be desirable.

Final mine closure, in a configuration that does not require long term monitoring or active management, is an important reclamation goal. This is sometimes known as a walk-away reclamation condition, or a clean closure. In order for a mining company to be able to walk away from a site, the site must be physically stable, it must be chemically stable, and a self sustaining post mining land use must be established.

Of these requirements for site closure, chemical stability is increasingly a concern for the industry. The coal mining industry has once again led the way for the hard rock industry. Coal companies are currently responsible for operating numerous acid rock drainage treatment facilities, especially in the eastern U.S. The western hard rock industry is just beginning to face the chemical stability issue with the first wave of closures from the early 1980s gold boom. It is safe to say that the hard rock industry would prefer to develop technologies to avoid the need for long term treatment of mine drainage. The field is currently wide open. While there is no consensus among the regulatory community as to what constitutes a chemically stable closure, the mining industry is forging ahead with technology development. Progress in this area will affect how mines are closed in coming years.

During mine closure, one of the most important environmental management roles is risk management.

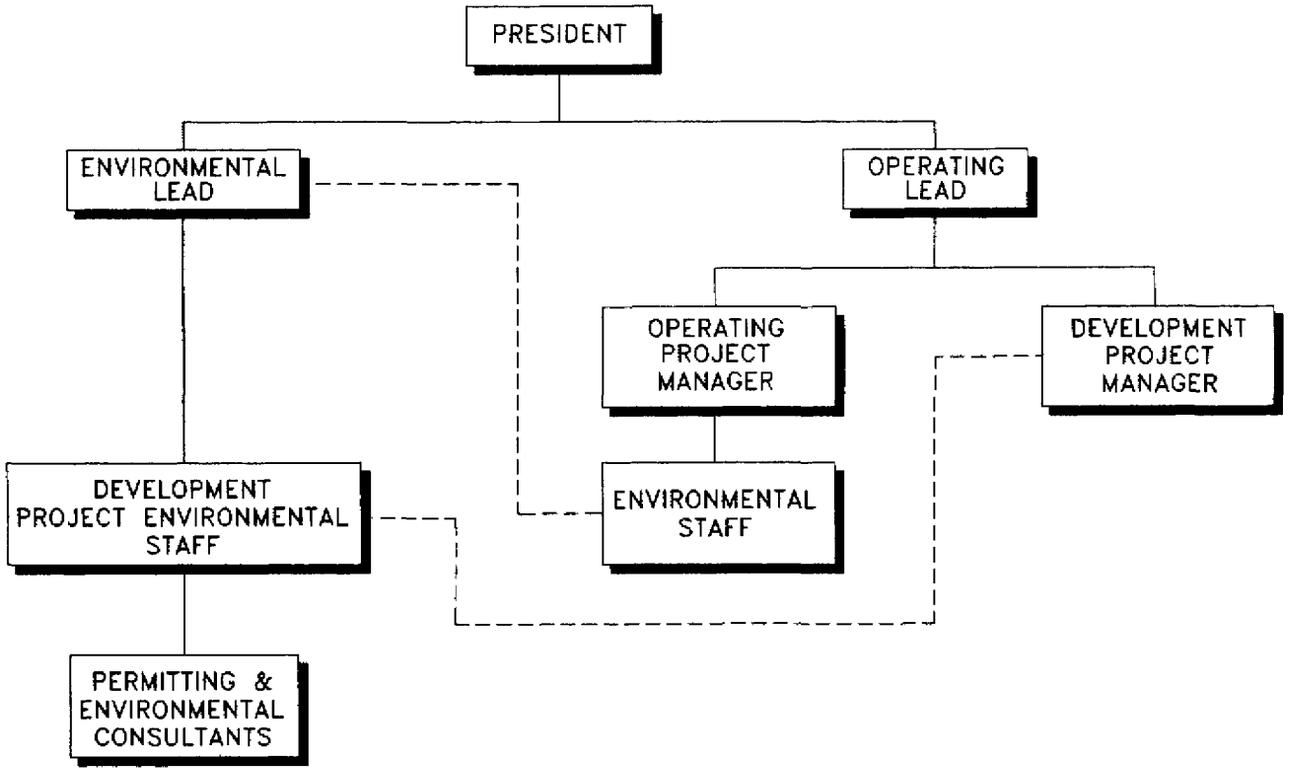



**Figure 1** Decentralized Environmental Management Organization.

Long term post closure liability, discussed in the following section, must be balanced against current costs for reclamation. The answer is unique to each operation and each operator. The important task for the environmental manager is to make sure the appropriate questions are fully considered in designing the site closure.

### 9.4.6 POST CLOSURE

The post closure period is easily defined in clean closure situations. It begins when all permits are vacated and all bonds released. This definition does not apply to sites that cannot achieve walk-away conditions. For such sites, the post closure period could best be defined as beginning when all long term steady-state site activities are in place. This means that permits, site maintenance facilities, and site practices have been agreed to, have been installed, and are operating. This type of site requires active management, but only at a maintenance level.

Although a clean closure gives great satisfaction and eliminates ongoing costs for site maintenance, it is no protection from long term liability. Long-term liability associated with mining sites remains with the owner or operator, and their successors, under the Comprehensive Environmental Response, Compensation and Liability Act ("CERCLA") (42 USC 9601 et. seq., Dec. 11, 1980), also sometimes known as Superfund. Some states are also considering statutes that would hold an operator or owner responsible for site conditions in perpetuity. The message is clear, mine owners and operators must take a very long view when designing, operating and closing mines. Long after closure the operator can be held accountable, even for conditions which were unknown at the time of the operations.

## 9.5 SAMPLE ORGANIZATIONS

As mentioned earlier, many mining companies have decentralized their environmental organizations and reduced staff to the minimum needed to oversee routine operations. Many of these organizations include a system of checks and balances that enables corporate oversight of operational environmental compliance. Figure 1, Decentralized Environmental Management Organization, shows a conceptual structure for decentralized environmental management. On this figure, solid lines represent direct responsibility and dashed lines represent secondary reporting responsibilities that implement systematic checks and balances.

To show how mining companies put these organizational principles to work, four North American

mining companies were asked to supply information regarding environmental organizations and responsibilities within their respective companies. None of the four companies employed a centralized environmental staff. Although this is by no means a comprehensive look at environmental practices in the industry, it is an important indication of current thinking in the mining environmental management field.

The four companies represent the entire spectrum of operating companies in the mining business. At the least complex end of the scale is an exploration-only company with no active operations and no plans to become a mine operator. Next in line is a small operating company with exploration plus three mine operating properties. A mid-sized operating company is represented by a firm having approximately 5 operating locations, 2 of those locations in the United States and the others overseas. The large operating company is represented by a multi-national firm with over 40 operating locations around the world. What follows is a brief synopsis contributed to by each of the organizations profiled.

### 9.5.1 EXPLORATION COMPANY

The exploration-only company has numerous exploration properties around the world and is developing, in cooperation with an operating partner, a mine in the northwestern U.S. It does not operate mines and does not anticipate doing so in the near future.

The company does not employ dedicated environmental personnel as its activities would probably not keep a person busy full time. Environmental responsibility for exploration projects is delegated to the exploration project manager. The project managers personally prepare permits and are responsible for reclamation upon project closure. Sometimes, as exploration projects grow in size or are affected by external environmental sensibilities, it is necessary to hire outside contractors to perform specific functions, for example, preparation of environmental assessments or environmental data collection, for some of the more advanced exploration projects.

For its mine development project, the company retains a contract environmental specialist to advise it. The company is not in the lead position in mine development and thus uses its externally contracted expertise to review the practices of the operating partner and provide necessary input.

Once the mine becomes operational, the company anticipates that it will continue to monitor that operation using contract expertise.

### 9.5.2 SMALL OPERATING COMPANY

The small operating company is represented by Canyon Resources Corporation of Denver, Colorado. Canyon is exploring for minerals in North America, South America, and Africa. It currently has a gold mine undergoing closure in Montana, one gold mine under construction in California, and an industrial minerals producing facility in Nevada. The company is a non-operating partner in development of a large, low-grade gold project in Montana.

The company has an environmental manager who reports to the president of the company. The manager of each operating property is responsible for environmental compliance at his respective operation. The managers report to the vice president of operations. The gold mining operations have environmental coordinators who report to the mine managers with cross reporting responsibility to the environmental manager. The industrial mineral facility does not have an environmental coordinator. Environmental duties at the industrial minerals site are shared among the staff with assistance from the environmental manager. Because the company is small, there is sometimes deviation from the defined structure.

The environmental manager is responsible for new mine permitting, commenting on and preparing company positions on proposed environmental legislation, participating in regulatory rule making, administration of an environmental audit program, providing technical and regulatory assistance to the operating properties, developing and implementing approved policies, and environmental reviews of potential merger and acquisition targets. Environmental management of exploration activities is generally the responsibility of the individual exploration project managers. As needed, assistance is provided by the environmental manager.

Mine managers and the mine site environmental coordinators are responsible for monitoring, compliance, and reporting of site activities. They are responsible for budgeting, planning and needed permit revisions. Site reclamation and closure planning are also their responsibilities. Some mine managers have taken the ultimate step to decentralize environmental responsibility by instituting employee performance bonus incentive systems that include environmental compliance items as part of the matrix used to determine employee pay.

Responsibility for community, press, regulatory and government relations is distributed throughout the company. As issues surface, they are logically assigned based on the specific issue, personnel location, knowledge, and personal contacts.

### 9.5.3 MID SIZED OPERATING COMPANY

The mid-sized mining organization operates two mines in the U.S. and holds majority ownership in three operations outside the country. It is developing a major new mine in the U.S. and is involved in several overseas development projects. This company has decentralized its

environmental responsibilities.

At the corporate level, both the vice president and general counsel and the vice president of operations have responsibility for environmental affairs. This dual responsibility provides an important check on environmental decision making and helps insure full consideration is given to important issues.

The director of environmental affairs reports to the vice president and general counsel. The director is responsible for environmental compliance oversight, commenting on and disseminating environmental legislation, coordinating environmental audits and permitting oversight. The director is responsible for proposing environmental policies for consideration by senior management and the Board of Directors. The director provides technical and regulatory expertise to senior management on environmental questions.

Mine site environmental compliance is the responsibility of the individual mine managers, who report to the vice president of operations. The site managers are close to the concerns and have necessary authority to respond to site specific issues. By placing responsibility on the site managers, the managers have a direct interest in environmental compliance and thus take a large role in environmental affairs.

Each operating site and each development project have environmental coordinators. The operating site environmental coordinators report to their respective site manager, but have cross responsibility to the environmental director. The development project environmental coordinators report to the environmental director but with cross responsibility to the project manager. This cross reporting is an important part of the check and balance system designed to ensure full consideration of environmental matters.

Operating site environmental coordinators are responsible for environmental compliance and planning, coordination with site personnel on environmental issues, environmental permitting and revisions to existing permits, monitoring and reporting, budgeting and reclamation.

Development site environmental coordinators are responsible for developing permit applications, meeting with regulatory personnel, tracking EIS development, providing comments on the EIS, monitoring, coordinating internal environmental studies, and coordinating with the project design team.

### 9.5.4 LARGE OPERATING COMPANY

The large operating company organization is represented by Cyprus Amax Minerals Company based in Englewood, Colorado. Cyprus Amax is one of the U.S.'s largest mining companies with over 40 operating locations on 4 continents.

Cyprus Amax has decentralized its environmental function by pushing responsibility for environmental compliance to the operating locations as a matter of policy. Each operating location has a designated environmental contact. Large operating locations may have 5 to 10 people within their environmental department. Smaller operating locations may assign the environmental coordinating responsibilities to a person who also has other duties. This company's operating locations are organized under four operating affiliates of the parent company. Each operating affiliate has a senior-level environmental manager, and some have additional support staff. The parent company also has an environmental director who reports to the senior vice president and general counsel.

Each of the operating property environmental personnel report to local management. It is considered desirable to have the local environmental contact report directly to the vice president or general manager (as appropriate) for each location. At operating locations where this structure is not implemented, the local environmental officer has direct access, if not direct reporting responsibility, to the vice president or general manager of the operation. Of the four division environmental managers, two report directly to the corporate director of environmental affairs, while the other two report to unit management.

The corporate environmental director is responsible, along with division environmental directors, for developing policy, maintaining an audit program, maintaining a performance measurement system, providing periodic reports to officers and directors, and providing environmental assistance to the exploration and operating locations. The corporate environmental and division environmental directors also offer training opportunities for site personnel and otherwise reinforce sound environmental performance.

Individual sites are responsible for obtaining and operating within environmental permits and otherwise ensuring that their operations are in compliance with all environmental requirements. In addition, individual locations are responsible for ensuring that personnel are appropriately trained as to their environmental responsibilities.

## 9.6 CONCLUSION

Mining operations environmental management is an emerging field that is still undergoing considerable change. Past changes were largely brought about by external pressures which changed the regulatory framework in which mining companies operated. Many companies are striving to switch from a reactive mode to one that anticipates and influences future regulations. Despite the continuing changes in the field, there has emerged a rough consensus among mining companies in

favor of decentralizing environmental responsibility. Most companies provide an internal check and balance system to assure continued quality environmental compliance.

### 9.6.1 ACKNOWLEDGEMENTS

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# Chapter 10

# SOLUTION MINING AND IN-SITU LEACHING

edited by J. T. Laman

*Solution mining of soluble salts, such as sulfur and potash, and in-situ leaching with chemicals of minerals such as uranium and copper are sufficiently different technologies that Chapter 10 is divided into two parts. Both solution mining and in-situ leaching involve the subsurface extraction of minerals, but the mining methods and environmental considerations are different.*

## 10.1 SOLUTION MINING

**by W. G. Fischer**

Solution mining is generally considered to be the extraction of minerals from beneath the ground in the form of a liquid or "brine." The solvent is most often water or water-based and the temperature is varied depending upon the characteristics of the mineral or minerals to be extracted. Sometimes the pH of the solutions must be adjusted to prevent corrosion or enhance dissolution. Deep-seated or hydrothermal brines are sometimes recovered without the addition of a solvent. Desalination of sea water is not considered to be solution mining. Solution mining can be distinguished from leaching by several differences commonly accepted by the practitioners: the solvent is usually water and contains no chemicals, solution mining removes large amounts of the host formation and creates caverns, and the brines are normally in contact with naturally impermeable strata rather than percolated through porous media.

Many minerals are water-soluble and have been solution mined. Sulfur is one of the most important chemicals to be solution mined. Halite, potash, the chlorides and sulfates of magnesium, and sodium sulfate have all been solution mined. Trona, nahcolite, and the hydrated borates of calcium and sodium are now considered solution-mineable. The geologic setting for these minerals can be quite variable. The natural confinement of the deposit must be intact and appropriate for solution confinement during mining or the deposit is not a good candidate for solution mining.

Environmental concerns for solution mining are similar to the operational concerns and are addressed by careful monitoring of solution pressures and flow volumes in operation and monitor wells. Monitor wells must be carefully positioned on the perimeter of the cavern to yield useful environmental and operational information, and yet not threaten the stability of the cavern. Solution mine wells must demonstrate mechanical integrity to prevent leaks from the casing or tubing, and the annulus between the outer casing and the bore hole wall must be sealed to prevent vertical leaks. The shape and size of the cavern will depend upon the thickness of the deposit and the well locations and operation.

### 10.1.1 CAVERN CONSTRUCTION

Drilling, casing, cementing, and operating practices are different for the solution mining of bedded deposits than they are for dome type deposits. They are also different if the cavity is intended for gas, air, hydrocarbon, or waste storage rather than the production of a commercial brine. The wells drilled at a later date in a mature brinefield usually differ from those drilled for the initial establishment of the mine. This is because the stress field has been disturbed around the older caverns which makes cementing more difficult when deformation, fracturing, and lost circulation are encountered. Also, the presence of possible cavity operating pressure makes it necessary to plan for the control of potentially high circulation rates at the surface.

Bedded deposits that are nearly flat-lying and relatively thin tend to cause a solution cavity to spread laterally rather than upwards. Even though the brine has a hydrostatic lifting effect on the mine roof which can reach half of the lithostatic load, it is not unusual to find roof deflection and breakage taking place as a cavity matures. Roof sagging can cause a cemented casing string to pull apart at a collar, or bedding plane slippage can cause the casing to collapse. Depending upon the site- specific geology, rock mechanics, and the operating plan, it may be wise to cement the casing from an up-hole packer located at the top of the production zone

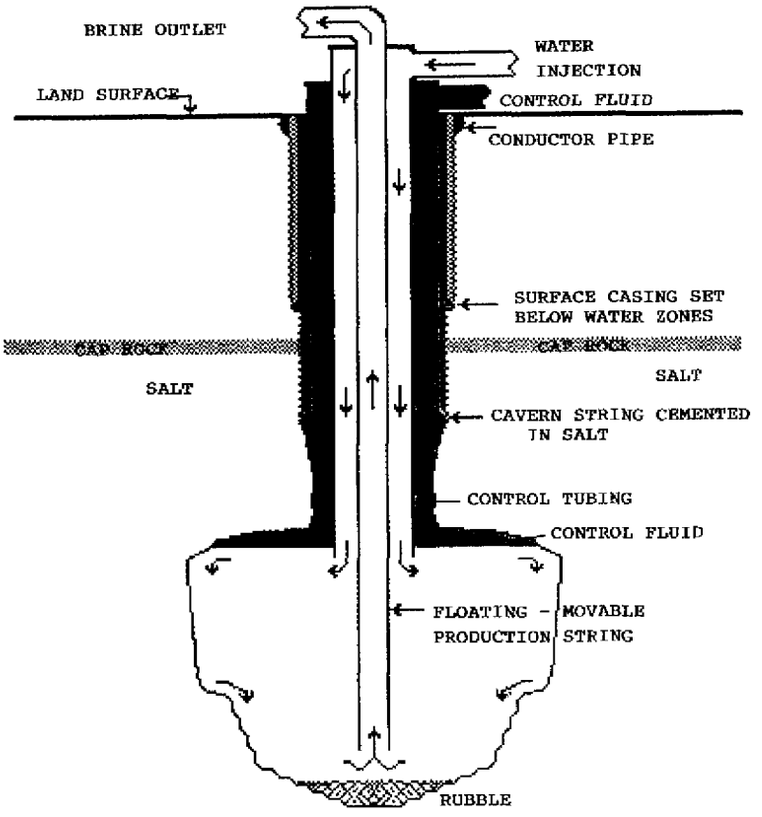



**Figure 1** Typical three-string development method for dome salt.

rather than from the casing shoe itself.

Thin bedded deposits can be solution mined via a single well with a concentric tubing installed such that both solvent injection and brine production can take place through a single well bore, or via multiple interconnected wells which are operated in pairs or other combinations depending upon the geologic setting. Interconnection of wells is accomplished using directional drilling, hydrofrac techniques or wash-though using air or hydrocarbon pads. Well construction can be a simple, single casing (often called a "long string") cemented in place or it can contain casing liners and other features if the products are corrosive to steel. Steel casing materials are preferred and PVC or other plastic casing downhole are seldom used. An exception might be the borate producers.

On the other hand, salt domes are vertically-oriented features in which tall cylindrical cavities can be generated that are very stable structurally and ideal for storage of numerous products. For liquid or gas storage a single bore hole incorporating three or more concentric casings, casing liners, and tubing strings is often used. The casing liner and tubing string are adjusted up or down to control cavity configuration during cavity development. In many ways the casing strings used in the solution mining of some salt deposits resemble the strings used for the Frasch sulfur process.

### 10.1.1.1 Salt Dome Cavern Development

The techniques used to develop storage cavities in dome salt are different from the techniques used in bedded materials; however, much of the terminology is the same. In the case of dome salt, a sample well is constructed in the general order described below and illustrated in Figure 1.

A large casing is placed in a hole drilled from the surface to a point below any possible alluvium or near-surface groundwater, and cemented into place. This casing is often called the "conductor pipe" since it is used to conduct the cuttings away from the drill hole and into a shale shaker, portable tank, pit, or other device used to separate the solids from the continuously circulated drilling fluid. The conductor pipe is often fitted with a gate valve or blowout preventer so that any gas encountered during the drilling process is also carried away from the work site to a point where it can be safely flared. Local water well and hydrocarbon drilling experience in the area is used to define the general depths, sizes, and initial design conditions necessary to complete a well with any given specifications.

The hole is then drilled to a solid anchor point in the

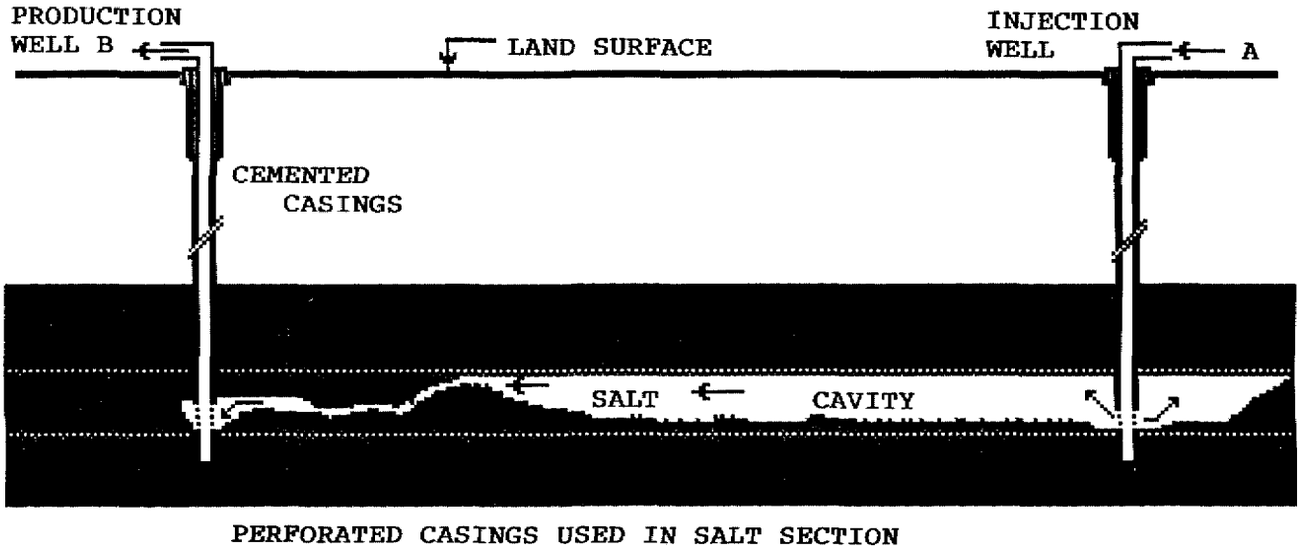



**Figure 2** Typical gallery operation used in bedded salt. Hydraulic fracturing or natural coalescence is used to establish connection.

top of the caprock (an anhydrite layer which usually overlies a salt dome) and a second casing of slightly smaller diameter is cemented into place. The depth at this point could be several dozen or even several hundred meters. The near-surface waters are thereby isolated from the salt that will be removed later.

Drilling is then continued down into the top salts of the dome, sometimes 300 meters or more. Another casing string is set in place and cemented. This casing, or perhaps even a fourth string, will be used to form the top of the cavity that will be mined in the salt below. Average depths to this final casing seat in recent years have been on the order of 1000 meters.

One or more tubing strings are lowered into the salt below the final casing to a point determined by the specific cavity design. These are called "mining strings" because they are not cemented in place but are periodically adjusted up and down to control injection and production locations and the brine-floating diesel fuel or other hydrocarbon blanket that is used to spread the dissolution out laterally by preventing upward migration. Generally, tall cylindrical cavities are preferred for structural reasons, although spherical cavities are sometimes used for gas storage.

When the solvent is injected into the tubing and the production is removed via the annulus of the production casing and tubing, the process is called *bottom injection* or normal circulation. The cavity can also be developed by injecting the solvent into the annulus between the production casing and the tubing and removing the production brine via the tubing. This is called *top injection* or reverse circulation. This terminology is common but not universal in its usage.

These two cavity development methods can be used interchangeably to control the shape of the cavern over its operating life. Mathematical models are available to predict dissolution patterns, and logging techniques are available to check the final results. Many salt wells have been in operation for more than 40 years.

When a storage cavity is developed to a desired size and shape, the salt brine is displaced by the commodity being stored. Some have rather active storage and removal cycles (e.g., Compressed Air Energy Storage, CAES), while others, like the Strategic Petroleum Reserve (SPR), tend to be permanent storage facilities for large quantities of fossil fuel.

### 10.1.1.2 Bedded Deposit Caverns

Development of solution caverns in bedded salt, potash, mirabilite, glauberite, thenardite, trona, and nahcolite most often consists of two or more interconnected wells that are operated in pairs to form a solution *gallery*. See Figure 2. Although it is physically possible to use single wells similar to practices used in dome salt, it is not popular because thin seams tend to be mined out quickly around the injection well, resulting in poor operating efficiency.

Before operating a multi-well gallery system, the wells must be interconnected so that solutions can easily migrate from one well to another while passing by the dissolving front. Several methods are used to accomplish this; hydrofracing, lateral drilling, air padding, or natural coalescence through continued operation of other wells in nearby galleries. When multiple seams are to be mined the normal practice is to mine the lowermost seam first and allow the natural fracture patterns that result from roof deflection and caving to expose the upper seams to solvent. Seams as thin as a few centimeters have been mined in this way.

A common practice is to set the production or injection casings below the lowermost seam and cement the casing from the bottom to the surface. After the cement has set, the well is logged and tested for integrity. Then it is either perforated in the lowermost seam or the casing is milled or otherwise breached (chemical cutters) to allow for local dissolving or hydrofracing.

#### *10.1.1.2.1 Hydrofracing*

Hydrofracing (short for hydraulic fracturing) involves raising the pressure within the casing until the hydrostatic pressure at the bottom of the hole exceeds the lithostatic load plus the tensile strength of the material to be mined. At this point a minute Griffith-type tensile fracture begins to form and a slight additional pressure will cause it to propagate away from the well bore.

The technique requires skill and intuition. A poor cement bond can allow the fracture to migrate up-hole or an unknown natural vertical fracture in the seam can take fluid, and the fracture can head off in a direction other than the target well. Pressurizing the target well is not always effective in preventing this situation. The greater the distance between wells, the lower the chances for a problem-free connection. A new brinefield can be established successfully by an experienced rock mechanic and drilling engineer, but that same brinefield may be very difficult to expand by hydrofracing once the cavities have been created and the stress fields have been modified.

Pressures must be accurately and continuously monitored during the process in order to detect unexpected fracture behavior. The practice of using glass beads or other propping agents to hold the fracture open, which is common in gas field development, is not necessary in the solution mining of soluble minerals. The practice can even be counterproductive in developing flow paths outside of the ore deposit

#### *10.1.1.2.2 Lateral Drilling*

Lateral drilling technology has developed quickly in the late 80s and early 90s. It involves drilling and casing a vertical hole down to the proximity of the orebody and then turning the hole toward a target well, using special down-hole motors and other devices. Although there were many early failed efforts to hit a target well, better connections can now be made with lateral drilling than with hydrofracing. Several choices are now available as to how rapidly the transition from vertical to horizontal can take place and how far away the target well can be. The process is costly, but it has the possibility of being more successful than hydrofracing.

#### *10.1.1.2.3 Air Padding*

Air padding involves the high-pressure injection of air with the solvent such that vertical dissolution is inhibited while lateral dissolution is speeded up. Enough air must be added to exceed its solubility at the bottom-hole pressure involved. Often a single well would be developed using a tubing for production. If connection is not made, the other well in the pair would then be operated in similar fashion until the two are interconnected. Sometimes oil, diesel fuel, or LPG are substituted for air in the padding process.

#### *10.1.1.2.4 Natural Coalescence*

Natural coalescence will occur sooner or later between most wells in a brinefield if the amount of material removed is sufficiently high. Sometimes this is desirable from the operating standpoint since virtually all of the natural resource can be removed from a multi-layer sequence over a period of time. Future wells can be drilled early in the program and simply left for mining to progress to them. This eliminates the cost of interconnecting the wells by artificial and sometimes statistically risky methods. On the other hand, if one gallery contains contaminants, both of the galleries could become less desirable for future use. Also, uncontrolled vertical cavity development can result in casing damage and subsidence problems. When two galleries coalesce, the bottom-hole pressure between them will equalize if they have been operated differently or contain bulk fluid of unequal density. This is normally detected as an increased flow at one well and a decreased flow at another, without any change in valve settings.

### 10.1.1.3 Cavern Monitoring

Monitor wells are drilled as part of the operating plan for all solution mines. Every bit of information that can be observed during drilling should be carefully recorded as the cavity is developed, even if there is no explanation for it at the time or the operator is not sure exactly what occurred. It is important to maintain a good daily log book because there is no way to go down into the cavity and see first hand how development is taking place. All

observations are made by a remote monitoring or logging technique and are therefore open to sometimes conflicting interpretations. Numerous wireline logging techniques are available to evaluate conditions near the bore hole.

The most valuable information will be the pressure and flow meter records and the chemical analysis of injection and return streams, including temperatures and specific gravities. This information is used to calculate the amount of material that has been removed by weight and by volume. Comparison with echo (sonar) logs, down-hole video or other remotely acquired data can then raise confidence levels that the cavity is of known dimension and orientation. Production records are therefore some of the best monitoring information that can be extracted during cavity development.

When a cavity develops an uncontrollable leak to any other formation or fracture network that prevents the generation of the pressure differential necessary to efficiently recover the brine or stored commodity contained in the underground cavity, a disaster has occurred. This can result in abandonment of the cavity with great financial and other loss. Fortunately, it is a very rare event that careful engineering and geologic study, with attention to detail, can usually prevent.

One of the worst things that can happen to a solution mine is leakage into an aquifer containing potable water. The injection and production wells present the greatest potential conduit for leakage if they are improperly installed or damaged by mining. A pipeline or surface facility leak might contaminate surface water or near-surface groundwater (such as a leaking pond liner or a faulty weld). Obviously, detecting potential leaks must be considered a top priority for the environmental as well as the financial viability of any solution mine.

Leak detection is done on the surface by installing flow meters on both ends of all long pipelines and both injection and production lines leading to and from the well field. Many times, redundant meters are used at critical locations. Pressure transmitters, often with redundant gauges, are used to signal abnormal loss that might be associated with a broken pipeline or open valve.

Monitor wells around cavities allow for pressure measurement and sample collection. Each potential source of leakage should be monitored. If pressure or other changes are detected, the causes should be carefully documented and analyzed. They may simply mean that the monitor well is functioning as planned, but they may also be a signal of changes taking place that need to be corrected.

The number and positioning of these monitor wells must be engineered with a thorough knowledge of the site geology. They must be carefully constructed to handle the maximum pressure that the mining operation is expected to exert upon them if a pressure excursion were to intercept them. Casing collars should be tightened to API specs and the cement should be of the highest quality. There must not be more than the minimum number needed to do the job since they are potentially one of the most efficient sources through which fluid loss can occur. Careless monitor well practices can result in the ultimate loss of cavern integrity. In the same manner, old and perhaps abandoned oil or gas wells that have not been properly sealed can represent a potential threat even though they may or may not be usable as monitor wells.

#### 10.1.1.4 Subsidence

Subsidence is a term used to describe the movement of the rocks or strata overlying mine workings as a consequence of ore removal. Movements are generally downward into subsurface openings but significant lateral movement is possible along deflecting bedding planes. Small upward movement is also known to occur. Subsidence is most severe in the vicinity of the openings and diminishes with distance. Sometimes faults or planes of weakness influence the site-specific magnitude of subsidence movements. Magnitude is also influenced by the overburden characteristics and the size and geometry of the openings. In many cases a shallow depression is formed on the surface with little or no indication of fracturing. This is called "trough" subsidence. Where the overburden contains layers of hard limestone, chert, or sandstone strata there is a possibility that high stresses generated by extracting large areas can overcome the strength of the roof rock and cause a rather sudden catastrophic failure to the surface resulting in what is called a "sinkhole."

Empirical and theoretical models have been developed to evaluate the effects of subsidence. These models are generally site-specific in terms of their calibration, the failure criteria used, the influence of time-dependent behavior, and the shape and size of the openings. Nonetheless, the basic principles are often applicable to similar conditions at other locations. Subsidence occurs over solution mines as well as conventional dry mines, but the influence of ground load is reduced as a result of the lifting effect of the confined brine within the cavities as opposed to the atmospheric air-filled openings of a conventional mine. Subsidence monitoring is advisable when large cavities are expected.

##### *10.1.1.4.1 Damage to the Surface*

Damage to the surface usually consists of cracks to foundations, outside masonry, and inside plaster. Sewer lines are sometimes broken or the drainage slope and direction are altered. It is a common practice to establish pins or monuments on the surface over all new underground mines and conduct periodic surveys to track

the onset and progress of subsidence.

When solution mining bedded saline minerals, where the direction and progress of mining cannot be accurately defined prior to mining, it is appropriate to consider taking early steps to measure subsidence in an effort to learn more about the cavity development. Since cavities formed in dome salt can usually be surveyed accurately as they are developed, they present less problem than bedded formations where the local pitch of the seam could be controlling the direction of cavity growth. The deep mine will generate less stress and deformation on the surface than a shallow mine of the same size, and therefore deep mining is often preferred.

#### *10.1.1.4.2 Damage to the Nearby Aquifers*

The effect of a dense brine-filled cavern on the relative compressional and tensile forces acting within nearby aquifers is minimal compared to the effects of the same sized cavern filled with atmospheric air. This is because the fluid in the cavity has a density of about half that of the rock itself. On the other hand, whether caused by solution mining or dry mine caving, the dilation of pore space can result in increased flow from water-bearing formations, and likewise, its compression can have the effect of restricting flow from such a formation. In any event, natural fractures can be opened up into nearby aquifers and cause contamination of the aquifer or dilution and contamination of the brine in the cavity. The relative pressure between the aquifer and the cavity will determine which way the flow moves. Monitoring efforts will usually show a pressure response in either the cavity or the aquifer or both. Solution mining of thick saline layers located near existing or developable drinking water sources is especially risky for both the aquifer and the cavity integrity.

### 10.1.2 WASTE MANAGEMENT

Solution mines made their historical beginning by supplying salt for human and animal consumption. These operations seldom left a waste requiring management over and above a small evaporation pond or crystal farm where the product was prepared. Modern chemical and fertilizer industries produce a wide range of products as well as wastes of varying toxicity, and now various industries are seeking less expensive ways to dispose of their waste products or off-grade unmarketable commodity.

#### 10.1.2.1 Well field

As most insoluble material remains in the cavern, the well field has much less waste associated with it than conventional mining operations of the same size. The brines are contained in competent tanks, ponds, and piping, and good housekeeping practices can easily take care of the fuels and lubricants associated with the pumphouse and the equipment needed to service and maintain it. The well fields used for the production of salt, potash, and trona are usually models of cleanliness.

Sometimes a gas flare or a gas-liquid separator is needed at the production wells and, if methods of transport other than pipelines are used (trucks, tankers, barges), a holding pond is needed ahead of the transfer station.

If the well field is used to recover a mineral that is not readily water-soluble, some provision must be made to make up the solvent. The solvent preparation step may have wastes associated with it. The mining of sulfur is an example of a situation where the product is stored on the surface, generally at or near the well field, in liquid as well as crystalline forms. The well field can therefore be used as an inventory holding facility in many instances. If these facilities are not well designed and maintained they can result in lost product or generate waste in the form of contaminated product or unusable solvent.

#### 10.1.2.2 Plant

The "plant" refers to some building or facility used to prepare the solvent, if it is other than water, and convert the concentrated brine into a usable commodity such as salt, fertilizer, soda ash, various acids and industrial chemicals. The waste products can be gasses such as water vapor, carbon dioxide, ammonia, hydrogen sulfide, and hydrocarbons or chemical vapors. Salt brine is itself a waste product of solution mining operations intended for development of cavities for hydrocarbon and petrochemical storage. Many of the various process purge streams constitute a large part of the plant wastes. The burning of limestone for the production of slaked lime and causticization produces a sludge or mud. Sometimes calcium and magnesium precipitates are a waste product. Calcium chloride has been a rather difficult waste to dispose of over the years. Prior to the environmental movement of the late 60s and early 70s it was not uncommon to dump the solids and waste brines into the nearest river or pump them into nearby porous rock formations. It was this practice, and a virtual disregard for the downstream impact, that generated sufficient environmental legislation to close down several industries and many plants.

The management of any processing plant in the United States that produces a waste (and to some extent they all do) must take the Safe Drinking Water Act (PL 93-523, as amended) very seriously. For the most part, the regulations can be found in Title 40 of the Code of Federal Regulations which can generally be found in your local library and better book stores. There are similar standards in many countries of the world.

#### 10.1.2.3 Maintenance

If the operation is not large enough to justify a separate environmental group to handle the well field and plant wastes, the responsibility is usually assigned to a technical, engineering, or maintenance department. In addition, the maintenance operation has waste generating problems of its own. The maintenance wastes are often more serious and hazardous to handle than the plant and well field wastes. They often require special protective gear, storage and transportation facilities, and licensed contractors. Examples are asbestos insulation and gaskets, PCBs in transformer cooling oil, used crankcase and gearbox oil, Teflon and similar plastics that yield deadly gasses when heated excessively, and fluorescent tubes whose coatings can be poisonous.

### 10.1.3 ENVIRONMENTAL CONSIDERATIONS

The environmental considerations of solution mining are somewhat different from those of open-pit and underground mining. Solution mining can be practiced from deep workings using workers underground but this is a rare case compared to the normal practice of drilling wells from the surface. For the most part, there is seldom a solid to dispose of at the surface. It is not even necessary to install holding or evaporation ponds in many cases, although somewhere in the well field-plant system there should be sufficient ponds or tankage to permit draining the piping network for testing and repair. Toxic gasses are seldom generated, and flammable gas is normally flared. Gasses are often chemically reacted and neutralized. The most likely environmental factors that must be considered are leakage into a formation capable of producing significant quantities of potable water, surface and intermediate disturbances due to subsidence damage, and problems arising from poor maintenance or operating practices. The disposal of brines generated from the solution mining of cavities for storage can be considered an environmental problem if the flow rates, temperatures, and concentrations are not carefully monitored and controlled. Low concentrations of brine can be safely discharged to rivers and streams in many parts of the world.

#### 10.1.3.1 Wellhead Excursions

The "gusher" is perhaps the most dramatic excursion. These rarely happen, but when they do they require quick action by the operator. A solution cavity is normally operated at sufficient wellhead pressure to lift the weight difference between the injection and production columns. An excursion at the wellhead or in the production piping can be minimized by stopping the injection. When the injection pump is shut off the production stream begins to slow at a rate determined by the hydraulics of the piping network and the gallery being injected. The system can be rapidly depressured by allowing the lightweight injection column to back-flow through the injection pump or otherwise be dumped into a controlled pond or storage area. The situation is not the same as an oil well "gusher" where the pressure is often unknown and uncontrollable. Safety as well as environmental hazards can result from a wellhead excursion. The degree of the safety hazard will range from zero to very serious depending upon the solvent, the pressure, the materials being mined, the dissolved gas present in the production stream, and the rate at which it is released when an excursion occurs somewhere between the well bore and the stripping facility.

##### *10.1.3.1.1 Cause*

Wellhead excursions are usually caused by improper design, poor maintenance, faulty operating procedures, or a combination of these. Typical examples are poor welds that fail or leak when pressured, flange installations with the wrong type or size of bolts and gaskets, use of valve bodies and tree fittings made of materials unsuitable for the brines involved, failure to consider the maximum pressure and the range of temperatures involved in the development, operation, and testing of wells in the system, and inattentive or untrained operators who fail to follow correct procedures. Vibration often caused by pumping and water hammer caused by check valves suddenly closing are areas that are frequently underestimated or overlooked by designers. Unchecked corrosion can be blamed for a number of wellhead and pipeline excursions. An operator can avoid these apparent environmental accidents by paying attention to the fundamentals of good design, operation, and maintenance. Initial and ongoing hazard reviews are helpful in pinpointing problems before they occur.

##### *10.1.3.1.2 Mitigation*

Once a wellhead excursion has occurred it is necessary to notify the proper environmental agency and other health and safety personnel as needed. The degree of hazard and the magnitude of the problem must be assessed quickly, especially if down stream water users must be alerted. In many cases the brines may have been weak enough to have done little or no damage (e.g., injection well water), but in others a strong or saturated brine may have mixed with local soil before flowing into a storm drain network, a municipal sewer system, a local stream, into nearby buildings or homes, and many other complicating factors. The composition of the material will be helpful in determining the pace at which corrective measures are conducted.

The actual circumstances involved will dictate

whether or not the soil must be replaced, fish kill must be monitored, accumulations must be pumped out and removed, buildings repaired, etc. It doesn't make any difference where you are located, the cost of correcting the problems caused by a wellhead excursion are several times the cost of prevention. The extent and type of mitigating measures will obviously be site-specific.

### 10.1.3.2 Surface Impacts

The land surface is important to someone, even if it is only stone, sand, ice, or a wetland marsh in a southeast Asian jungle. It is much more important if it has farm products, homes and other buildings located on it. Solution mines can be located beneath cities and towns and cover the entire range from desert to dense industrial and business facilities. The responsible operators will consider this carefully when they select the location and design their well fields. There may be no impact whatsoever beyond the noise and aesthetic disturbances, but caution is advised.

The impact of surface subsidence, if it is allowed to occur, can result in no more than a gentle downwarping or possibly a sinkhole in the wheat field or sage brush. On the other hand, it can turn corn fields into swamps, take out rail lines and other utilities, and damage structures and sewer systems to the point where they must be condemned and replaced elsewhere.

### 10.1.3.3 Site Closure

It was convenient to simply lock the door and walk away from an abandoned mining operation prior to the environmental movement that started in the early 70s. This is no longer a viable alternative. For many reasons it is appropriate to think ahead and plan for the day when the solution mine must be abandoned.

#### *10.1.3.3.1 Cavity Stabilization*

Before a solution miner can abandon an operation, the reclamation requirements of the operating permit must be satisfied. This usually involves a stipulation that the cavity be left in a stabilized condition such that dangerous reactions and behavior will not occur in the future. Such reactions might be expected if, for instance, waste hydrochloric acid were disposed of in a limestone or dolomite formation. The reaction between this waste and the carbonate rocks would produce carbon dioxide. This reaction would continue until it reaches completion or is otherwise neutralized by the operator. Many of the solvents used in solution mining continue to react with the materials being mined long after the well field is shut in. Water is no exception when the ore is water-soluble. The driving force for dissolution exists until the bulk fluid becomes saturated at the underground temperature. The cavity will continue to grow, even during shut-in, until saturation occurs, but fortunately this does not take long since the bulk fluid within the cavity is normally very close to saturation during cavity operation. Storage cavities and those used for waste disposal are generally designed to be stable under all conditions. Liquid-filled cavities are generally more stable than gas-filled cavities, but this is not universally true, especially if the very soluble magnesium minerals are present.

In many cases the cavity will tend to build pressure due to long-term creep and cavity closure. In time, the cavity could reach a pressure high enough to support the overburden load. If the stress field is homogeneous the cavity should achieve stable equilibrium. If one of the horizontal stress components is abnormally low, some believe that the shut-in pressure could generate new fractures in the formation or in the roof.

Finite element models are used in the industry to estimate or calculate the anticipated roof deflection over a large cavity that has been shut in. These models usually involve a certain amount of core testing for physical properties along with the introduction of various failure criteria – limited tension allowed, bedding plane slip, time-dependent creep, the Mohr-Coulomb failure criterion, and others. Some of these models are reliable and cost-effective ways of evaluating cavity stability.

A closed liquid-filled cavity will have an overburden lifting effect which is equal to about half of the overburden load. Hydrocarbon, petrochemical, and similar storage cavities are obviously so valuable that they cannot be abandoned without displacement of the products contained therein if leaks or other indications of instability are detected. The possibility of filling a cavity with solid waste, mill tailings, and other undesirable solids should be considered.

#### *10.1.3.3.2 Plant and Equipment*

If the plant and the equipment cannot be converted to another use, they are normally reclaimed before abandonment. Auctions are often held for the sale of buildings and equipment with the stipulation that the buyer must remove his purchase within a specified period. If the plant is old and the equipment obsolete, it is often necessary to advertise heavily in those areas of the world where low labor costs can offset equipment inefficiency. This is usually done by selling to professional used equipment dealers who can advertise and sell through a wide network of clients who have difficulty justifying new equipment. Regardless of how the transaction is managed, the plant site is usually cleared of abandoned structures and equipment and returned to nature or the highest prior use.

#### *10.1.3.3.3 Surface Issues*

Once the surface has been cleared of abandoned and obsolete structures there remains an obligation to inform the potential buyer that certain hazards may still exist that might prohibit the construction of certain sizes or types of structures. As an example, high-rise apartments or high-density offices should not be permitted if the cavities associated with the plant are located beneath the abandoned structures. Many of the older plants and solution mines were constructed prior to significant social and environmental restraints. There was no legal or financial obligation in the past to meet the ever tightening restrictions of today and tomorrow. The title to surface rights should therefore be restrained by covenants that bind the buyer not to drill wells into the abandoned cavities or use said cavities for unauthorized purposes. In addition, if wastes were left on the site, they should be described in the title along with warnings as to the hazards they represent. These types of restrictions are seldom, if ever, mentioned in a real estate contract with the understanding that caveat emptor is the final word. Obviously, the potential hazards associated with unrestricted building over plant wastes and hidden cavities goes well beyond the usual problems of bad roofing, plumbing, wiring, and construction details that caveat emptor was intended to address. The best way to clear up this problem between current and future buyers and sellers of the surface over potentially dangerous solution cavities is unclear in light of the broad range of surface uses, social mores and circumstances that exist in a world filled with solution cavities of all sizes and types. The problem is not one of irresponsible mining technology, but rather, irresponsible and outdated real estate law.

Where mines are located in sparsely populated areas the problem is much less severe in that abandonment requires restoration to the highest prior use. This was not terribly difficult when that use was wildlife, grazing, hay, or grain crop farming. In these areas of the world there are few solution mines located beneath metropolitan areas. The extensive subsidence settlement of the suburbs of Mexico City resulting from brine extraction at a nearby large "surface solution mine" is a typical example of uncontrolled real estate development in an area where solar evaporation and solution-mining technology is applied. The issue of surface management following abandonment of a solution mining operation will be with us for decades to come.

#### *10.1.3.3.4 Well Field*

A final set of logs, including a cement bond log, should be run prior to commencing well field abandonment. Normal practice calls for pulling any intermediate tubing strings and setting a bridge plug near the bottom of the long-string cemented casing. The well to be abandoned is then filled with a cement slurry by pumping it down drill pipe located above the plug. The pumped volume of the cement is measured during the process and the drill pipe is then pulled up to this level. A second plug is then pumped and the process is repeated until the casing is completely full of cement. The well represents the greatest risk of a leak from the cavity, and it must be carefully sealed.

Each solution mine is site-specific in terms of the downhole conditions to be expected during the abandonment process (e.g., the combination of depths of various casing strings, the location of aquifers with respect to the cavities). It is often necessary to resort to more complicated cementing procedures if bridge plugs cannot be installed or the intermediate strings cannot be recovered. Detailed descriptions of the use of fishing tools, reamers, casing cutters, floating-foam cementing techniques and similar modern practices common to the petroleum industry are beyond the scope of this text.

Some regulations require the final casing to be cut off below plow depth while others require that a permanent riser be left as evidence that a well once existed at that location. Pipelines are quite often salvaged unless the environmental disturbances caused by pulling buried lines is significant. Power and other utilities can either be removed or left in place depending upon future plans for the area.

#### *10.1.3.3.5 Long-Term Monitoring*

It is often appropriate to leave select monitoring wells installed if there is a potential for future problems with nearby drinking-water aquifers. Sometimes a production or injection well connected with the cavity is left in place as a means of monitoring should future instability be anticipated.

The period of time required for long-term monitoring depends upon the proximity to drinking water sources and the degree of hazard involved. Each well field is site-specific in this respect and somewhat dependent upon the commodity being mined, geology, and surface use following mining. It is obviously in the best interest of the operator to minimize the need for monitoring into perpetuity by doing a quality job of well field development and cavity stability evaluation.

## 10.2 IN-SITU LEACHING

**by J. T. Laman**

In-situ leaching (ISL) is a method used to extract mineral values from a deposit through the use of chemical solutions without significant disturbance of the host formation. Unlike solution mining of soluble salts, this mining method does not create large subsurface cavities

in the deposit. A number of closely spaced injection wells and production wells are assembled into well fields to extract the mineral values in-situ by circulating chemical solutions. Chemical solutions are confined to the ore zone by controlling the hydrologic gradients in the well field and by impermeable geologic features. Regular sampling of monitor wells which encircle the well field insure confinement of chemical solutions. In-situ leaching is applied to mineral deposits located above and below the water table.

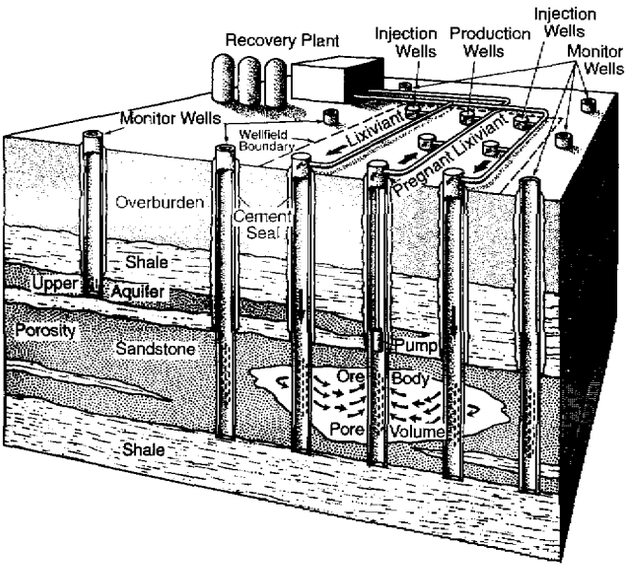



**Figure 3** Conceptual drawing of a uranium ISL mine below the water table.

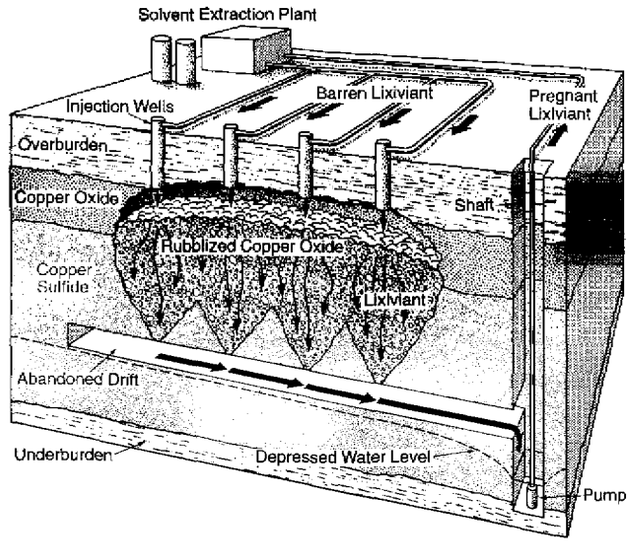



**Figure 4** Conceptual drawing of a copper ISL mine above the water table.

The chemical solutions used for ISL are called *lixiviants*. Lixiviants can be acidic or basic or neutral, and frequently contain oxidants. The impact of lixiviants on groundwater systems results from the chemical reactions with the host formation. Stopping or reversing the effects of these chemical reactions occurs during groundwater restoration after the mining activity has ceased. Restoration processes are designed to return the groundwater to its pre-mining quality or use.

ISL has been used commercially to extract uranium from permeable sandstone formations in Texas, New Mexico, and Wyoming, and copper from fractured hardrock oxide deposits in Arizona. In the future gold, silver, and possibly other minerals may be extracted by ISL methods, although not all geologic settings are suitable for ISL. Typical ISL mines for uranium and copper are shown in Figures 3 and 4.

The bulk of the waste from ISL mines is in liquid form. Water treatment processes which reduce the volume of waste water, lined evaporation ponds for storage of waste solutions and sometimes deep well injection for disposal of solutions are part of the waste handling systems.

### 10.2.1 WASTE GENERATION AND MANAGEMENT

The quantity of liquid and solid wastes from in-situ leaching operations is less than that from open-cut or underground mining techniques which generate solid waste as a result of overburden removal, waste rock storage, and tailing impoundments as well as liquid waste from mine dewatering. ISL requires no rock excavation, material handling, crushing, or grinding operations, because the lixiviant liberates the mineral from the host rock in-situ with little, if any, disturbance of the host rock. The solid waste at ISL mines is a relatively small quantity and is generally from precipitates, evaporates, and filter residues. The liquid waste solutions from groundwater restoration generate the largest waste volume associated with ISL.

An ISL mine is composed of two parts, the well field areas and the plant area. The waste handling facilities are normally a lined evaporation pond and at some sites a deep disposal well. During site closure the residues in the evaporation pond are either entombed on site or hauled to a licensed disposal area, the wells are plugged and abandoned, and the plant removed from the site.

#### 10.2.1.1 Well Field Wastes

The drill cuttings from the well installation are collected in mudpits along with the drilling fluids used. These mudpits are usually simple holes in the ground or portable tanks. The size of the mudpit depends upon the diameter and depth of the bore hole. Drilling fluids can be a variety of media such as air, air and detergent, water and detergent, bentonite, and synthetic muds. Depending

upon the composition of the mineral cuttings and drill fluids, the drill hole wastes are either buried near the well or hauled off site for proper disposal.

Once the well field is operating, downhole precipitation and scaling can require periodic maintenance. The most common problem is calcium carbonate scaling, which is normally handled by taking the well or pipeline out of service and flushing with acid solution for short periods. The waste solutions are small in volume and contain some suspended solids.

Pipeline failures can result in spills and if the spill contaminates the soil with constituents which degrade the use of the soil, this can create a solid waste. Normally, isolation of the spill from surface waters via engineered drainages is the primary concern.

Typically, well field wastes are small in quantity and can be handled with standard operating procedures, which include segregation of wastes, impoundment in ponds, and off-site disposal at licensed disposal sites.

### 10.2.1.2 Lixiviant Wastes

The lixiviant is the chemical solution used in in-situ leaching. Normally, chemicals are added to ambient groundwater from the mine zone to make the lixiviant.

The lixiviant is cycled many times between the well field and plant. When it accumulates undesirable elements at concentrations that have an adverse impact on the plant or well field, a portion of the lixiviant is wasted and fresh water added to the remaining lixiviant. If the problem impurity is present in large quantities, a special processing step can be used to remove it. However, normally impurities are present in small quantities and dilution is used to control their concentration in the lixiviant. This dilution occurs by removing or wasting a small amount of the lixiviant before it is returned to the well field. In the well field, the missing waste volume is made up by a inflow of ambient groundwater into the well field. This waste volume is called a "bleed stream" and is impounded in an evaporation pond or injected into a disposal well. The solids in evaporation ponds are eventually either buried on site or transported to another licensed disposal site depending upon the composition of the waste.

The dilution of the lixiviant that occurs in the well field as a result of the bleed is a small consumptive use of groundwater. For example, if 1000 liters per minute were pumped from the well field but only 980 liters per minute injected into the well field, then a bleed stream of 20 liters per minute would result from 20 liters per minute being removed from the groundwater system.

### 10.2.1.3 Plant Wastes

ISL plants are composed of a series of plant processes. Each process may generate a waste either during normal operation or during maintenance activities. Common plant processes are discussed below.

#### *10.2.1.3.1 Filtration*

Filtration prevents the plugging of equipment and wells by suspended solids. Suspended solids can be windblown debris, sand, or scale. Many types of filter devices are available for plant use. Some, such as the cartridge type, use consumable filter media which become part of the waste volume. Another type is the sand filter, which utilizes a bed of media that must be regularly backwashed; the filtered wastes are washed out with the backwash solutions. Filter manufacturers can identify the operational wastes to be expected. Filter wastes are generally impounded on site in lined ponds or tanks.

#### *10.2.1.3.2 Solid Ion Exchange*

The resin beads used in solid ion exchange are generally durable and last a long time. However, thermal shock, chemical shock, and mechanical abrasion can break the beads and create a small waste volume which is normally trapped in a filter. When resins become fouled with impurities and cannot be regenerated, the spent resin is wasted. This waste volume can constitute about 1% of the resin inventory per year.

#### *10.2.1.3.3 Solvent Extraction*

The waste from liquid ion exchange is caused by stable emulsions which do not separate into an organic phase and an aqueous phase. These emulsions must be periodically removed from the solvent extraction circuits. The volume of these stable emulsions can vary significantly from plant to plant but still only constitute a small percentage of the process inventory. This material is usually stored in ponds, drums, or tanks and processed by filtering or disposed of off-site.

#### *10.2.1.3.4 Precipitation*

There are many chemical reactions that yield precipitates, and these reactions are used to remove desirable or undesirable elements from process solutions. Precipitates can be fine or coarse, but once a precipitate is formed it is necessary to dewater it. Either the water or the precipitate may become the waste, depending upon the process. The equipment used for dewatering can be thickeners, filters, or settling ponds. The volume of waste depends on the process.

#### *10.2.1.3.5 Electrowinning*

As the recovery process of choice when using solvent

extraction, electrowinning uses electricity as an input and causes copper to plate out on the cathode as a product. Oxygen gas and sulfuric acid are by-products. The acid is used in other processes, and the oxygen escapes to the atmosphere; neither is considered a waste. Small amounts of hydrocarbon may get carried into the electrowinning process and can constitute a small, but permittable, release to the atmosphere.

#### *10.2.1.3.6 Reverse Osmosis*

This process involves specially designed membranes which under hydrostatic pressure will allow pure water to pass through the membrane and thereby separate pure water from other dissolved constituents. In practice about 80% to 85% of the pure water can be separated from the feed steam to the process. Of course, the remaining 15% to 20% of the water now contains nearly all the dissolved constituents. The pure water is called the product stream and is normally returned to the well field to help restore the mine zone. The reject stream containing very high concentration of total dissolved solids is a liquid waste.

#### *10.2.1.3.7 Electrodialysis*

A series of closely-spaced selective membranes which are alternately charged with positive and negative current results in the separation of cations and anions from water containing high total dissolved solids (TDS). As the ions are removed, the TDS content is reduced and a treated water with few ions is produced as well as a waste brine water containing the bulk of the cations and anions. The low-TDS water can be used to facilitate well field restoration.

#### *10.2.1.3.8 Plant Wash Down*

Since all other ISL plant wastes are relatively minimal, plant wash down waters and spills inside the plant building can be a measurable segment of the total wastes. These liquid wastes are simply sent to the evaporation pond.

### 10.2.1.4 Restoration Wastes

Groundwater restoration begins when no new mining chemicals are added to the barren solution being returned to the mine zone. The restoration process ends when the sub-surface reactions caused by the in-situ mining process are stopped and the mining chemicals are removed from the groundwater. The restoration waste water containing the mining chemicals is the largest waste volume associated with ISL mines.

The flushing or draining of the residual barren and pregnant solutions from the mine zone is accomplished by continued operation of the well field with no addition of new mining chemicals to the barren solutions. Although slow, the solution mining reactions will continue until the Eh-pH of the groundwater has been returned to ambient conditions. Ambient groundwater conditions are restored by removing the mining chemicals which are present as dissolved solids. Occasionally, reducing chemicals, such as hydrogen sulfide, are circulated through the mine zone to stop any further oxidation of heavy metals. The soluble residues of the reducing chemicals must also be removed from the groundwater during restoration.

Dissolved solids are removed from the groundwater by simply pumping the undesirable groundwater into an evaporation pond or disposal well, or by surface treatment to remove the dissolved solids and injection of treated water into the mine zone which aids in the flushing of mine chemicals and reduction of the waste volume. Generally, surface treatment and injection of treated water is used during the first phase of groundwater restoration, and ambient groundwater flushing is used in the last phase. Reverse osmosis and electrodialysis are popular surface treatment processes; both concentrate dissolved solids into a small waste volume and generate a clean water product. Ambient groundwater is drawn into the mine zone by pumping with little or no injection of treated water. The ambient groundwater dilutes and aids in flushing any remaining dissolved mining chemical residues from the mine zone and helps to stabilize the chemical equilibria between the dissolved constituents and the constituents not in solution. Restored groundwater needs to exhibit chemical stability over a period of time.

The liquid waste containing the mining chemicals removed during restoration can be disposed of in a deep disposal well, where permitted, or impounded in an evaporation pond. When the water evaporates, the remaining solid waste is entombed on-site or disposed of in a licensed non-hazardous or hazardous waste site depending upon the waste composition.

For copper and other ore bodies containing sulfides, the potential for long-term acid mine drainage reactions needs to be evaluated. Sulfuric acid is the lixiviant for copper ISL. The chemistry for sulfide minerals is more complex than for oxide minerals, and dormant bacteria can begin to grow under the acidic conditions required for ISL. These bacteria are beneficial to mineral extraction but pose a problem for restoration because they have the ability to continue to generate an acidic and oxidizing environment suitable for their continued growth even after the addition of mining solutions is stopped. The acid, iron, and copper mobilized by the continued growth of bacteria constitute a waste source that can require long-term treatment.

## 10.2.2 ENVIRONMENTAL CONSIDERATIONS

### 10.2.2.1 Baseline

Establishing the baseline conditions in the groundwater and on the surface prior to in-situ leaching is normally done while collecting supporting information for appropriate permits and licenses. Since site closure and the termination of groundwater activities may depend upon favorable comparisons of premining data to post-restoration data, a valid and working definition of *baseline* is important. Surface impacts of in-situ leaching are small and can be measured, monitored, and mitigated in much the same way as other surface disturbances and will not be discussed in this section. Groundwater considerations will be discussed. Many local regulatory agencies have guidelines available regarding baseline issues.

There are two basic ways to define general groundwater quality before and after solution mining. One approach uses a well-by-well comparison: water quality data for a specific well is collected prior to mining, data is collected from the same well after restoration, and the data compared. The other approach collects data from several wells and establishes a representative groundwater quality for an area; after restoration of the area a group of wells is sampled and the representative water quality data for the area before and after is compared.

In selecting an approach, the number of water wells available for sampling before mining and the number after mining needs to be considered. Typically, the number of premining wells used for aquifer studies and water quality sampling is considerably less than the number of wells used during mining. However, all the mining wells are potentially available for water quality sampling after mining ceases. The well-by-well technique poses more problems because the number of wells used to represent the restored area is small and may not be located uniformly throughout the well field area. Furthermore, there is always a risk that a well may be lost or damaged. Of course, if a baseline is established for each mining well prior to injection of chemicals, then the number of wells used in the well-by-well comparison is large and the costs for the operator are also great. Establishing representative values for an area is the more flexible approach; it accommodates the use of an appropriate number of the available wells after mining and assures that wells will be in the most representative locations.

Another issue is the statistics of water quality data. Groundwater quality can vary somewhat from point to point in the same aquifer. Hence, small variations in constituent concentrations between two wells in the same aquifer are normal. Variations in constituent concentrations in the same well can be real or can be the result of laboratory or sampling discrepancies. However, the slow rate of groundwater movement makes chemical variations in the same well due to temporal fluctuations unlikely. The result of these spatial, sampling, and analytical factors is that when each baseline well is sampled a number of times a range of values for each parameter is developed. All the values for a constituent can be averaged using statistics. Care must be taken to select and use the appropriate statistical technique. Formulas for normal distributions and student-t distributions have been used.

Unless a very large number of values are available, the impact of an "outlier" can be significant. An outlier value is one that is several standard deviations farther from the mean than all other values and is suspected of being an erroneous measurement. An outlier can be defined in terms of deviations from the norm, or sometimes it is more practical to simply ignore the high and the low value and average the remaining values. Whatever adjustments are made to the data, it is important to represent the aquifer composition fairly and accurately and to avoid creation of calculated values which are not representative of the situation.

In comparing data from different wells within the same aquifer, or premining and post mining data from the same well, it is important to understand the statistical method used and verify that comparison of different data sets is statistically valid and consistent with analytical detection limitations. Sometimes concentration values are reported as "not detected" rather than as a value. Parameter-by-parameter comparisons can be difficult and may require subjective decisions because some parameters such as mercury are more dangerous than others such as iron.

It is very important to establish valid baseline data because site closure will depend upon comparisons of baseline data to post-mining data. Baseline measurements based upon too little data or suspect data will create serious future problems. Good quality control procedures are very beneficial.

### 10.2.2.2 Well Field Wells and Exploration Holes

Improper plugging of old exploration holes can create avenues for vertical communication between aquifers. Fortunately, natural swelling of clays can sometimes plug old exploration holes. Newer exploration holes are routinely plugged with bentonite or cement. When in doubt about the presence or absence of vertical migration paths between aquifers caused by exploration holes, it is best to test the confinement before chemicals are injected by increasing the pressure in the mineral- bearing aquifer and monitoring the adjacent aquifer for a response to that pressure.

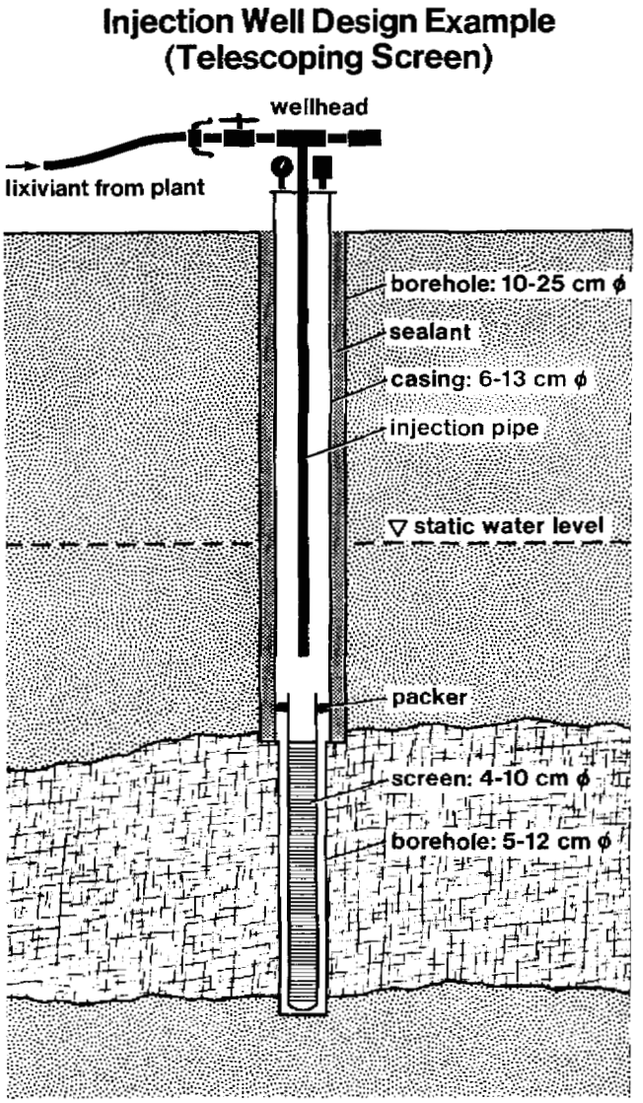



**Figure 5** ISL injection well design example (telescoping screen).

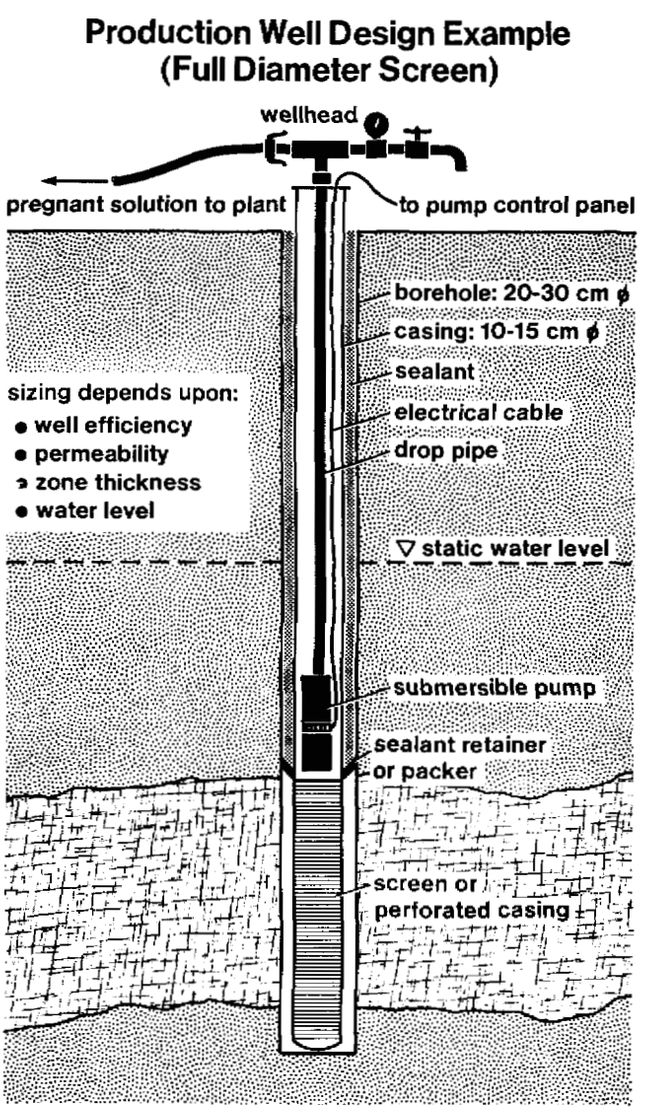



**Figure 6** ISL production well design example (full-diameter screen).

Concern about vertical excursion pathways extends to well casing and completion procedures. Solution mining wells are cased from the surface to the mineral-bearing aquifer and the casing is cemented in place over the entire casing length. The cement is designed to prevent solutions under pressure from migrating upward in the annulus between the casing wall and the hole. The casing is designed to provide a leak-proof conduit for the solutions. Figures 5 and 6 show typical ISL well completions; other drilling and completion procedures are possible.

The success of the casing and cementing is confirmed by testing. Every well must pass an integrity test and be periodically retested to insure that no leaks have been caused during operation. Local regulatory agencies can advise about approved integrity test procedures.

### 10.2.2.3 Excursion Monitoring

An excursion is a movement of mining solutions outside the well field area. The well field area is the area inside the outermost wells or the mineralized area being actively solution mined. The well field area is surrounded by a ring of monitor wells installed for the purpose of detecting unexpected movements of mining solutions. Water samples are collected from the monitor wells at regular intervals and analyzed for key indicators, known as excursion parameters. An increase in the concentration of an excursion parameter indicates that mining solutions may be moving outside the well field area. When an increase in the concentration of an excursion parameter exceeds a defined detection limit, then a confirmation water sample is immediately taken and analyzed. If the

confirmation analysis verifies the elevated concentration level of an excursion parameter, then the operator takes corrective action.

The number and location of monitor wells are site-specific and depend upon the geology and hydrology of the site. In the uranium industry it is common to locate monitor wells no more than 120 meters from the edge of the deposit or nearest mining well and to space monitor wells no more than 120 meters apart. Closer spacing is sometimes used. It is important to surround the well field with monitor wells. Occasionally, when the hydrologic gradient is a factor, additional monitor well(s) are placed down-gradient of the well field.

Excursion parameters are selected for ease of detection and strong link to the mining lixiviant. Anions are used more often than cations because the movement of cations is frequently retarded by ion-exchange capacity of the clays. Monitoring of the water level in all monitor wells can be useful if done frequently and with sufficient accuracy to monitor direction of groundwater flow. Detection limits for excursion parameters need to be high enough to avoid false positive indications and account for normal water sampling and analysis fluctuations.

#### 10.2.2.4 Excursion Correction

Horizontal excursions are corrected by stopping the injection in the area suspected to be the source of the excursion and by increasing the withdrawal of groundwater near the source. This reverses the flow gradient and in time will draw the migrating chemical solutions toward the pumping wells and back inside the well field. In addition to the migrating chemical solutions ambient groundwater is also collected and this significantly increases withdrawal volume required to correct the excursion. Many times the impoundment capacity and waste water treatment equipment become the bottleneck. In serious situations, all injection of chemical solutions can be stopped until the excursion is corrected.

Vertical excursions into the overlying aquifer are more difficult to correct because there are usually very few wells to work with and identification of the migration path can be difficult. Remediation of vertical excursions requires the plugging of the migration path and then clean-up of the affected aquifer.

#### 10.2.2.5 Spills and Leaks

Spills can occur in the plant, in the well field, or in the piping between the plant and well field. The major cause of spills is pipeline failure, and the major cause of leaks is ruptures in a pond lining. The liquid released during a spill or leak is usually high in dissolved solids, contains heavy metals, and can be either acidic or basic. Ideally, man-made or natural barriers will confine the chemical solutions to the surface and prevent migration into the groundwater.

Ditches are desirable to divert rainwater, snowmelt, and other forms of meteoric water around and away from the plant, well field, and pipelines. A spill collection and containment system for the plant and well field areas is used to prevent process solutions from contaminating surface waters. Spills can be returned to the process or impounded with the other process wastes.

Lined impoundment ponds rely upon leak detection systems and multiple linings to prevent solution escape. Leak detection systems use a network of piping installed beneath the pond liner to collect any leaking solution. The appearance of solutions in the leak detection piping is the first sign of a leak. Sometimes a second lining is installed under the primary pond liner to provide a barrier to downward percolation should the primary liner fail. The leak detection piping can be installed between the liners. Consideration should be given to the problem of how a pond leak will be detected and repaired as most ponds will eventually develop a leak.

#### 10.2.2.6 Plant

In-situ solution mining plants are designed to alter the composition of mining solutions through an assortment of plant processes, such as ion exchange, solvent extraction, precipitation, reverse osmosis and others. Nearly all the processes involve the use of industrial chemicals and acids or bases during normal operation or during maintenance. Confinement of leaks and spills within the plant area is accomplished through troughs and sumps strategically located in the plant floor. At times the plant foundation is designed with one or more spill collection troughs and sumps depending upon whether or not it is desirable to separate leaks and spills from different parts of the plant area. Liquid wastes collected in plant sumps are either returned to the process or discharged to the impoundment area.

Vapors from open tanks and vessels can be a hazard, especially in enclosed plant buildings. Proper ventilation design is needed in these cases.

Dust and solids from plant operations can be an environmental concern if the composition of the dust is dangerous. For example, dust from a uranium-drying operation requires special consideration to prevent its escape to the environment. However, typically the environmental concern for dust or solids in a solution mine facility is much less than for liquid spills and leaks.

#### 10.2.2.7 Maintenance

At one time or another equipment, pipelines, and vessels will require maintenance or repair. For serious emergencies, the well field can be shut down and this

immediately limits the volume of chemical solutions on the surface and in the plant. The well field can be restarted when the problem is fixed. For normal or planned maintenance, the well field may or may not be shut down depending upon the plant design. Duplicate equipment is sometimes installed so that one unit can continue to operate while the other is shut down for repair or preventative maintenance.

#### 10.2.2.8 Site Closure

After groundwater remediation and mine zone stabilization are complete, the surface facilities need to be removed, the wells plugged, the impoundment areas shut down, and the surface reclaimed and contoured where needed. Scrap equipment and wastes need to be segregated into hazardous, non-hazardous, or radioactive (in the case of a uranium operation) and disposed in the proper manner. On-site burial of some wastes may be allowed. Off-site disposal may be required for others.

Reclamation of the surface involves the removal of surface facilities, roads, and power lines. In areas where the top soil has been removed and stored, it must be replaced. The surface must be contoured to provide stability from surface water drainage.

Well field reclamation requires the removal of piping, the electrical distribution system, and the downhole pumps as well as any well field shacks or buildings. Each well is filled with cement or bentonite mud to within a few meters of the surface. After the cement or mud has set up, the top few meters of the well is cut off and the hole filled with soil.

The impoundment area is generally a lined pond. If evaporation was used to reduce the volume of liquid waste, the lined pond could be large. If all wastes must be removed from the site, then the pond contents as well as the liner and leak detection piping need to be removed and transported to an approved disposal site. However, if wastes which pose little hazardous or toxic danger can be disposed of on site, then the lined pond can be used to entomb those wastes. After the wastes are placed in the pond, the pond is capped with an impermeable material such as clay. The cap is contoured to prevent surface erosion and sometimes covered with topsoil and vegetation.

The last consideration for site closure is long-term monitoring. In cases where groundwater quality on site is not the same as water quality off site, the use of long-term monitor wells can insure no unexpected impacts occur off site. Long-term wells can monitor the key water quality concerns on a regular basis and also record water level. If more than three monitor wells are used, then the water level can be used to monitor the direction of groundwater flow and insure that changes in the groundwater flow direction are detected. Long-term monitoring is not needed in cases where the restored water quality is essentially the same as that of the surrounding waters.

### 10.2.3 GROUNDWATER RESTORATION

Mine zones and groundwater can be restored. The technical concerns are the prescribed "consumptive use" of the groundwater and the ultimate fate of the contaminants that have been removed.

Groundwater restoration is the process of restoring the groundwater in the mine zone to a quality that is compatible with the surrounding groundwater and about the same as was present in the mine zone before chemicals were injected. Restoration processes also need to stabilize the host aquifer composition so that groundwater flowing through the restored mine zone in the future is not degraded. Heavy metal solubilization and clay ion exchange can occur in restored aquifers which are not stable.

#### 10.2.3.1 Standards and Restoration Targets

Ideally, a good numerical definition of baseline water quality in the mine zone was established prior to the injection of the first chemical solutions. If not, a suitable understanding of premining water quality and premining use classification must be determined from best available information. Restored groundwater in the mine zone should have the same use as the groundwater had before solution mining activity. Normally groundwater classification is based upon the highest potential use. Drinking water quality is the most stringent use classification; water quality appropriate for stock consumption or irrigation requires less stringent criteria. Determination of potential groundwater use is based on the composition of the groundwater. Local regulatory agencies can supply information on the use classification criteria appropriate for a specific project location.

Continuing groundwater restoration activities until the water quality in the restored groundwater is the same as the baseline conditions assures that the post-mining use is the same as the premining use. Achieving "baseline conditions" is a more stringent restoration target than attaining "use criteria." Rarely can restored groundwater exceed baseline water quality and be stable. As restored water quality approaches baseline water quality, it can be difficult to determine whether a small deviation in a parameter's concentration is caused by statistical factors or actually represents unrestored groundwater. Ideally, the statistical factors and techniques used to evaluate restoration values will be the same as those applied to premining baseline values. In practice, it is unlikely that all the factors will be the same. For example, the number and location of wells used to establish the premining baseline may be different from

those available for restoration sampling, and small differences in a parameter's value may be attributable to location.

Another technique is to establish "restoration targets" for each water quality parameter. These are established by subjective review of the baseline data and knowledge of drinking water standards or other use criteria, followed by numerical selection of an appropriate restoration target value for each water quality parameter. For example, if no heavy metals were detected in the baseline data, then the drinking water standard for each heavy metal would be selected as the restoration target value; on the other hand, if the total dissolved solid (TDS) concentration of the baseline was greater than the recommended concentration for drinking water standards, then the restoration target value for TDS, based on baseline data, would be greater than drinking water standards. The target restoration value for each parameter is based upon use criteria or baseline data, whichever is most appropriate. This technique establishes attainable restoration targets and does not degrade the future use of the water.

### 10.2.3.2 Natural Restoration Processes

Bacteria, dispersion, adsorption (retardation), and clay ion exchange are some of the natural processes that affect the concentration of chemical species in the solution or not in solution. Changes in the composition of the water can cause certain chemical species to either precipitate from solution or be dissolved into the groundwater. The geochemistry of groundwater systems is explained in more detail in other references. With regard to groundwater restoration it is important to realize that groundwater systems are dynamic and groundwater quality can vary within the same aquifer.

Both reducing and oxidizing *bacteria* are present in aquifers. When dissolved oxygen is available — in shallow aquifers or portions of the aquifer near the recharge area — bacteria that consume oxygen will be active; when there is no dissolved oxygen available, reducing conditions will dominate. Bacteria can influence the composition of the groundwater. Their activity is controlled by temperature and the availability of nutrients. In slow-moving, cool groundwater systems bacteria reactions will be slow. The pore space in aquifers acts like a filter. The movement of bacteria can be limited by small pore space; i.e., the bacteria are too large to move freely in small pore spaces.

*Dispersion and diffusion* processes also impact water quality. Where a pocket or slug of groundwater has an unusually high concentration of a constituent there is a tendency for that constituent to diffuse into surrounding waters and seek a more uniform and lower concentration. As groundwater moves down-gradient, dispersion will tend to spread contaminants into greater volume and hence reduce contaminant concentration.

*Adsorption* processes depend upon the composition of the aquifer. Not all materials have the same adsorption properties. Clays such as montmorillonite tend to adsorb more chemical species than a siliceous sand grain. The adsorptive capability of an aquifer depends on the amount of clay and other constituents present. Not all adsorption is permanent. Contaminants can be adsorbed and thus removed from solution. Over time other ions can be adsorbed and displace the contaminant from the adsorbing surface; then the contaminant is again in solution and will move with the groundwater until it is adsorbed and desorbed again. This process is called *retardation.* The movement of the contaminant is retarded and is slower than the movement of the groundwater. The contaminant can continue to move in the groundwater until it is no longer desorbed.

*Clay ion exchange* can affect groundwater composition and permeability of the aquifer. Ion exchange occurs when an ion in solution such as sodium is attracted to a clay particle and the clay particle releases another ion to solution such as hydrogen. The sodium ion is no longer in solution, and the clay has exchanged one positive charge for another. In the case of montmorillonite clay, the sodium ion will cause the clay to swell and reduce permeability. Every type of clay has a different affinity for ion exchange, and each ion has a different affinity for clay ion exchange. Ion exchange is also influenced by equilibrium forces, so that very high solution concentrations can increase the affinity of that chemical ion for clay exchange. The composition of clays can change during mining and during restoration. If the clay compositions is not stable, then restored water quality will not be stable.

### 10.2.3.3 Groundwater Sweep

Groundwater sweep is a simple restoration technique, but it is slow and consumes a large volume of groundwater. When there is no injection of solutions into the mine zone and the well field pumps continue to withdraw water, ambient groundwater is drawn into the mine zone and toward the pumping wells; it mixes with and flushes the chemical water from the mine zone. This flushing and mixing with ambient groundwater is called *groundwater sweep.* The chemical properties of the ambient groundwater also help to stop the mining reactions and stabilize the mine zone. Poor sweep efficiencies and mild ambient groundwater chemical properties can extend the time and increase waste volume, especially in places where the permeability is not uniform since the higher permeability flow paths will be flushed with much greater volume than will flow paths with lower permeability.

Groundwater sweep is used to draw any chemical solutions on the well field perimeter into the well field

area. Also, the use of ambient water in the mine zone to mix or flush treated water helps stabilize the restored area at the end of the restoration process. Whether or not to augment groundwater sweep with surface treatment depends on site-specific factors.

#### 10.2.3.4 Pump-and-Treat and Re-injection Processes

Groundwater can be conserved and restoration time reduced by injecting treated water into the mine zone. Groundwater is conserved because only a portion of the water pumped is wasted and that wasted portion depends upon the surface treatment process. Restoration time is reduced because greater volumes of treated water can be circulated through the mine zone when injection and pumping occur simultaneously than can be drawn through the mine zone by pumping alone (groundwater sweep). The chemical properties of the treated water may be different from those of the ambient groundwater and can be used to enhance restoration, especially in the early phases. Ambient groundwater promotes stability in the last phases of restoration.

Reverse osmosis and electrodialysis are used to remove the dissolved solids resulting from the solution mining activity. Both processes generate a treated water product containing very few, if any, dissolved solids and a small waste volume. The waste volume contains the removed dissolved solids and is impounded in lined evaporation ponds prior to final disposal. The clean water product is returned to the mine zone. By removing dissolved solids and stopping the in-situ leaching in the mine zone, the mine zone groundwater can be restored.

Ion-exchange processes are used to remove a specific constituent, such as uranium or calcium, in order to make a by-product or to enhance the performance of the reverse osmosis process. It is desirable to design a surface treatment process that can produce a treated water product that meets or exceeds the target restoration goal for every parameter.

Injection of treated water is important to these processes. Besides reducing waste volume and speeding the flushing of the mine zone, chemicals can be injected to enhance restoration. When continuing in-situ reactions involving clays and heavy metals create undesirable soluble ions, injecting chemicals to stabilize the clays and stop the heavy metal mobilization is sometimes better than waiting for natural processes to eventually control the problem. For example, a reductant, such as hydrogen sulfide, can be added to the treated water. The reductant will consume any remaining oxidant in the mine zone and precipitate many heavy metals. Once the source of the soluble heavy metals is controlled, groundwater restoration can be completed.

Adding chemicals to solve one problem can create others, and care should be exercised when using chemicals to restore groundwater. For example, treated water or chemicals can induce permeability loss by clay swelling or precipitation. Loss of permeability slows the restoration process by slowing the movement of solutions through the mine zone. Changes in the composition of the water in contact with the clays can result in a change of the clay composition and the clay may swell or shrink. For example, sodium ion causes montmorillonite clays to swell, but potassium ion causes them to shrink. Precipitation reactions are likely when the hydrogen ion concentration is reduced (pH increases in value). Some permeability losses are reversible; others are permanent.

#### 10.2.3.5 Restoration Pore Volumes

"Pore volume" is a general term used to measure the relative amount of solution circulated through the mine zone. A pore volume is the amount of liquid which would fill all the pore space in the mine zone. One pore volume equals the volume of the mine zone in cubic meters times its porosity. However, due to well field sweep efficiency and effective porosity considerations, when one pore volume has been circulated, it does not mean that all the liquid in the pore space of the mine zone has been displaced once.

Restoration of a uranium ISL well field can be accomplished in approximately 4 to 12 pore volumes. Extraction of the uranium may take 6 to 20 pore volumes. In addition to the hydrologic sweep efficiencies, geochemical factors such as mineral type and distribution and lixiviant composition can influence the efficiency of restoration and extraction. It is difficult to compare restoration pore volumes for solution mines in different geologic settings and different well field configurations.

#### 10.2.3.6 Long-Term Considerations

At the end of groundwater restoration, the water in the mine zone will be very similar to the ambient groundwater or baseline water composition so that future movement of groundwater through the mine zone will not alter the groundwater quality. Natural movement of groundwater is relatively slow and there is sufficient time for soluble constituents to interact with host rock. Computer models are available which can project the concentration of a chemical species as it moves down-gradient in a groundwater system. However, the technical assumptions used in the program and the input parameters need to be understood to insure a valid result. Sometimes it can be shown that natural processes will reduce the future down-gradient concentration of a groundwater constituent.

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# Chapter 11
# PLACER OR ALLUVIAL MINING

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Placer mining has always been an important segment of the US mining industry. During the pre-Revolutionary War period, bog iron ore was produced in the Eastern US, which was followed by gold mining in the Carolinas and Georgia during the first half of the 19th Century. However, the California Gold Rush was the most important factor in raising US placer mining to the status of a major, world-class industry. The California placers evolved from small artisanal operations to hydraulic mining and then to large- scale dredging. This course of events was subsequently duplicated in many Western States and Canadian Provinces. Placer mining is still important in Alaska, where even off-shore dredging has recently been practiced.

## 11.1 INTRODUCTION AND GENERAL DESCRIPTION

Placer mining occurs on alluvial deposits, and the terms *placer* and *alluvial* mining tend to be employed on an interchangeable basis. The deposits may be either concentrated in situ or transported and naturally concentrated. The term *placer* derives from the Spanish word *playa* or beach. Placers may be found as colluvium or in streams or benches, and may even be buried. Economic deposits, while primarily gold, also include tin, titanium minerals, and even platinum. Non-metalliferous deposits also exist and are worked at various locations both within and outside the United States.

In current usage, the term *placer mining* is employed to denote *both* the excavation and physical processing of deposits. Actual mining may be done by ground sluicing, excavating by dredges and loaders, and even underground drifting. Recovery is usually accomplished by gravity methods, although mercury has been used in the past and in some cases up to and including the present. Placer mining uniquely affects the environment. Placer mining usually disturbs relatively large surface areas in relation to the depth that is mined (in comparison to other forms of mining). Even modern strip mining of coal usually consists of excavating the earth more deeply than does placer mining. Unreclaimed placer mines are common and very noticeable for their size and suffer from their visibility. Cases in point are at Marysville and The Malakoff State Park, California; Sunbeam, Idaho; Virginia City, Montana; and along Interstate 70 west from Denver to Glenwood Springs, Colorado.

Placers consist of weathered, dense materials that have been naturally concentrated. Tailings are not chemically active except where paleo channels are being mined. In that case, possible alteration can lead to the formation of new minerals that become unstable when exposed to weathering, or when chemicals are added to the mineral separation process. Placer tailings, being weathered, have the economic and environmental advantage of being chemically inert.

### 11.1.1 PLACER OPERATIONS

Placer operations, even today, can vary in scale from hand panning to the use of very large-scale equipment. They may be categorized as follows:

*Artisanal methods.* Dahlonega, Georgia, the California '49ers, Ballarat in Australia, the Klondike, and lately Sierra Pelada in Brazil are examples of gold rushes that started with artisanal, or hand mining. This method consists of panning or shoveling onto a sluice by an individual or a small group of people. In recent years, small dredges have applied suction to gather sand and gravel from a stream bed. These methods can treat a limited amount of muck, which may be as high 50 $m^3$ per hour, but is commonly about 5 to 10 $m^3$ per hour. The environmental impact from artisanal placer mining is usually minor; however, numbers of these small operations in a restricted area can have a major effect on a stream and its aquatic life. The subsidiary effect of unregulated cutting down nearby trees for living quarters, fire wood, and sluices can destroy a watershed.

*Small-scale mining.* A step up in size from artisanal mining is the employment of small equipment both for mining and then processing the placer material. Mining may be accomplished by bulldozer, front-end loader, back

hoe, or even dragline. The accompanying small process plants are usually skid mounted for ease of mobility. These units treat from 50 to 1,000 $m^3$ of material per hour. One type unit, known as a "doodlebug," can either be land based or floating. It consists of a trommel or punched plate screen, sluices or jigs, and a stacker. Consequently, the doodlebug can be used to reclaim as it excavates. A method employed in the Far North, where the working season is between 100 and 180 days per year, is the Ross Box. Placer feed is dozed onto a ramp where high pressure water streams clean and move the unscreened muck over a metal sluice run. As an alternative a vibrating grizzly may be employed with a sluice.

*Large-scale mining and processing.* Conventionally, a floating bucket ladder dredge is used for large-scale mining in the 150 to 1,000 $m^3$ per hour range. The dredges are mobile, self-contained mining and processing units. Buckets are attached to a continuous chain mounted on a supporting frame. Each bucket weighs from 0.5 to 4.0 tons, and can dig and carry 125 to 1,000 kilos of gravel to the dredge. Although a few dredges will dig deeper, most dredges dig from 10 to 30 m below the water surface. Process equipment consists of trommels, jigs, and tables, which is followed by a stacker. Properly handled from the stacker, an adequate job of reclamation can be accomplished.

*Other methods.* At various times in the past a variety of other methods have employed to mine placers. These include hydraulicking and underground techniques. Hydraulic placer mining is now rarely done in the United States due to the environmental difficulties of dealing with the waste material. **Sect 2.3.2** deals with the problems encountered in California over a Century ago.

### 11.1.2 CURRENT OPERATING PRACTICES

Large-scale placer mines normally handle ore of low unit value. This ore is more easily broken than at hardrock mines, and the recoverable minerals have usually already been liberated from their host rock. Consequently, the processing of placer minerals, particularly when realized on a large scale, has low unit costs. Gravity separation in water, and sometimes in air, is the economical process normally used for placer mineral recovery. Fortunately, air and water, by themselves, are not pollutants. The environmental problems caused by the usual forms of placer mining (as described above) arise from the sorting of material to separate ore from gangue, rather than from any deleterious substance within the ore. This separation often results in the release of suspended material. Past, and even present, use of mercury has caused environmental problems.

To minimize mining and separation costs, materials are moved only as far as is absolutely necessary. This can result in a mined- out area that is an eyesore and in which the natural ecological balance has been heavily altered if not destroyed. In hydraulic mining and dry open pit types of placer mining, poor mine planning and lack of reclamation can result in the same problems associated with any other form of uncontrolled surface mining. Placer operations in water may even be more environmentally disruptive to the on- site or nearby streams or lakes and their supporting aquatic life. In dredge mining and other underwater placer mining methods, it is least expensive for slurries of sand tailings to be deposited closest to the mine face, gravel to be deposited farther away on the sands, and barren cobbles and boulders to be deposited farthest away on the gravel. If a future supply of nicely segregated sand and gravel is desired, this is the correct way to leave the tailings. The resulting hillocky surface of tailings will not erode, but it will be a poor host to vegetation. While surfaces like this have resulted from placer mining, it is not necessary to leave such a surface behind. Processing can be altered and stacking partially controlled to change the location of at least part of the deposition of fine and coarse tailings. However, a change in method will increase operating costs, and the engineering work necessary to prevent the problem must be completed before operations begin.

A second problem for most placer mines results from slurrying placer ore and water. Continuous movement of the mine face and the need to use large quantities of water make the problem especially serious. Some clays and fine organic materials do not settle out of suspension easily to yield a clear mine effluent, and some are so difficult to settle as to preclude placer mining where the regulatory standard is high and the mine cannot avoid discharging process water into external waterways. Usually, however, placer slimes (fine clay and organic material) can be settled and the water brought to a satisfactory condition in large retention areas with wide spillways discharging shallow flows. Simple tests of pilot plant slimes will give the settling time, degree of compaction, and maximum velocity of water the slimes can take without breaking up. This information can then be incorporated into the design of settling areas for slimes that settle normally. Storm flows must also be allowed for.

Although gravity separation is the most common form of placer mineral recovery, gold placer recovery has traditionally also included the use of mercury amalgamation at the mining site for final gold recovery. Kept covered with cold water, never touched with the bare hands, and treated as the toxic substance it is, mercury in high concentrations should not be a danger. However, if it escapes into the environment it then becomes an insidious threat to life.

Placer concentrates are often removed from the mine face to some central metallurgical plant for upgrading by

more sophisticated methods of concentration than gravity separation. Magnetic and electrostatic separation are the most universal forms of further concentration for placer minerals, but grease tables, heavy media, flotation, cyanidation, and other chemical means of concentration can be used as well. Those processes are not unique to placer mining and are therefore only mentioned in passing.

## 11.2 PERMITTING AND RECLAMATION PLANNING OF PLACER DEPOSITS

**by R. C. Pease**

### 11.2.1 PERMITTING

Permitting of placer mines in the United States is governed by federal, state, and local laws under the same process that controls the permitting of lode mines. Permitting is a collective term that can mean the issuance of a specific permit, a series of permits, or the approval of a plan of operations instead of a permit. Permits may be required for specific segments of a placer operation, and the types of permits needed may vary, depending on whether the proposed project is located on government or private property.

The scope of environmental review deemed necessary for a project depends on the size of the project, land ownership, the sensitivity of the project, and regulator's policies. Large projects situated on federal land can require preparation of thorough environmental impact statements with public comments as dictated by the National Environmental Policy Act (NEPA), while small projects are frequently approved following completion of less formal environmental assessments. A full discussion of general permitting regulations can be found in the Second Edition of *Surface Mining*. Most states have adopted laws equivalent to NEPA that apply to projects situated on private land. In California, for example, the California Environmental Quality Act (CEQA), governs the permitting of projects on private land, and the local governments are the lead agencies of that process. After permits are approved, these local governments share the compliance enforcement responsibilities with state and federal regulators.

Once a plan of operations has been approved (or a use permit granted) the operator must obtain all necessary accessory permits (water quality, building, etc.) many of which must be secured before the operation can start. Specific design and engineering details may have to be submitted with these permit applications. The prudent project proponent should determine which agencies will issue such permits and estimate the amount of time it will take to obtain them well before submitting the necessary applications.

A critical path chart is a convenient way to illustrate permitting, along with operational time schedules, because conflicts that can cause startup delays readily become apparent. An environmental critical path chart should list the permits that have to be obtained, the tasks that have to be undertaken, and the projected dates on which they will be (hopefully) approved. This chart shows the estimated dates that permits will be in hand, plus the times that other compliance activities can be undertaken, so as not to delay mine construction and operation.

#### 11.2.1.1 Air Quality

Placer mines may use heavy equipment for earth-moving that can create the potential for dust emissions. Operations using chemicals in ore processing and refining are regulated under federal or state laws. However, relative to lode mines with extensive milling needs, placer operations usually have very minor air quality impact. Air quality permitting and monitoring are evaluated on a site-specific basis to assure that operations comply with air quality standards.

The two permits usually required are the authority to construct and permission to operate. The operating permit might require monitoring of dust particulates or diesel or other fumes. Meteoric information (precipitation amounts, wind speed and direction) can be required for interpreting air quality data.

Mitigating measures are available that adequately address air quality concerns. Chemical vapors can be mitigated through the installation of scrubbers in smelter stacks of processing plants and the utilization of heavy equipment containing built-in or attached emissions control packages. Dust control measures might include watering roads or using biodegradable polymers.

#### 11.2.1.2 Water Quality

Since placer mines commonly occur in alluvial plains or lowland areas near rivers, lakes, and other surface water, where the groundwater table is near the land surface, there exists the potential for water quality degradation. This concern becomes more important in placer mines that utilize large quantities of water during gravity concentration of ore, because that water has to be treated, stored, or disposed of. New operations on previously mined land may find that the hydrological environments of shallow aquifers have been altered such that the migration of turbid water might occur more easily than anticipated. This occurs at dredgefields where permeable gravel tailings have been deposited into groundwater on top of less permeable sand tailings and un-mined ground. As the dredge pond becomes turgid, the effluent water might migrate rapidly through coarse gravel tailings, slowly through sands, and very slowly through un-mined

ground. The mine operator should carefully evaluate ground and surface water flow direction and permeabilities to assess the potential for water quality impacts, and design protective measures into the mine plan. The aspects of water quality that are of major importance to placer deposits are described below.

#### *11.2.1.2.1 Sedimentation*

By far the most important water quality concern in placer mines is sedimentation of downstream waters. Sedimentation pollution is most likely to occur from discharge of high density waste slurries and seepage of turbid water into shallow aquifers followed by migration into surface streams.

Placer effluent limitation guidelines were added to the US Clean Water Act in 1988 as part of the Ore Mining and Dressing regulations. In addition, state laws limit the amount of turbidity added to water as measured to upstream (ambient) levels. Allowable limits will be specified in National Pollution Discharge Elimination System (NPDES) permits issued for each project and they may vary from state to state. It should be remembered that monetary fines can be imposed for violations of effluent standards.

Preventive measures should include careful design of settling ponds to contain sediment. Settling ponds should be located as far away from surface water bodies as possible. Waste slurries act as natural liners of settling ponds, having a tendency to fill in voids in gravel with silt and clay particles. Over time, permeabilities will decrease, especially in the bottom of such ponds. Extra pond storage volume must be able to accommodate large precipitation events and handle storms of specific duration and intensity. The NPDES permit will usually specify whether or not pond sizing must accommodate design storm events.

#### *11.2.1.2.2 Concentrates*

Most placer sediments that comprise an orebody contain small quantities of "heavy minerals" that usually amount to less than one percent of the total ore volume. Gravity separation of the heavy minerals produces a concentrate, informally termed "black sand." Black sand may contain other heavy metals in addition to the ore mineral. The type and percentage of minerals in the black sand component will vary on a site specific basis.

In US deposits, iron sulfide makes up the bulk of the heavy metals. It is not directly considered to be a dangerous mineral, although indirectly it can lead to the formation of acid mine drainage. Naturally occurring metals that may appear in trace amounts can include copper, lead, cadmium, and arsenic. To evaluate the contents of metals in concentrates, representative samples of black sands should be taken during the design phase of the proposed project and submitted to a certified laboratory to be analyzed for concentrations of total and soluble metals. In most cases, the metals within the ore concentrates will be inert, and so, even if the total metal values are high, the soluble metal fraction will be very low, and therefore will not pose a pollution danger. The soluble concentration is of greatest importance, because it is that fraction that can be leached out of the rock and into surface water and groundwater. While the chances of finding naturally occurring toxic levels of metals is low, NPDES permits sometimes require mine operators to monitor effluent water as a preventive measure. In addition to toxicity concerns, sulfide-rich concentrate piles need to be properly managed and stored in a dry condition to prevent precipitation seepage and runoff that might cause oxidation, acidic drainage, and increased metal solubility.

Processed concentrates found to contain toxic minerals and metals in excess of allowable limits must be stored and transported in accordance with state and federal hazardous materials regulations. However, because toxicity levels of concentrates rarely exceed allowable limits; conventionally, they may be permanently stored on-site. Exceptions arise when processing reagents are added to the concentrates and cannot be totally removed.

#### *11.2.1.2.3 Dewatering*

Dewatering placer mines by pumping poses a legitimate concern for the quality of nearby streams and aquifers. If the water pumped from a mine cannot be stored on-site, which depends on the "net" rainfall, it must be discharged to surface waters that flow away from the mine and off the property, or to containment ponds where it can percolate into the ground. Through infiltration, this water may contact aquifers. The quality must be acceptable if it is to be commingled with other waters. Problems arise when the general chemistry of the water pumped from the mine differs from the receiving water, or when the mine water contains a deleterious element (i.e. arsenic) in excess of allowable standards. Furthermore, governing agencies are concerned about the impact of mine water discharges on downstream fish and wildlife resources. When setting maximum discharge limits for streams that are known to be fisheries, NPDES permits might use more stringent limits than human drinking water standards. (Note: conventionally the US EPA requires waters to be "swimmable, drinkable, and fishable," with the last criterion tending to be the most difficult to attain.)

Prior to applying for an NPDES permit, background data should be gathered on ground and surface water chemistry and aquatic life around the project site. The prospective operator should sample both the mine water and receiving water and determine the concentration of key generally occurring minerals and metals. In addition

to exposing a potential problem, permitting agencies will sometimes request a background test prior to accepting an NPDES application. NPDES permits may also require a water chemistry ongoing analysis of ground and surface waters during the mining operation.

#### *11.2.1.2.4 Chemicals*

The potential for industrial chemical contamination led to the adoption of federal regulations requiring spill prevention and control and emergency response plans. Recently, most state and local governments have developed similar regulations. These plans should be developed by or for the mine operator and then submitted as part of the application for NPDES and operating permits. Chemicals that might be addressed in these plans include processing agents and petroleum fuel products. Detailed descriptions of the treatment, monitoring, and disposal of wastes derived from these products have to be stated in these plans.

### 11.2.1.3 Hydrology

In placer mining, where the groundwater table must be lowered to reach relatively deep ores or in which the aquifers are shallow, hydrological impacts to the surrounding region can be of importance. In addition to the water quality impact described above, mine dewatering might cause the groundwater table to drop around the mine. While dewatering may be an important environmental concern, it also adds operating expense and is therefore important to project economic feasibility. Because placers tend to be situated in sedimentary aquifers, the volume of water being removed can be quite large. Therefore, the operator should determine if mine dewatering will reduce nearby stream flows, or if water supply wells on adjacent properties will be affected. Both the operating expense and the environmental concerns can be assessed with an aquifer drawdown test. Testing of the aquifer usually requires the installation of a pumping well and one or more monitoring wells. Well test pumping is conducted on a continuous basis over a long period of time to cause drawdown in the monitoring wells. Various aquifer parameters, such as transmissivity and hydraulic conductivity, are calculated from the pump tests, and the volume of groundwater to be removed is estimated. Water chemistry can also be sampled during these tests. Following the test and based on the derived parameters a mine dewatering program and schedule can be designed which will include the method (dewatering well, pumping a pond), and pump sizes and locations. The need for hydrological studies to satisfy an environmental impact report should be determined prior to submitting a project application.

### 11.2.1.4 Wetlands

Wetlands are of interest to placer miners because alluvial deposits tend to occur in lowland regions near water where wetlands form. Permits to disturb wetlands are granted by the US Army Corps of Engineers through Section 404 of the Clean Water Act. Marginal wetlands are difficult to identify and have been the focus of governmental interpretation, a problem that has been compounded by the fact that the regulations are currently in a state of evolution. The federal government has generally maintained a no-net-loss policy, meaning that any wetlands that are destroyed must be replaced with other wetlands of equal or greater size. Accomplishing this requires mitigation plans that must be submitted as part of the Section 404 permit application.

Research into wetlands replacement has resulted in successful mitigation of habitats disturbed by mining. Settling ponds have been found to be suitable for reclamation as wetlands, and other topographic depressions can be planted into wetlands if situated near the water table or a surface water source. At the present time, construction of artificial wetlands can be potentially troublesome to the mine developer if the post-mining use of the land subsequently requires excavation of the newly developed wetlands. If this is the case another permit might have to be obtained and a new mitigation plan developed.

### 11.2.1.5 Stream Bed Alteration

Modifications to stream beds and installations of stream crossings, constitute alterations that may require special permits. Stream beds can be an important consideration in placer mining because dredges work in such riparian habitats and they may have to be traversed or diverted and mined. Some states, such as California, have their own government agencies that enforce stream disturbances.

### 11.2.1.6 Storm Water Permits

In 1990, the EPA finalized regulations that require industrial facilities to have storm water permits pursuant to the Clean Water Act. They went into effect the following year, and some states have already adopted their own versions of the regulations. The purpose is to direct precipitation runoff through industrial facilities so as to prevent pollution.

The policies require operations to have water pollution prevention plans plus proposed monitoring programs. Monitoring is approved in the NPDES permits. Mining operations in which storm water discharges do not contact overburden, products, or wastes can be exempted. The impact of these new regulations on placer mining is unknown at this time, but it would appear that erosion and sedimentation will be the issues

of most concern to placer operators when developing these plans. Routine erosion control practices may prove to be satisfactory preventive measures.

#### 11.2.1.7 Noise

In regions where residences are situated near mines, noise impacts have to be addressed. Although not specifically developed for mining, some local governments have noise policies that set maximum allowable levels. These levels are usually tracked during mining at a receptor location, such as a residence, and if a complaint is filed the mine operator has to correct the problem. While noise mitigation has generally not been a serious concern to the mining industry, municipalities have developed alternatives that allow business enterprises to exceed maximum noise levels through the purchase of noise easements. The operator negotiates an easement with the impacted neighbor and pays a fee.

Heavy equipment manufacturers have improved noise attenuation on most types of mining equipment, including drills, so that optionally purchased "noise packages" can make a significant reduction in overall noise levels. Drills, for example, can be equipped with special mufflers and sound attenuation blankets. Even straw bale walls or insulated plywood have been found to make a significant noise reduction. Natural topographic barriers, such as hills, also help reduce project noise and, if possible, should be considered in noise reduction design.

### 11.2.2 RECLAMATION PLANNING

Reclamation plans are required for domestic mines as governed by state reclamation laws. Reclamation plans for placer and lode operations have many of the same general needs, such as topsoil salvage, recontouring, revegatation, and financial assurances. This sub-section addresses concerns that are pertinent to placer mine reclamation planning.

#### 11.2.2.1 Post-Mining Land Use

Before the reclamation plan is designed, the post-mining land use should be determined so that the reclamation work prepares the site for that end use. If the future land use cannot be determined up front, then the general type of use (such as open space or even intense development) should be known. Studies that predict changes in future land value might be useful when deciding the end use of the land. For example, if a mine is to be located near a population center and growth is expected, then reclamation as a housing development might be attractive. In an unpopulated region, reclamation as an open grassland might be appropriate. Another important consideration is whether or not the site should be kept available for future mining. When considering land use alternatives, local government land use and zoning laws should be reviewed to see if the proposed end use will comply with existing zoning, because in environmentally sensitive areas zone changes can be difficult to obtain.

#### 11.2.2.2 Bonding

Financial assurance obligations should be assessed when designing reclamation plans. Surety bonds may be required to cover the cost of restoration to satisfy the end use, or they may only be required to cover erosion control. They usually have to be posted prior to startup of earthmoving. Because of this, concurrent reclamation can be beneficial because it allows for incremental bonding, so that total bonding requirements need not be posted at one time. The method of bonding (letter of credit, certificate of deposit, see Chapter 16) should be determined as soon as possible, because it may influence the final design of the reclamation plan. If a large amount of money, or credit, has to be deposited up front because an insurance policy is not attainable, the mine operator may opt for a low cost post-mining land use.

#### 11.2.2.3 General Design Considerations

Reclamation design is discussed very thoroughly in the Second Edition of *Surface Mining Handbook*. Listed below are general aspects that are of greatest importance to those involved in placer reclamation on previously mined or even unmined properties.

##### *11.2.2.3.1 Drainage Design*

Drainage can either be restored or diverted with properly designed new systems that will control runoff and adequately drain the post-mine landscape during major storm events.

##### *11.2.2.3.2 Recontouring*

If the area will have to be recontoured, the operator must determine the desired result. As an example, recontouring to establish a forest can accommodate a much different topographic design than that for a housing development.

##### *11.2.2.3.3 Swell and Compaction*

Loosened ground has a bulking capacity that should be considered when determining post-mine topographic elevations. In addition, the mined and even processed materials tend to compact somewhat over time after they are in place. In California placers, a maximum swell of 30 percent is probably a reasonable average. Certain operating procedures can reduce swell, such as mixing

fine sediment with coarse gravel tailings. While this will add significantly to operating costs and may even be mechanically difficult to achieve, it reduces swell.

In rural land, machine compaction of the soil base layer near the ground surface is usually not desirable and can inhibit successful revegetation. It also will add a large cost to reclamation. An intense land use, such as a housing development, might require compaction, and this need should be factored into pre-project reclamation costs.

#### *11.2.2.3.4 Revegetation*

The type of vegetation planted during reclamation should be guided by the intended post-mining land use. The monitoring of the revegetation program depends on that use. For example, revegetation for the sole purpose of erosion control should require much less management than returning land to prime agricultural condition.

#### *11.2.2.3.5 Test Plots*

Test plots may be needed to determine the types of plants that will succeed and to estimate maintenance needs. Such plots should be planted to provide data for at least one year prior to starting reclamation.

#### *11.2.2.3.6 Concurrent Reclamation*

It is generally more feasible, economically, operationally, and aesthetically, to reclaim a portion of a site each year than to wait until the end of the operation. This allows heavy equipment and personnel to be utilized more efficiently for both mining and reclamation. Furthermore, the appropriate regulatory authorities may also insist upon this practice.

#### *11.2.2.3.7 Settling Ponds*

Ponds can be revegetated in place, using clay as the soil base. Grasses and wetlands-type plants may succeed on such ponds.

### 11.2.2.4 Previously Mined Land

Special design problems occur when reclaiming previously mined land where topsoil was lost, the landscape rearranged, and drainage altered. Reactivation of mining in dredgefields where bucket line dredging occurred and in hydraulic mining areas are two examples. The most difficult aspects of reclamation in these situations are the mechanics of creating a surface sediment layer that will support plant growth and recontouring the site for future use.

#### *11.2.2.4.1 Dredging*

Bucket line dredging has been a successful placer mining method in the United States since the beginning of the 20th Century. In some locations, billions of cubic yards of material were mined. Large-scale dredging usually creates four types of waste: 1) cobblestones that pass over the grizzlies; 2) coarse gravel (greater than one-quarter inch in size) that does not pass through a trommel screen and is discharged via a stacker; 3) sand and silt jig or sluice tailings; and 4) clay wastes that are pumped into settling ponds. The normal mining method results in the deposition of sand wastes at the bottom of the dredge pond and coarse gravel wastes on top of the sands with the resulting surface landform being a thick layer of gravel absent fine sediments.

Experiments in California have indicated that fine sediments (jig tailings) can be emplaced into the gravel by pumping in an effort to fill the gravel voids with sediment. Due to operating constraints, this redeposition will not maintain a consistent thickness, and further it will not provide an ideal medium for revegetation, although the resulting surface layer of sandy gravel may support a sparse cover of grasses and legumes. This approach is most useful where the operator intends to improve the stability of the gravelly tailings for an intense land use such as building development. The presence of the gravel is desirable for revegetation because it tends to prevent runoff and erosion while it also insulates the plant roots. A better situation is where the jig sands can be removed from the new mining areas as overburden and then deposited on top of coarse gravel tailings, which results in a thick gravelly sand layer suitable for building or recreational uses.

Another option is to pump settling pond clay onto the coarse gravel stacker tailings. Berms would be required to contain the sediments and the dozer cuts would be relatively high. This alternative would be most applicable in areas where settling pond space is limited. An eventual ground cover of grasses can be successfully established on such material, and in some regions even wetlands- type vegetation can be established.

#### *11.2.2.4.2 Hydraulic Mines*

Reactivation of underground or surface mines on old hydraulic mine sites poses another type of reclamation challenge, because topsoil has been lost, leaving an existing land surface of exposed in situ native sediments. Reclamation testing in California has shown that native sediments will support sparse plant growth that can reduce the overall erosion potential and improve the

visual appearance of the landscape. Thus, in old hydraulic sites where re-mining occurs the best reclamation practice for developing a soil base layer may be to make sure that a layer of native sediments containing sand, silt, and clay is placed over any tailings and is used as a substitute for topsoil. To enhance revegetation mulch and amendments may be added. Tests have indicated that gravel is necessary in these materials for successful plant development because the gravel insulates the plant roots.

#### 11.2.2.5 Regulatory Involvement

Regulatory personnel who do not understand the difficulty of reclaiming previously mined areas may overestimate the potential success of such efforts. Suppose, for example, a historic placer mine that contains no topsoil is surrounded by prime agricultural land. It would be futile to require the remining operator to reclaim the site to compare with the agricultural surroundings. Indeed no operator should agree to guarantee successful reclamation in this situation. Reclamation with sparse ground cover for erosion control as open space would be more practical. Regulatory agencies should not expect impractical results when the terrain conditions are not suited for it. They must use common sense when reviewing and approving reclamation plans for previously hydraulically mined areas.

## 11.3 NEARSHORE ARCTIC DREDGE MINING

**by P. C. Rusanowski**

### 11.3.1 BACKGROUND

Offshore dredging for gold has been of interest in Alaska since the turn of the Century when gold was discovered at Nome. This interest initially focussed on the beaches for several miles around the city, but soon moved to wading-depth waters offshore. In a study of heavy mineral deposits of the EEZ, the Bureau of Mines (1987) summarized 14 major beach and offshore placer deposits. However, at least twice that number exist if one includes known occurrences and existing mining claims and leases. Only one of these, offshore of Nome, has been commercially developed on a large scale. Intermittent commercial beach placer mining has also occurred near Yakutat, on the northern Gulf of Alaska, and near Bluff on Norton Sound, east of Nome. Recreational placer mining still occurs today along the beaches at Nome, particularly for short periods after major storms in Norton Sound.

The only successful major commercial offshore placer mining occurred on State leases offshore of Nome in Norton Sound. Commercial mining was started on these leases in 1985 by Western Gold Exploration and Mining Company, Limited Partnership (WestGold). The WestGold mining operation lasted for six years and recovered more than 130,000 ounces of gold from less than 2% of the lease area. After the first year of production, WestGold used the mining vessel, Bima, in its operation. Although the Bima was the largest operating offshore bucketline dredge in the world, capable of recovering over 45,000 $m^3$ per day, it typically operated at less than 15,000 $m^3$ per day due to limitations related to shallow water depths in the leased area (Rusanowski, 1991). Although lasting only six years, this operation provided a wealth of geological, geophysical, environmental, and operational data for offshore Arctic dredging operations. The WestGold operation has also served as a model for offshore dredge mining and permitting by both the State and federal governments (Gardner, 1992; Rusanowski, 1991; MMS, 1991). Information presented in subsequent sections draws heavily upon the experiences gained from the Bima and WestGold's mining operation at Nome.

Most of the environmental information that exists for the marine environment has been gathered in association with marine tailings disposal from land-based mines. Several of these mines have been summarized as case studies by Ellis (1982, 1989). Most of these summaries illustrate an increasing awareness of the environment by the mining company, and a concomitant evolution of the tailings disposal methodology to reduce impacts and safeguard other marine uses in the vicinity. Recently, both the Bureau of Mines and the Minerals Management Service, respectively, have completed comprehensive reviews of submarine tailings disposal (Baer et. al., 1992) and environmental impacts associated with offshore mining (Hammer et. al., 1993). These two references provide excellent sources of published and unpublished materials, both having drawn extensively from company "gray literature," which is often difficult to locate.

Environmental concerns associated with Arctic offshore dredging tend to be similar to concerns expressed in other geographic locations. A comparison of issues raised by the Minerals Management Service in their EIS for the Norton Sound mining program (MMS, 1991) with environmental concerns for marine mining on the outer continental shelf ( Cruickshank et.al., 1987) show few differences. A list of typical concerns appears in Figure 1. These concerns can be broadly categorized into perceived use conflicts, biological ecosystem integrity, and physical disturbance. While it is easy to identify a list of concerns, it is much more difficult to determine which concerns need to be dealt with, and how to maximize limited environmental investigative resources in a dredging project.

**Figure 1** Typical environmental concerns associated with offshore dredging

- Entrainment
- Feeding impairment
- Attraction/avoidance
- Loss of benthic and epibenthic organisms
- Migration disruption
- Life cycle disruption
- Displace existing marine uses
- Smothering
- Dislocation
- Habitat destruction
- Ecosystem perturbations
- Trace metal bioconcentration
- Toxic effects
- Localized nutrient enrichment
- Turbidity/suspended sediments
- Localized anoxic conditions
- Changes in sediment characteristics
- Persistence of mine footprint
- Coastal erosion
- Shoaling/navagaion hazards
- User conflicts
- Noise and aesthetics

Concerns of this sort can be analyzed by use of an interaction matrix (Parsons and de L. Boom, 1974) to examine important interrelationships and linkages between the expressed concerns. An example of such an interaction matrix is shown in Figure 2 for a coastal marine ecosystem. Resolution of a concern, as discussed above, requires identification of the appropriate interaction to achieve any success. This type of interaction matrix clearly shows the importance of analyzing both physical/chemical and biological components prior to developing an observation program. By taking a more holistic, ecosystem approach, the importance of expressed concerns can more easily be related to physical/chemical and biological components that would actually be investigated during a dredging operation, and ultimately used to resolve an issue. Such an exercise will facilitate development of a monitoring program that, over time, will resolve concerns and issues raised during the permitting phase of the project; and ultimately lead to reduced study costs.

## 11.3.2 APPROACH TO MONITORING

There has been only one large-scale monitoring effort associated with offshore dredging in Alaska. In many ways, the Bima monitoring campaign set the standard for future programs (Rusanowski, 1991). It was used as the model for mining in federal waters offshore from Nome (MMS, 1991); and was the impetus for a federally sponsored workshop to consider both baseline and monitoring requirements for environmental concerns (MMS, 1990). The approach presented below builds on the Bima monitoring program and these studies to address a more holistic approach which stresses ecosystem relationships; physical and biological nature of impacts; identifies issues and concerns; and considers public policy in developing site-specific environmental monitoring plans.

### 11.3.2.1 Perceptions And Communication

In the past, the tendency of regulators and industry has been to focus on monitoring as an isolated end in the permitting process. Little effort was put into understanding what perceptions might be driving the regulatory issues or how public input related to the process. Permitting issues were largely left to the regulator to articulate, and industry then provided scientific rationale and developed necessary monitoring components to address these issues. However, currently in Alaska, as elsewhere, public perceptions are playing an increasingly large role in determining whether major industrial projects are approved, and in what form. Single issue or narrowly focussed interest groups have become extremely effective at using emotional rhetoric, providing selective information, and manipulating the public process to influence regulatory decisions and public policy. In short, if a mining company is now going to be successful in developing a project, including offshore dredging, public concerns and issues must be addressed early in, and throughout, the permitting process.

The key to working with public perceptions, single-interest user groups, and the regulatory community lies not so much in what you are doing as in what you are not doing. Today the focus is often on minimizing such things as disturbance, physical destruction, pollution, and risk. The relationship of these four factors to the business at hand, or whether it will have a positive environmental benefit, is often ignored. That relationship is the "cost of doing business", and if it is too high, the answer is "don't do business." In this type of a confrontational atmosphere, it is difficult to successfully support a project design based solely on economic, scientific or technological criteria. Such arguments need to be sold to the public and regulatory community prior to their application in a project. Knowledge of, and familiarity with technical and economic limitations in a project, can only be effective when there is a receptive forum. When a project is being evaluated for permits, a regulator may readily accept such criteria; however, public skepticism or opposition, regardless of merit, may have a greater influence on the actions of the regulator, and ultimately on the outcome of the

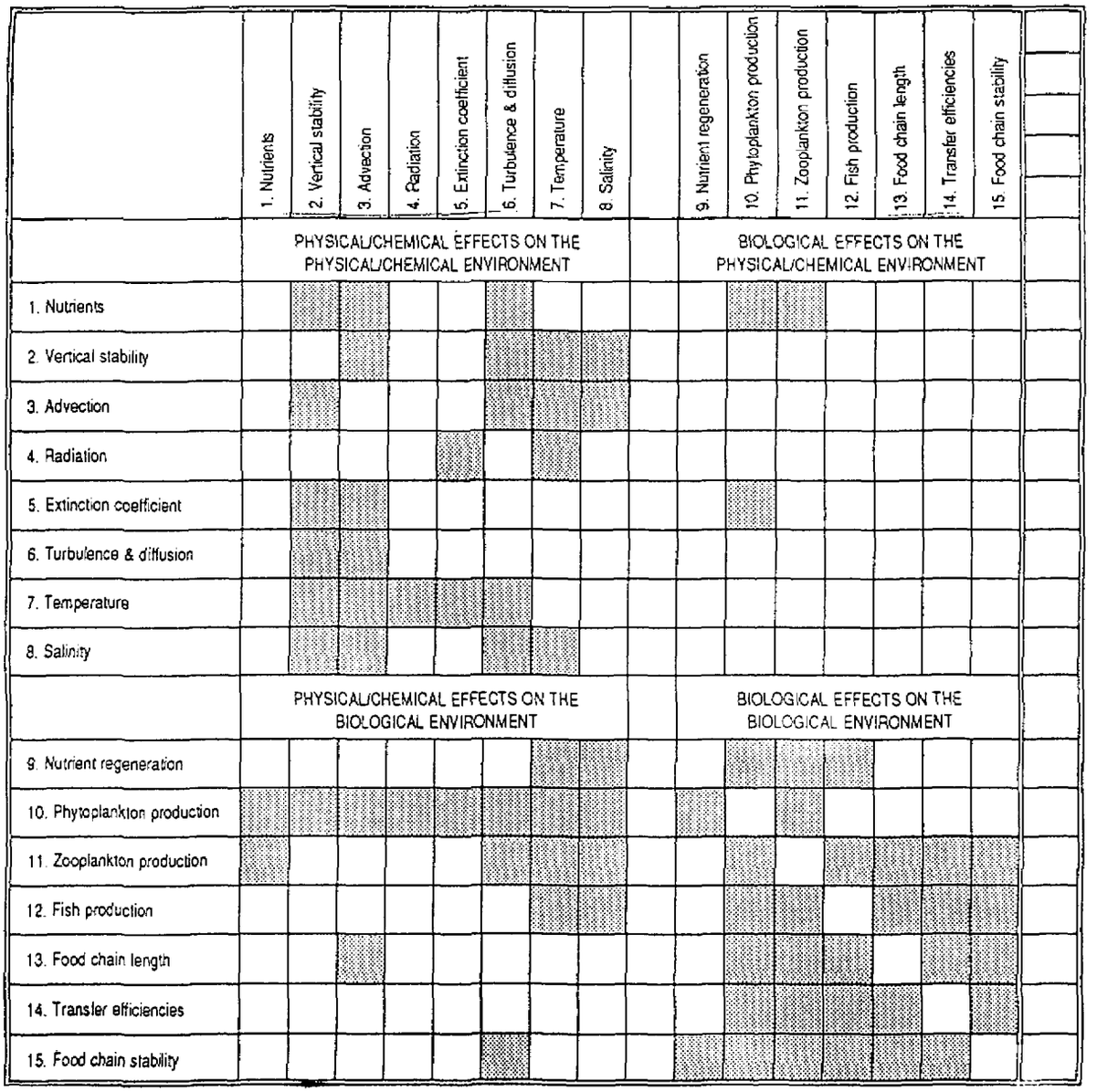



**Figure 2** Interaction Matrix for Fifteen Selected Physical/Chemical and Biological Factors Important to Marine Ecosystems (After Parsons and de L. Boom, 1974).

permitting process.

The missing component of the permitting process is an effective mechanism to communicate with both the public and regulatory communities. This communication is especially critical for projects with high public visibility or which generate considerable public debate. During the permitting of the Bima, a mechanism was developed that proved extremely effective in resolving this communication problem (Rusanowski, 1991). Specifically, a project review committee was formed to interact on a regular basis to review the project status (Figure 3). The committee was composed of representatives from all regulatory agencies, the mining company and its consultants, and local interest groups (native organizations, local government, and representative interest groups identified during the permitting process). This committee provided the mechanism for information exchange on a regular basis, both during the permitting process and after the dredging operation began. It provided an opportunity for interested parties to track the permitting and mining activity, comment on those activities, discuss monitoring requirements and review the ongoing results of those efforts, without compromising the responsibilities and

authorities of the regulatory agencies or delaying project schedules. Through discussion at meetings, unresolved issues and concerns were highlighted and subsequently acted upon, if needed, by appropriate agency authorities. The project review committee provided a necessary communication mechanism to ensure each interest group that their concerns and issues were both considered and resolved through the monitoring program.

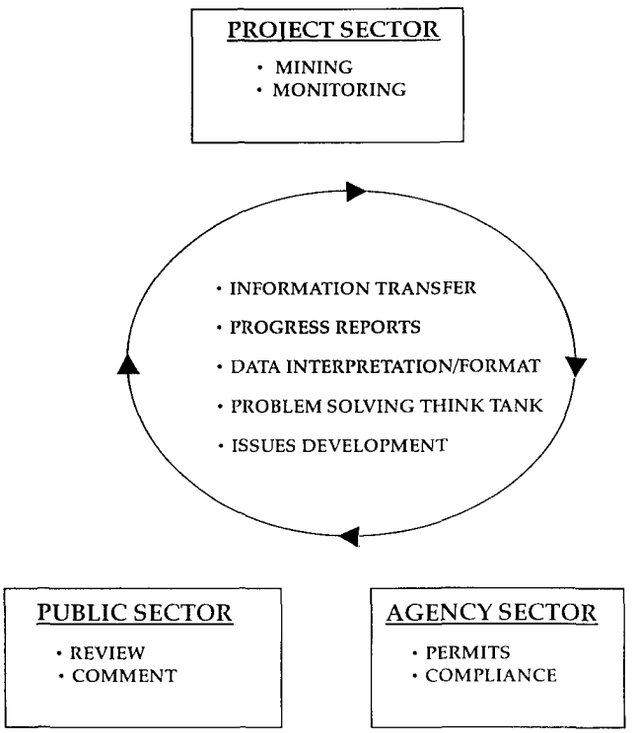



**Figure 3** Organization and Activities of a Project Review Committee.

**Figure 4** Typical components of an ecosystem monitoring/assessment program

**Physical/chemical components**

- Water: currents, chemistry, variability
- Sediment: particle size, surface relief, chemistry

**Biological components**

- Characterization of trophic level assemblages: carbon reservoirs, energy flow pathways
- Important species: biotic dependency, human dependency
- Pathways of contaminant movement: representative species, toxicity, exposure, bioconcentration

**Human health components**

- Subsistence issues
- Food source exposure
- Comparative health risks

**Monitoring components**

- Definition of monitoring issues: data gaps, issues and concerns
- Development of testable hypotheses
- Sampling program and statistical design: replication, power and efficiency
- Reference stations: baseline control, comparative/reference
- Modeling: assumptions, verification

### 11.3.2.2 Ecosystem Monitoring Program

To develop an ecosystem monitoring program, one must be able to characterize an ecosystem in terms of physical/chemical, biological and human components (Figure 4). These characterizations are initially developed from scientific literature, historical information, previous studies in the area, or other sources of data and information relevant to the project and geographic area. These components are then used to identify issues and concerns related to a particular project. Then, testable hypotheses are developed to address identified issues and concerns related to a monitoring program. Each of the components of an ecosystem monitoring program is described in the following sections.

#### *11.3.2.2.1 Physical/Chemical Components*

The two sub-components for which information is needed are water and sediment. With respect to water, a description of its movement and chemistry within the project area is needed. It is also necessary to know how variable this sub-component is with respect to diurnal variations, seasons, or episodic weather events. The most important variable regarding sediment is particle size, because turbidity is related to the percentage of silt and clay in sediments that may be disturbed by offshore dredging activity. Very large particle size (cobble, boulder) is another important variable. Finally, information is also needed on sediment chemistry to address potential concerns with heavy metals movement into surrounding waters, or other changes in water

quality related to sediment disturbance and resuspension in the water column.

#### *11.3.2.2.2 Biological Components*

In contrast to classical biological analysis and evaluation, which stresses individual species, an ecosystem monitoring approach deals primarily with trophic-level assemblages. Individual species are usually used as indicators of impact at a particular trophic level. Biological characterization of an area recognizes all trophic levels, but emphasizes those of most concern or those potentially impacted by a project. The ecosystem approach emphasizes importance by first recognizing those trophic levels, or groups of organisms, which comprise the largest biomass within that environment. These are referred to as carbon pools or reservoirs. Importance is also emphasized by determining the pathways of energy flow within an ecosystem; that is, identification of energy sources for the ecosystem and how it moves from one carbon pool to another.

While individual species are important, the ecosystem approach recognizes that many different organisms may occupy the same trophic level, and it is the overall response and resiliency of that trophic level to environmental stress that is most important in assessing project impacts. However, it is not possible to track all species at any trophic level. Therefore a subset of indicator species from important trophic levels is typically selected for inclusion in an assessment program. Species should be selected not only to represent a given trophic level, but also to represent species of perceived biotic importance (i.e., related to major routes of energy flow within the ecosystem), or species of direct human dependency. In the latter case, this may be species of commercial importance, or to other human uses within the ecosystem, such as a food source for marine mammals used for subsistence by a native community.

Another biological component that must be evaluated is pathways of contaminant movement. These pathways may be generic or nearly unique, depending upon the type, concentration and source of contaminant. In this evaluation, it is also important to select representative trophic-level species of concern, and to identify contaminant movement between trophic levels. Toxicity of potential chemical pollutants must be ascertained from literature or other sources to relate perceived concerns to our present scientific knowledge and expectation of environmental risk. Two of the important factors that must be included are the levels of exposure to a chemical in the ecosystem and the tendency of organisms to bioconcentrate the specific chemical to harmful levels.

#### *11.3.2.2.3 Human Health Components*

A unique element of the Arctic is the high use of natural resources for subsistence by native groups and rural populations. Often, the majority of dietary protein requirements are obtained from fish and wildlife gathered from the local environment. This fact makes subsistence issues and concerns of extreme importance in the permitting of a project. Sometimes potential effects on subsistence can be mitigated in the project design or operations. Oftentimes, however, the only approach is to include subsistence issues within monitoring programs to ensure that any effects can be recognized and corrected before subsistence resources are impacted. It is important, when studying human health issues, that subsistence uses be clearly delineated with respect to identified concerns, and the route and source of exposure be defined. Without such delineations it is unlikely that monitoring will resolve any of the subsistence concerns raised by agencies or the public. It is also important to characterize human health issues and concerns with respect to other health risks which are part of the local customs and community infrastructure. The only way to ensure that monitoring efforts are efficient and effective is to provide a comparative framework for evaluating perceived risks. Understanding the nature and extent of risks related to a particular project, in present community health risks, provides a framework to establish their importance and the need for incorporation into a monitoring program.

#### *11.3.2.2.4 Site-Specific Monitoring Components*

We have now discussed the gathering and integration of information related to an ecosystem into an evaluation program. This information provides the basis for developing a site-specific monitoring plan for a project. The purpose of a site-specific monitoring plan is to address and resolve issues and concerns raised during the permitting process which could not be adequately answered with existing information. As these issues and concerns are resolved during the monitoring program it would no longer be necessary to continue in its original form, and could be modified to address other issues, or eliminated. However, it should be noted that as part of the permitting process, monitoring requirements are also developed and stipulated which allow agencies to evaluate the project and ensure that it is operating in compliance with applicable laws and regulations. Such requirements are usually in place for the duration of a project.

The initial step in developing a site-specific monitoring plan is to identify the issues and concerns that need to be addressed, and any data gaps that pertain to them. With the background information from the previously discussed components, it is possible to develop specific testable hypotheses for each issue or concern. These hypotheses form the basis to develop a sampling program for the project. Selection of trophic

levels, species, and other elements is a function of the ecosystem information gathered in the previous components. However, it is important to include an intended statistical design within the sampling program. Many biological assessment programs fail to pay enough attention to replication of data and the power and efficiency of the sampling design, which leads to weak or inconclusive analyses or conclusions. Both the number of replicates at a station and the power of the data sets (ability to detect a statistically significant difference between two sets of data collected from one or more stations) significantly affect the cost and efficiency of a sampling program. These, and other requisite statistical parameters, should be established prior to initiating a study program.

While considerable effort is generally expended on the selection of sampling stations in a study program, relatively little effort is placed on the location of reference stations unaffected by project activities. In general, there are two ways to identify reference stations. One type of reference station is to locate a baseline or control site that will not be impacted by the project, yet is close enough to the operation to be part of the program. This is often quite difficult to do. There is also a measure of uncertainty within the control or baseline station data, since its similarity to the impacted area is never known precisely. At best the control site approximates the conditions found at the impacted area. Another approach is to establish comparative reference stations for a program. A comparative reference station is the more practical approach to develop an ecosystem monitoring program. The comparative reference station establishes the level of background noise occurring in similar areas of an ecosystem. One observes the natural fluctuations within an ecosystem and compares them to fluctuations seen at impacted stations to determine whether significant impacts have occurred and what part of the ecosystem is being affected. Recovery is measured by establishing that impacted areas exhibit patterns of spatial and temporal fluctuations similar to those observed at the reference stations. The emphasis is on patterns of change over time, reflecting typical ecosystem functioning, rather than on specific species presence or numerical dominance.

A final element that may be included in a monitoring program is modeling of various ecosystem components and project-related pollutants. Modeling most commonly involves assessments of toxicity or dispersion of a pollutant from a discharge source. The use of any model must be shown to be relevant to the project and issue being addressed. Both the assumptions used in the model and the actual data must be clearly defined and related to the project area. If possible, the model should be calibrated and field-verified to show that it reliably predicts parameter responses.

Modeling was employed by WestGold during its mining operations at Nome. Modeling was initiated by adapting an existing dredge spoil disposal model (DIFCD), that had been developed by the US Army Corps of Engineers (Johnson, 1988), to simulate the discharge from the mining vessel Bima. The model was modified, calibrated, and verified over a period of three years until it accurately predicted plume characteristics from the Bima (Demlow et al. 1989). However the modeling was then carried a step further to predict compliance with permit limitations based on operational conditions during dredging (Garvin et al. 1991). The modeling showed that the most important parameters affecting turbidity were current speed, silt concentration of sediments, and water depth. Using these parameters, nomographs were constructed to predict turbidity at the edge of the mixing zone (Figure 5). This technique provided a reliable mechanism to both predict water quality parameters at the edge of the mixing zone, and, if necessary, to modify dredging operations to stay within permit limits.

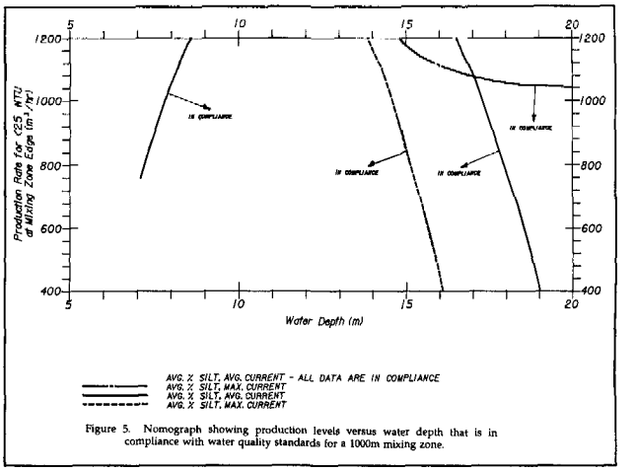



Figure 5. Nomograph showing production levels versus water depth that is in compliance with water quality standards for a 1000m mixing zone.

**Figure 5** Nomograph Showing Production Levels Versus Water Depth that is in Compliance with Water Quality Standards for a 1000m Mixing Zone.

### 11.3.2.3 Quality Assurance/Quality Control

A common shortcoming of many monitoring programs is the lack of well-developed and standardized quality assurance/quality control programs. The level of effort in this area often varies with the training, professional pride, and awareness of the importance of work performed. However, these plans are essential to the reliability and utility of data generated within monitoring programs, and ultimately to the credibility of the overall monitoring program. The purpose of such plans is to ensure that all data gathered in a monitoring program are

of sufficient quality to allow well-informed and meaningful interpretation.

The terms *quality assurance* and *quality control* have been used interchangeably in the past. However, quality assurance refers to a total program for over-viewing the reliability of monitoring data. Quality control is the routine application of procedures for controlling the measurement process, and is an internal process at the project level. Both are commonly included in a single quality assurance/quality control plan. Typical contents of such a plan are shown in Figure 6. With the high resolution of modern laboratory methods, it is necessary to have these plans for all laboratory analytical programs as well. Trace contamination of samples can occur from a wide variety of sources, especially in remote Arctic locations (Figure 7). Without a rigorous quality assurance/quality control program, monitoring data might only demonstrate poor technique rather than actual concentrations of contaminants in the environment.

**Figure 6** Typical topics for inclusion in a quality assurance/quality control plan

- Project description
- Personnel organization and responsibilities
- Quality assurance objectives
- Sampling procedures
- Sample custody/chain of control
- Calibration procedures and frequency
- In-house analytical procedures
- Contract lab analytical procedures
- Contract lab quality control plan
- Data reduction, validation and reporting
- Spedific procedures used to assess data precision, accuracy and completeness
- Internal quality control checks
- Performance and system audits
- Preventive maintenance
- Corrective action plan
- Quality assurance reports

### 11.3.2.4 Estimated Monitoring Costs

Monitoring programs are not only technically challenging in the Arctic but tend to be quite expensive compared to equivalent programs in temperate climates. This is due largely to the fact that little infrastructure exists to defray costs. Mobilization and demobilization costs are major components of all field programs, often running up to 30-40% of field program costs. Due to the remoteness of most project locations, logistics must consider all contingencies and have duplicate equipment for critical items. Transportation costs also tend to be considerably higher than one might expect since commercial air service is limited, forcing extensive use of charter aircraft. In many cases, travel is easier in the winter when surface travel can be accomplished by snow machine and off-road vehicles. Offshore work platforms must rely on local fishing vessels or be transported at considerable expense to the work location. This often requires modification of field programs to accommodate commercial fishing activities.

**Figure 7** Common sources of contamination associated with environmental monitoring programs

- Storage area
- Processing area
- Work plataform
- Sample containers
- Sample collection equipment
- Field storage containers
- Field techniques
- Wash water
- Acid rinse water
- Laboratory chemicals
- Inappropriate laboratory technique
- Inadequate quality control
- Inadequate quality assurance

Logistics costs tend to be highest for physical/chemical monitoring components. A single survey, involving high resolution bathymetry and side scan sonar for 10-14 days, can run 30-45% of program costs just to mobilize/demobilize the survey. Actual field day rates for such surveys typically run $4,000-$6,000, but can vary considerably depending upon actual boat costs. Analysis of data and reporting can run an additional 30-40% of field costs. For planning purposes, and to estimate a rough range of survey costs, it is convenient to use an estimate of $400-$800 per line-kilometer of data collected. Another way of estimating total program costs is to use a rough estimate of $10,000-$15,000 per field survey day, if the total survey duration is more than five days. However, actual costs can vary considerably, based on specific program requirements weather conditions and survey design.

Biological surveys can use a variety of sampling techniques. However, for benthic ecological surveys, scuba-diving techniques are usually employed when dealing with gravel and cobbles substrates. Sandy substrates may rely more heavily on remote grab sampling techniques. The use of diving techniques is

more labor intensive than grab sampling. Field costs for benthic diving surveys generally run $4,000-$5,000 per day. Use of remote grab sampling techniques can reduce that cost by as much as 50%. In either case, typical analytical and interpretation costs run $250-$400 per sample. Another way to estimate total program costs is to assume a cost of $900-$1,000 per sample collected. Fisheries and water quality sampling can generally be conducted for 40-70% of benthic survey costs. However, boat costs may vary due to differing survey requirements. Water quality analytical costs are highly variable and are dependent upon detection limits, procedures, and extent of quality assurance/quality control programs. Extremely low detection limits specified in some permits can necessitate using ultra clean field techniques which can increase sample collection and analytical costs several fold.

Modeling costs are extremely variable. The actual modeling effort is a small portion of the total cost. The most significant costs relate to acquiring appropriate data for the model. In the case of the Bima, more than $300,000 was spent on modeling. However more than half of that amount was devoted to acquisition of physical oceanographic and water quality data needed to perfect the model. Typical oceanographic data collection involves the use of instrument arrays that can cost $3,000-$10,000 per month, per station. Again, major additional costs are related to logistics to deploy and recover such instrument arrays and can add up to 50% of total program costs. Since the DIFCD model has been perfected for the Bima, similar applications would be considerably reduced since the model is non-proprietary.

Implementing a good quality assurance/quality control program can run between 10-20% of total monitoring costs. These costs are spread between all program elements, but are most easily computed for laboratory analyses, where approximately 10-15% more analyses are required to account for duplicates, blanks and control samples. This is also an up front cost, as the quality assurance/quality control plan must be put together prior to commencing a monitoring program. Such preparation costs can run $5,000-$10,000, or more, depending upon the magnitude of the monitoring program.

Putting all of the different elements together, a typical environmental monitoring program can cost $250,000-$400,000 to cover the basic components for a major dredging project. Physical monitoring accounts for 25-40% of these monitoring costs. With such high costs, it is essential to make sure that monitoring addresses a genuine project concern or issue. Public concerns and agency comfort with a project can have a great influence on monitoring costs. A monitoring effort is wasted if resolution of public and agency issues is not achieved. Over time, as issues are resolved, they should be dropped from a monitoring program. As new issues arise they should be incorporated, but only through the same rigorous analysis that occurred during development of the original monitoring program. In the long term, the environmental monitoring program should reflect only those elements needed to ensure that operations are in compliance with permit limitations. For small projects, this may be achievable within the initial permitting and review process, with a minimal need for monitoring. However, for large or complex projects it may take several permitting cycles or renewals, with extensive monitoring, to reach this point.

## 11.4 DEWATERING ALASKA PLACER EFFLUENTS WITH PEO

**by S. K. Sharma and B. J. Scheiner**

### 11.4.1 INTRODUCTION

In placer mining, gold-bearing gravel is treated in a washing plant to remove boulders, small rocks, sand, and fines while trapping the gold particles. This is usually accomplished by placing the gravel into a trommel or on vibrating screens where the gravel is sized from 0.5 to one inch. The undersized material is washed into a sluice box or some other recovery device, while the small rocks, sand, and fines flow off the end of the sluice box into a sump where a majority of the rocks and sand settle out. The water containing the fines and some sand flows out of the sump and into the existing pond system at the mine site. The rocks and coarser particles are removed from the sump on a regular basis by either a loader or dozer. In the pond system, the rest of the settleable material drops out leaving the fine grain silts and clays. This is commonly referred to as the non-settleable fraction of the gravel being treated. With time, more of the fine material will settle resulting in water containing ultra fine or colloidal particles that will remain suspended indefinitely. Release of this turbulent water into wells and streams is a potential source of contamination.

In the past few years, the effluents from placer mining have received considerable attention from a variety of agencies with regulatory authority, such as the Environmental Protection Agency (EPA), Alaska Department of Environmental Conservation (DEC), Department of the Interior Bureau of Land Management (BLM), and others. EPA has proposed regulations pertaining to water quality and DEC has issued regulations setting a standard for water discharge of 5 Nephelometric Turbidity Units (NTU) above the background of the receiving stream. BLM is enforcing reclamation standards on federal lands.

Based on proposed and existing regulations, the miner is faced with many operating and economic factors. To meet water standards, a large pond will be required to allow settling of fines. To build such a pond, the miner

must first have a suitable site, which may not be possible for all mine sites, and secondly, the miner must finance the costly operation of moving the required dike material. Operation of a loader or dozer has proved to cost approximately $100.00 per hour. Construction of a large pond requires considerable, costly earth moving. Another cost included in the requirement of a pond is the reclamation cost. Since this pond will become filled with fine solids that will not support land fill, reclamation will be difficult. Usually, smaller ponds are easier to reclaim, but small ponds will not provide the retention time needed to produce water by natural settling that is acceptable under the regulations. Therefore, the miner is faced with regulations requiring low-turbidity water as well as the cost of reclamation.

The Bureau of Mines, Tuscaloosa Research Center, has developed a unique dewatering method that removes the solids from the water (Scheiner, et al., 1985; Smelley, et al., 1980; and Smelley, et al., 1987). The technique consists of flocculating a waste slurry with a polymer and dewatering the resulting flocs on screens. Static screens and rotating trommel screens have been used alone and in combination depending on the material treated. The solids from the screens can be discharged into a pit or landfill and the water can be returned to the existing ponds to be recycled to the mining operation or possibly even discharged to the environment. This technique has been applied to a variety of mineral waste slurries.

The flocculating agent most commonly used is polyethylene oxide (PEO), a commercially available, nontoxic, water soluble, non ionic polymer. In a test conducted by EPA to equate the toxicity of PEO to aquatic organisms, it was determined that PEO was not acutely toxic (Cummins, et al., 1987).

### 11.4.2 PLANT DESIGN AND OPERATION

The Bureau-developed dewatering technique was field tested in Alaska for two summers. During the first year, tests were conducted at three different placer mine sites; Crooked Creek in the Circle mining district, Fairbanks Creek in the Fairbanks mining district and Olive Creek in the Livengood mining district. The flowsheet for the first year's test unit (Figure 8) was mounted on a truck. The waste slurry was pumped to the conditioner mixer (tank mixer) where it was mixed with a dilute solution of PEO. The water and flocculated solids flowed out of the tank onto the static screen, where the solids moved down the screen, while released water went through the screen and flowed to a pond for either recycling or discharge to the stream. The solids were stored in a pit where they continued to dewater, reaching a solids content high enough to be handled by mining equipment. The static screen was built in two sections of stainless steel wedge wire, each 8 ft wide and 4 ft long. The upper section of the screen had slot openings of 2.75 by 0.02 in. (L x W) and was at an angle of 58°, while the lower section had slot openings of 2.75 by 0.01 in. (L x W) and was at an angle of 50°.

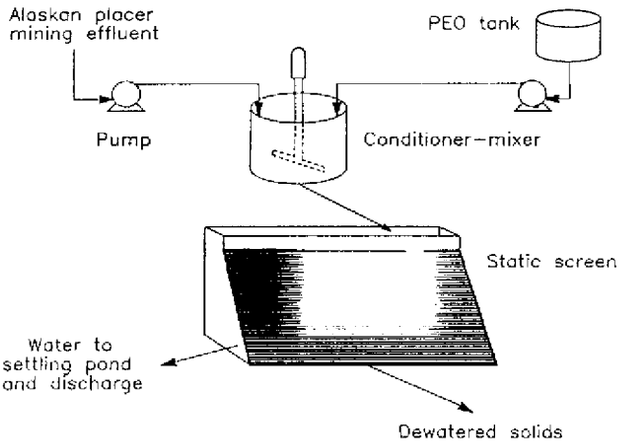



**Figure 8** General layout of the small-scale unit that was mounted on a truck.

The flocculent, PEO, was made in a mixer shown schematically in Figure 9. The mixer consisted of a tank equipped with a stirrer, a vibrating feeder to add the dry PEO, and a water spray system to wet the PEO particles as they fell into the tank. The flocculent was made as a 0.25% solution and was diluted to 0.01% or 0.02% solution in a tank for use.

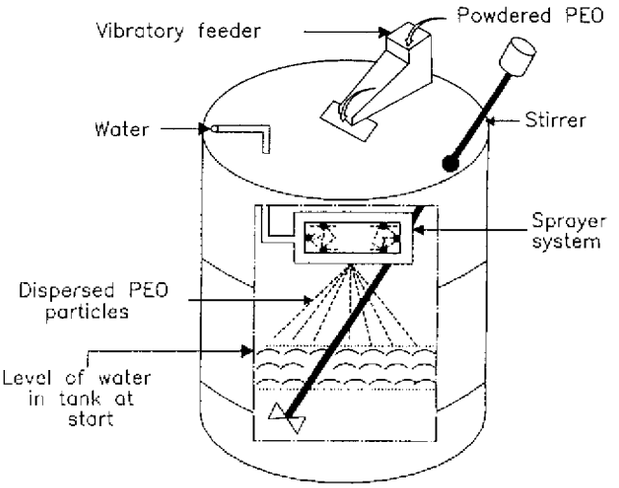



**Figure 9** Schematic of PEO mixer.

Based on data from previous tests, the flowsheet for the second summer was altered. As shown in Figure 10, a large unit was designed to handle up to 1,000 gpm of placer effluent. The main difference in this unit and the previous unit was the exclusive use of in-line mixing instead of tank mixing. A 6-in. pump with a capacity of about 1,100 gpm with no head pressure was used to deliver the waste slurry to the unit. PEO pumps with variable speed drive systems and with capacities of 45 and 20 gpm, respectively, were used to inject the PEO solution in-line by using 2-in.-diam pipe. Placer effluent was delivered to the system by 6-in. pipes of various lengths. A Kenics static mixer (2-10 elements) was used, when needed, to increase the turbulence in the pipe. (Reference to specific products does not imply endorsement by the Bureau of Mines). The flocculated slurry was emptied into a trough at the top of the screens and overflowed onto the screens. The water went through the screen into a trough and was allowed to flow by gravity into the secondary pond. The dewatered solids rolled down the screen and discharged into a pit. The screen was comprised of two sections, with the top section set at an angle of 47° and the bottom section at an angle of 38°. A common aluminum window screen, 16 by 18 mesh, was used as the screening device for the flocculated solids. The PEO stock solution was made as 0.33% rather than 0.25%.

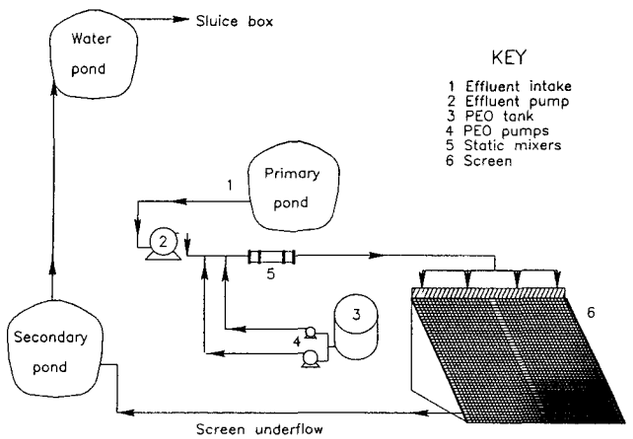



**Figure 10** General layout of large field test with a capacity to handle 1,000 gpm of placer effluent.

## 11.4.3 RESULTS AND DISCUSSION

### 11.4.3.1 Field Tests Of The First Year

#### *11.4.3.1.1 Crooked Creek*

The first test site was at the Gelvin Mine located on the Crooked Creek near the town of Central, Alaska. At this mine, 90-100 $yd^3$ were treated per hour with a water usage of 1,000 gpm. The material coming out from the sluice box flowed to a sump where most of the sand and gravel settled and were removed periodically by a front end loader. The waste stream continued to flow into a large pond where the rest of the settleables dropped out. The non-settleable slurry then flowed into an extensive tundra filter and was finally recycled back to the sluice box. The waste slurry treated in the dewatering unit was taken prior to the tundra filter and was fairly constant in terms of solids content (0.8 to 1.0% solids) and had turbidities of 4,000 to 6,000 NTU.

Initial tests showed that the non-settleable solids could be removed readily from the slurry on the unit with a PEO dosage of 0.05 to 0.10 lb of PEO per 1,000 gal of effluent treated. The turbidity of the underflow water from the screen was 200 to 400 NTU. To provide additional contact time between the PEO and the slurry, a new conditioner mixer was designed and installed on the unit. Tests conducted using this mixer showed that a PEO dosage of 0.026 to 0.058 lb/1,000 gal of the slurry was required to produce a screen capture recovery of 70 to 80%. The rest of the solids passed through the screen, but settled immediately in the pond to produce water with a turbidity of 200 to 240 NTU. Better results were obtained when a polymer additive, Catfloc T, was added prior to the addition of PEO to the conditioner mixer. The results in Table 1 show that the addition of 0.008 lb/1,000 gal of Catfloc T reduced the PEO dosage from 0.05 to 0.016 lb/1,000 gal and produced a screen underflow with a turbidity of 280 NTU.

**Table 1** Field test results at Crooked Creek

| PEO dosage lb/1000 gal | Catfloc dosage 1b/1000 gal | Turbidity of supernate NTU |
|---|---|---|
| 0.058 | NA | 215 |
| .026 | NA | 240 |
| .114 | 1.17 | 105 |
| .056 | .59 | 160 |
| .002 | .29 | 240 |
| .010 | .59 | 155 |
| .012 | .59 | 155 |
| .016 | .08 | 220 |
| .016 | .008 | 280 |

NA - Not applicable

#### *11.4.3.1.2 Fairbanks Creek*

The second test site was the Cook Mine located on the Fairbanks Creek. At this mine, 60-70 $yd^3$ were treated

per hour using about 1,200 gpm of water. The material was moved with a dragline, fed into a trommel to remove rocks, and then fed to a sluice box through a hydraulic lift. Water from the sluice box flowed into a primary pond where some of the water was recycled back to the sluice for reuse. Overflow from the primary pond flowed into a number of ponds in series before it was discharged into an overburden drain system. The dewatering unit was set up below the second pond.

Initial tests on this slurry showed that the tank mixer would not produce strong flocs, even after 16 by 18 mesh wire was added on top of the screen. Tests conducted using flexible plastic hose as an in-line mixer produced strong flocs and increasing the length of the hose increased the floc size and solids captured on the screen. It was also determined during the initial testing that different retention times were required for two types of mixers and for the different concentrations of the PEO. For 0.01 pct. PEO, optimum retention time was 70 to 80 s, while for 0.02% PEO, it was only 60 to 70 s. During the testing program, placer effluent with turbidities ranging from 150 to 3,100 NTU was treated. It was determined that PEO consumption increased as the solids content of the placer effluent increased. For example, when the waste water with a turbidity of 1,000 NTU was treated, a PEO dosage of 0.01 lb/1,000 gal was required to produce almost 98% screen capture and screen underflow with a turbidity of 30 to 40 NTU. However, when the turbidity of the sample was increased from 1,000 to 3,000 NTU, the PEO dosage required to obtain 98% screen capture also increased to 0.045 lb/1,000 gal.

#### *11.4.3.1.3 Olive Creek*

The third and final site selected for this project was the Geraghty Mine located on the Olive Creek near the Livengood district. At this site, the miner was handling about 60 $yd^3$ of gravel per hour and utilizing about 1,000 gpm of water. This mine had a series of settling ponds and recycled all of its water. In fact, because of the lack of water flow in Olive Creek, water was usually in short supply. The water management system consisted of a primary pond approximately 120 by 130 by 3 ft deep, where most of the sand and gravel settled out. This pond flowed into a secondary pond, 165 by 125 by 4 ft deep, where some settling of the fines occurred. Water from this pond was pumped to a third pond and from there water was used for the mining operation. This elaborate system had been used by the miner for the past eight years.

Based on the preliminary tests, it was determined that the tank mixer was not very effective in providing the best mixing conditions to produce high quality water at low polymer dosage. Therefore, the flow sheet was redesigned so that an in-line mixer could be used for the field tests. In this setup, the PEO was injected in the slurry line about 15 ft from the slurry pump. The mixing of polymer and slurry was produced by the turbulence created by a very high flow rate in the hose. As shown in Table 2, a PEO dosage of 0.01 lb/1,000 gal produced a supernate with a turbidity of 44 NTU and screen recovery of almost 98%. The feed solids varied from 0.38 to 0.55% whereas the turbidity ranged from 1,450 to 2,000 NTU. The data shown in Table 3, indicated that 0.01% PEO concentration gave superior performance when compared to 0.02% PEO. For 0.01% PEO, the dosage requirement was approximately 0.02 lb/1,000 gal while for 0.02% PEO it was close to 0.03 lb/1,000 gal. As previously effected at Fairbanks Creek, a 16 by 18 mesh screen was overlaid on the top section of the wedge wire screen.

**Table 2** Effect of PEO addition on unit performance at Olive Creek

| Feed % solids recovery | Feed water turbidity NTU | Screen Water NTU | PEO dosage lb/1000 gal | Screen % |
|---|---|---|---|---|
| 0.55 | 2,000 | 25 | 0.016 | 99 |
| .45 | 1,550 | 35 | .016 | 99 |
| .53 | 1,900 | 44 | .010 | 98 |
| .38 | 1,450 | 62 | .008 | 4 |
| .40 | 1,600 | 245 | .004 | 10 |

**Table 3** Effect of PEO concentration on dewatering efficiency, Olive Creek

| Feed % solids | Underflow turbidity NTU | PEO conc % | PEO dosage lb/1000 gal | Screen recovery % |
|---|---|---|---|---|
| 1.05 | 33 | 0.02 | 0.026 | 77 |
| 0.93 | 60 | 0.02 | 0.034 | 99 |
| 1.01 | 32 | 0.01 | 0.016 | 81 |
| 1.09 | 18 | 0.01 | 0.023 | 99 |

### 11.4.3.2 Field Tests of the Second Year

Based upon the previous year's results, the flow sheet for solids removal was altered and tests were conducted at Olive Creek near Livengood. At this site, the mine production rate was about 50-60 cubic yards and the water consumed was approximately 1,600 gpm.

The PEO was injected into the feed line upstream of the dewatering screen. In-line mixing through 400 to

1,000 ft of pipe combined with a wide range of Kenics static mixers (two to 10 elements) were tested. During initial testing on the primary pond, 600 ft of 6-in. pipe and the 2-element static mixer produced best results. However, when the unit was transferred to the secondary pond, 600 ft of pipe alone produced good flocs. In both tests, treated water was recycled back to the secondary pond. The feed, which varied widely in solids content from 0.09 to 6.0% and turbidity of 5,000 to 25,000 NTU, was dewatered using 0.01% PEO solution. The analysis of the solids in the placer effluent showed that there was a direct relationship between the feed water turbidity and initial solids.

The PEO dosage required to dewater this placer effluent varied with initial solids and was calculated in pounds per gallon of slurry treated. The PEO dosage required for effective flocculation increased from 0.06 to 0.15 lb/1,000 gal with an increase in initial solids from 1 to 4%, as shown in Figure 11. It was also found that the PEO dosage did not only depend on the initial percent solids but also depended on the Reynolds number, in the mixing system which is directly proportional to the slurry flow rate. The results shown in Figure 12, indicated that when the Reynolds number increased from 50,000 to 162,000, the PEO dosage decreased from 0.15 to 0.03 lb/1,000 gal. Finally, taking all the variables in consideration, it was found that a PEO dosage of 0.02-0.14 lb/1,000 gal was required to produce a dewatered product of 33 to 43% solids and screen underflow with turbidity of 20 to 50 NTU's, Table 4.

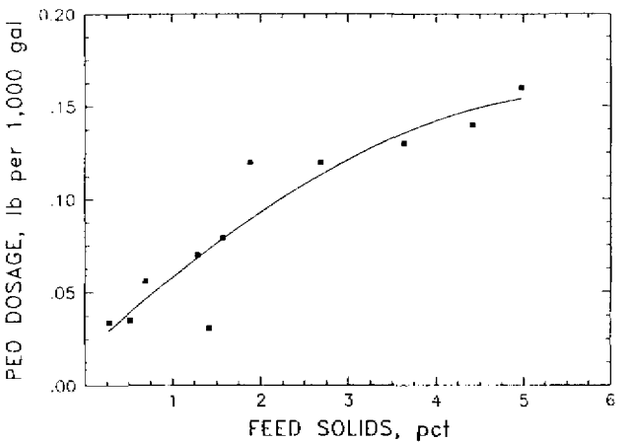



**Figure 11** Relationship between initial solids and turbidity of feed for Alaska placer effluent.

A cost estimate of the Bureau of Mines process for dewatering Alaskan placer effluent streams with PEO was determined and is reported in an open file report (Magyar, 1987). The cost estimates are for dewatering plants processing 1,000 gpm of effluent slurry at three representative turbidity levels. Both the placer and dewatering plants operate on the same one shift-per-day, six days- per-week schedule for the 100-day Alaskan operating season. Estimated fixed capital costs for these plants processing placer slurries with effluent turbidities of 1,000, 3,000, and 5,000 NTU are approximately $29,000, $31,000, and $34,000, respectively, on a fourth quarter 1986 basis (Magyar, 1987). Operating costs are estimated to be $0.34, $0.37, and $0.40 per thousand gallons of effluent slurry including amortization and chemical cost.

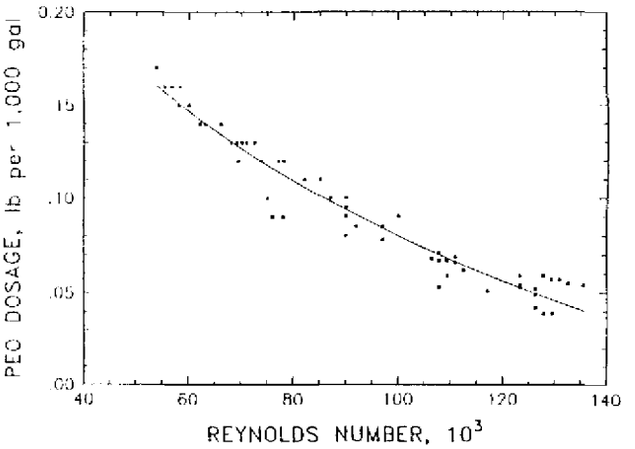



**Figure 12** Effect of Reynolds number on PEO dosage for the large field test unit.

## 11.4.4 TREATMENT OF OTHER WASTE SLURRIES

This dewatering process has successfully been applied to other mineral slurries such as coal, kaolin, drilling mud waste, mica, and crushed stone operations. Field tests were conducted on a coal slurry generated at mine sites in Alabama and Kentucky. Results of these tests showed that solids contents in the 50-60 pct range were obtained using 0.12-0.15 lb/ton of PEO. Results also showed that this technique can be used on a wide variety of drilling mud wastes. In this project, four different water-base and one oil-base drilling mud waste was dewatered. The water-base waste was dewatered from 0.3% solids to 62% solids using 0.9 lb/ton of PEO and the oil-base waste was consolidated from 57 to 72% solids with a combination of PEO, Percol and bentonite clay. Similar results were obtained with mica, kaolin, and bentonite waste slurries.

The results from field testing at two crushed stone operations showed that slurry from the impoundment pond was dewatered using 0.3 lb/1,000 gal of low-cost polyacrylamide and produced a dewatered product of 45 to 50% solids. This material continued to dewater after

**Table 4** Results of the field test at the Olive Creek, second year

| Mixer length ft | Feed turbidity NTU | Initial solids % | PEO dosage lb/1000 gal | Solids content % | Underflow turbidity NTU |
|---|---|---|---|---|---|
| 600[1] | 26,500 | 4.41 | 0.14 | 42.9 | 46 |
| 600 | 26,000 | 5.40 | 0.19 | 40.5 | 45 |
| 600 | 14,000 | 2.42 | 0.07 | 33.8 | 47 |
| 600 | 05,800 | 2.42 | 0.06 | 42.2 | 33 |
| 600 | 05,400 | 0.78 | 0.05 | 42.5 | 31 |
| 600 | 05,200 | 0.60 | 0.03 | 20.1 | 40 |
| 600 | 02,000 | 0.25 | 0.02 | 35.6 | 32 |
| 600[1] | 01,300 | 0.52 | 0.04 | 33.2 | 20 |
| 600 | 00 300 | 0.09 | 0.02 | 33.2 | 26 |
| 800[1] | 15,000 | 2.68 | 0.12 | 41.3 | 50 |
| 800 | 6,200 | 0.68 | 0.06 | 39.7 | 39 |

[1]Two element static mixer was used with pipe

exiting the screen and reached a solids content as high as 70% in 24 to 48 h. The aforementioned results demonstrate that the Bureau-developed dewatering technology has been successfully applied to a wide variety of minerals and materials operations. This technology is portable and is versatile in its application.

## 11.5 ENVIRONMENTAL ASPECTS OF MERCURY IN MINING

**by L. W. Cope**

### 11.5.1 MERCURY IN NATURE

Mercury is a naturally occurring element which is most commonly found as the mineral cinnabar (HgS). Mercury vapors are a frequent constituent of volcanic gases and hot springs. The earth's crust is estimated to contain 0.1 ppm, with a normal range from 0.01 to 0.3ppm of mercury. Near some mineral deposits the earth's crust can contain thousands of ppms. Thus the detection of anomalous quantities of mercury exuded during the formation of hydrothermal mineral deposits is a common geochemical method for locating metallic ore bodies. The World Health Organization in 1976 estimated that earth degassing liberates approximately 100,000 tons of mercury per year. The characteristics of mercury are shown in Table 5.

Either naturally occurring or introduced mercury can be converted to methylmercury by anaerobic (in the absence of oxygen) bacteria. This conversion commonly occurs in lake bottom mud. Methylmercury is relatively soluble in water, so it can be geochemically mobile. However, in the company of sulfates, in an acid or reducing condition, insoluble mercury sulfide is precipitated. In a basic medium, with either the carbonate or hydroxyl ion present, insoluble mercury carbonate or hydroxide will form (Lindsay, 1979).

$$Hg(CH)_3^+ + 2H_2SO_4^{[H]} \rightarrow HgS + CH_4\uparrow + H^+ + 5H_2O + SO_3^{-2} \quad (11.5.1.1a)$$

$$Hg(CH_3)_2 + CO_3^{-2} + OH^- \rightarrow HgCO_3 + 2CH_4\uparrow + O_2 \quad (11.5.1.1b)$$

$$Hg(CH_3)_2 + OH \rightarrow Hg(OH)_2 + 2CH_4\uparrow + O_2 \quad (11.5.1.1c)$$

**Table 5** Characteristics of Mercury

| | |
|---|---|
| Name | Mercury (Quicksilver) |
| Chemical symbol | Hg |
| Molecular weight | 200.59 |
| Specific gravity | 13.59 (water = 1.00) |
| Appearance | Silvery liquid at normal temperature and pressure |
| Boiling point | 356.9° C<br>674.4° F |
| Melting point | Minus 38.9° C<br>Minus 38.0° F |
| Vapor pressure | 0.0012 mm Hg at 20° C |
| Solubility | Insoluble in water (0.002 g/100 g water at 20° C)<br>Soluble in nitric acid |
| Reactivity | Can form shock-sensitive products with acetylene and ammonia gases.<br>Can attack Cu and Cu alloys, will alloy with most metals, and combines with S |
| Other | Stable, odorless, non-combustible, no hazardous decomposition products |

From: Anon.., 1988a; Anon., 1978; and Anon., undated

### 11.5.2 MERCURY IN PLANTS

Mercury is not essential to plant life, and has very little detrimental effect until a high concentration is reached (Gough, et. al, 1979). Plants can take mercury from the soil, but the usual exposure is a result of human-induced conditions. For example, mercury compounds in agricultural fungicides can concentrate in the stems, leaves, or fruit depending on the plant species. Mercury chemicals sprayed on plants will be absorbed to a lesser degree. Mosses have a particularly high tolerance for mercury. Wetlands plants adsorb mercury the same as they do other metals.

Seed grain is often treated by a mercury-bearing fungicide to keep it from spoiling. Despite prominent warnings to the contrary, this grain has been on occasion used as food by humans. Several years ago, in the Middle East, wheat seed containing eight ppm of methylmercury was baked as bread. As a result several people died. 0.5 to 0.8 milligrams of mercury per kilogram of body weight is normally a lethal dose (Wiles, 1993).

### 11.5.3 MERCURY AND ANIMALS

Animals grazing on plants growing in soil with background levels of mercury will not be affected by the metal. This is because their normal rate of elimination is greater than the small amount consumed. However, the buildup of mercury-containing fungicides on the leaves and stems of plants can be toxic to animals. Mammals exhibit symptoms of poisoning similar to human beings (see next sub-section). Birds are particularly sensitive to mercury poisoning.

In a recent event, a potable water reservoir was developed where high concentrations of mercury were present. Fish were planted in the reservoir to enhance its recreational value. As organic debris and oxygen-robbing materials gathered at the bottom, anaerobic bacteria converted the residual mercury to methylmercury. This compound entered the food chain from organisms to fish to birds with a notably detrimental effect on the local raptor population.

A more serious incident occurred at Minamata, Kyushu Island, Japan, in the 1950s. The effluent from a plastics plant containing the minute amount of 1.6 to 3.6ppb of methylmercury was discharged into a nearby bay. After a period of time, the buildup of mercury in the food chain was to 3.5 to 19ppm in plankton and 30 to 102ppm in mollusks. Human consumption of the shellfish poisoned about a hundred people, of whom some half died (Wiles, 1983).

### 11.5.4 MERCURY AND HUMAN BEINGS

#### 11.5.4.1 Mercury Exposure

Mercury can be admitted into the human body as a vapor, the elemental liquid, or as a water soluble methylmercury. The greater portion of the ingestion is by inhalation of mercury vapor, which is readily absorbed into the respiratory tract. Only small amounts of liquid mercury can be absorbed through the skin; however, it is readily absorbed through the mucous membranes, or breaks in the skin. Elemental mercury ingested orally in water or foods is very poorly absorbed through the gastrointestinal tract (Anon, 1988a).

Agricola, in 1556, mentioned that workers at gold amalgamation plants were well aware that mercury vapors were a health hazard. Whenever mercury was distilled from amalgam or ore, the workers stayed upwind to avoid breathing the fumes. During the mid Nineteenth Century the effects were widely understood although mercury was commonly employed to treat diseases usually of a venereal nature. Lewis Carrol in *Alice in Wonderland* speaks of the "mad hatter." The existing hat making industry employed mercuric nitrate to block out beaver skins into felt hats, and, over time, the workers tended to develop the classical symptoms of mercury poisoning including tremulous manifestations.

#### 11.5.4.2 Effects of Mercury Exposure

By whatever path mercury enters the body, its limits, chemistry, dispersion, effects, and excretion are well known. The average daily mercury intake over a long term basis before it has a human impact is estimated to be 4.3. micrograms ($4.3 \times 10^{-5}$ grams) per kilogram of body weight per day. Curiously, small amounts of swallowed metallic mercury are generally not considered to be toxic. This amount is only absorbed at the vaporization rate.

Elemental mercury vapor is oxidized to the mercuric form after absorption by body tissues. The majority of the mercury lodges in the kidneys and liver where it is excreted in the urine and bile. A very small amount is deposited in the brain, where it may remain for years. There are instruments available which can measure minute quantities of mercury in a human's blood, urine, hair, and breath.

Short-term exposure to a large concentration of inhaled mercury vapor can cause coughing, headache, chest pains, difficulty in breathing, and can even lead to pneumonia. These symptoms can be noted within four hours of ingestion. Long-term or repeated exposure is indicated by a series of symptoms. These progress from tingling around the mouth, fingers, or toes, and fatigue, vision and hearing problems or loss, spastic tremor, and finally coma and death. Other symptoms such as personality changes, memory loss, depression, and hallucination may also occur (Amdur, 1991). Tests by the New Jersey Department of Health have shown that mercury does not cause cancer in animals.

#### 11.5.4.3 First Aid

First aid for people exposed to mercury is logical and straightforward. In all cases, immediate attention should be sought. Washing with soap will counteract skin exposure. If a large amount of vapor is inhaled, the person should be kept warm and rested. If a large quantity of liquid mercury is swallowed, and the person is conscious, he or she should be given water and induced to throw up. In all exposures, prompt action should be taken, including moving the person away from further exposure. Medical examinations for exposure to mercury include tests of blood, urine, kidney function, and the nervous system, and chest X-rays. Special drugs as well as blood dialysis are used to treat mercury poisoning.

### 11.5.5 MERCURY'S USE IN MINING

The affinity of metallic mercury for other metals makes it especially useful for the recovery of free gold. It is particularly effective in the recovery of fine gold which might otherwise be unrecoverable. Mercury will also readily alloy with native silver and copper as on amalgamation plates. In the event the free metal surfaces are oxidized, tarnished, or grease-coated the mercury and metal will be prevented from alloying. If mercury has been "sickened" due to the presence of arsenic or vegetable or mineral oils it will not combine with other metals. Sickened mercury can be reactivated by distillation or treatment with weak alkaline cyanide, dilute nitric acid, or caustic solutions.

Mercury has been recovered from its ores prior to 400 BC. It was used during Roman Times for gold recovery. Reputedly, the Roman invasion of the Iberian Peninsula was undertaken to obtain copper and mercury. By the 16th Century mercury was extensively used in the New World in the Patio Recovery Process in the Spanish-American Colonies (which quickly resulted in the painful death of the animals employed within the "patio"). Up until the 20th Century the development of nearby mercury deposits was economically almost as important as finding precious metal deposits. Thus, Huancavalica in Peru and New Almadén in California were very important mines in their own right.

Mercury was employed at most 19th and early 20th Century small and even large precious metal placer operations, particularly in which the dredges also served to hold the concentrating equipment. Currently, in developing nations "colagalleros," i.e., individual or small groups of underfinanced miners in vast numbers tend to use mercury. It is the "poor man's panacea." Mercury is added to the sluice or pan concentrates in a "batea" or wooden bowl. The miner stirs the slurry with his bare hand until there is no visible free gold. The mercury and amalgam are removed with the surplus mercury recovered by squeezing through cloth or a chamois. The amalgam is retorted and the mercury fumes are condensed and recovered. Costing several dollars a pound, the small miner, by necessity, must maximize mercury recovery.

The processing of amalgam from a dredge or other large-scale placer plant is the same as by the individual miners, except mixing is by machine rather than by hand. Mercury recovery at larger operations also tends to be higher (as is the quantity of handled material). Losses of mercury in placer use will currently vary and can be as much as ten percent of the quantity employed. This "lost" mercury typically washes into a river, stream, or lake and remains an ongoing environmental problem.

**Table 6** Permissible and Recommended Exposure Limits

| | |
|---|---|
| Occupational Safety and Health Administration (OSHA) | Permissible exposure limit is 0.1 mg/m$^3$ air ceiling concentration, not to be exceeded at any time |
| US Environmental Protection Agency (EPA) | National ambient air standard for emissions from a stationary source is 2,300 g/day. |
| National Institute for Occupational Safety and Health (NIOSH) | Recommended airborne exposure limit is 0.05 mg/m$^3$ averaged over a 10-hour work shift, with a recommended ceiling concentration of 0.1 mg/m$^3$ |
| American Converence of Government Industrial Hygienists (ACGIH) | Recomended airborne exposure limit is 0.05 mg/m$^3$ averaged over an 8-hour work shift. |

*Above limits are for air. When skin contact occurs, overexposure can result, even when air levels are below the limits.*

From Anon., 1988a; and Anon., undated.

### 11.5.6 RETORTING

Early-day placer miners often retorted amalgam on a shovel over an open fire. Others would put the amalgam in a potato and heat it. The gold and mercury would be separated, with all the mercury presumably retained within the potato. The safest separation method was and still is with a retort, but their use still has some risk. Mercury retorts have a chamber into which the amalgam is placed. When the chamber is heated, the mercury is driven off as a vapor. The vapor travels through a tube with a jacket for the circulation of cold water. The

mercury vapor condenses as a liquid for reuse. The end of the condenser is kept under water to avoid escape of mercury fumes. It should be noted that the temperature in the amalgamation chamber must be maintained or water may be sucked into it causing an explosion. Tight fittings and good ventilation are essential to a safe operation.

### 11.5.7 MERCURY REGULATIONS AND SAFETY PRECAUTIONS

In the United States the use of mercury in placer mining is highly restricted, with various federal agencies regulating its employment. Complementary state control also exists, which is in a highly transitory condition. The placer practitioner employing mercury must be well aware of what is "on the books" and "in the oven." Table 6 outlines the exposure limits by different federal agencies.

Used with the proper safeguards, mercury poses no problems to either human beings or the environment.

The following is a recommended list of precautions:

- Have a well-ventilated work place.
- Use gloves, impervious clothing or apron, face shields, and appropriate respirator.
- Use hoods and vapor condensers when retorting amalgam.
- Monitor air in areas where mercury is being stored, handled, or used.
- Use procedures which minimize any loss of mercury.
- Have traps in slurry streams to catch lost mercury.
- Work over a floor designed to catch spilled mercury.
- Have spill cleanup supplies available.
- Keep contaminated tools and clothing in airtight containers until they can be disposed of in a suitable hazardous waste location.
- Persons working with mercury should be regularly tested for mercury levels in their blood and urine (Anon., 1978).

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# Chapter 12
# COAL

edited by B. A. Filas

## 12.1 INTRODUCTION AND BACKGROUND

The coal industry is the only mining sector in the United States that is subject to mine-specific environmental regulation under federal law. With the passage of the Surface Mining and Control and Reclamation Act of 1977 (SMCRA), Congress mandated that all coal operations develop environmental information, file operation and reclamation plans, and post an adequate reclamation surety prior to the development of any coal mining operation.

Domestic coal production has been steadily increasing since the mid 1950s. Despite regulation under SMCRA, production has continued to rise at a constant rate into the 1990s, with about 60% coming from surface mines and 40% from underground mines. While overall coal production has risen since SMCRA, the number of both surface and underground mines has diminished (Office of Surface Mining Reclamation and Enforcement, 1993).

As a precursor to discussing the environmental and regulatory aspects of coal mining, it is appropriate to include a discussion to provide a basic understanding of coal mining and processing operations. This discussion is not intended to be comprehensive but, rather, sufficient to provide the environmental professional a basic understanding of the fundamental principles of each process. Detailed information on the following subjects is covered in other publications (Cassidy, ed. 1973; Leonard, ed. 1991; Hartman, ed. 1992).

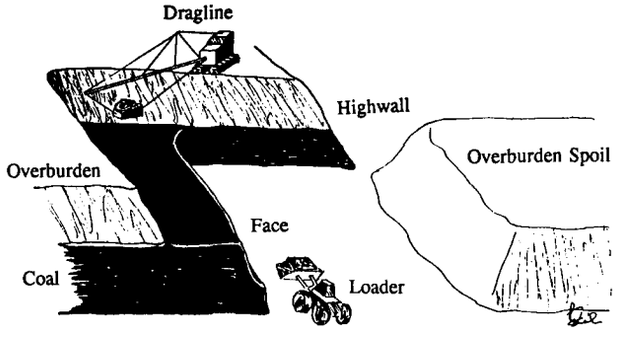



**Figure 1** Schematic drawing of a surface strip mining operation. Courtesy: Greg Peiker.

### 12.1.1 SURFACE MINING

Coal is most commonly found in relatively flat, tabular deposits resulting from prehistoric deposition of organic materials. Because coal deposits are typically flat-lying, the most common surface mining method is strip mining. While other methods are sometimes used, strip mining is usually the most efficient, and it also allows for efficient concurrent reclamation (Figures 1 and 2).

The most common strip mining operation takes place on a flat-lying coal seam overlain by overburden materials and soils. The term "strip mining" describes the process by which sections of earth are advanced in sequential strips along the surface of the land. The excavation operation begins with the removal and storage of topsoil, followed by the removal of overburden material. Once the soil and overburden are removed to expose the coal seam, the coal is excavated.

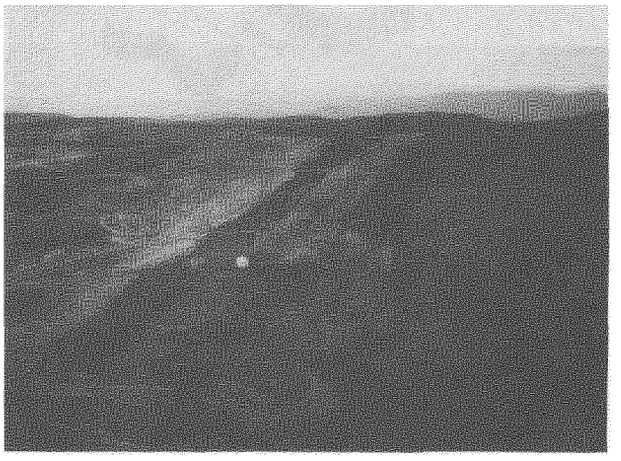


**Figure 2** Active surface mining operation excavates overburden in linear strips to expose the coal to be mined. Courtesy: Colorado Division of Minerals and Geology and Trapper Mining Inc.

The equipment most commonly used in strip mining includes a variety of shovels, draglines, front-end loaders,

trucks, bulldozers, and graders. This equipment is used to selectively remove the different layers of material in separate and distinct stages. The topsoil and subsoil materials must be salvaged and made available for reclamation, and the overburden must be used to backfill the strip to the approximate original contour.

Each strip is designed such that there is only a relatively small area where the coal seam is actively mined. This allows the overburden to be removed on the advance side of the active coal mining face and to be concurrently placed on the retreat side where the coal has already been mined out. Large draglines facilitate high production of overburden and efficient placement on the retreat side and reduce the handling of waste.

### 12.1.2 UNDERGROUND MINING

Underground mining methods vary depending on seam thickness, pitch, overburden characteristics, the number of seams to be mined, and any number of other site-specific factors. The two most common underground coal mining techniques are the room-and-pillar and longwall methods (Figures 3 and 4).

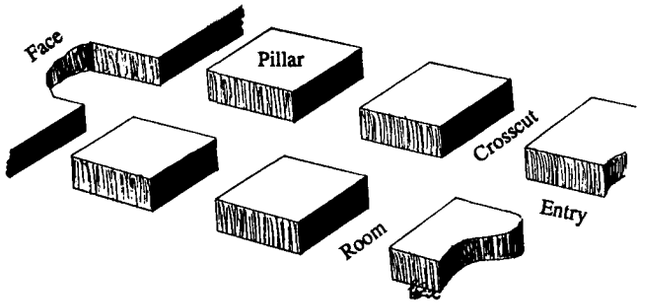



**Figure 3** Schematic drawing of an underground room-and-pillar operation. Courtesy: Greg Peiker.

Underground coal mines present some unique environmental conditions that are not experienced in non-coal mines. The presence of explosive gasses and dust in the mine has resulted in the health and safety aspects of coal mining also being regulated under a separate regulatory program pursuant to the Coal Mine Health and Safety Act of 1969 and subsequently the Federal Mine Health and Safety Act of 1977. Specifically, special "permissible" equipment must be used that does not have open combustion or flames. Federal requirements for permissible equipment limits the types of equipment used underground and the result is substantial uniformity in underground coal mine equipment. The major power source is electricity.

The most common types of underground coal mining equipment used for both room-and-pillar and longwall operations are continuous miners, shuttle cars, and roof bolters. Longwall operations also use shearers and shields. Both continuous and longwall operations may often use battery-power scoops, track haulage equipment, and conveyor systems. Because the equipment used in underground coal mining is specially adapted for cutting and loading a comparatively soft product, and at the same time must meet the permissibility criteria, this equipment is produced for and used almost exclusively by the coal industry.

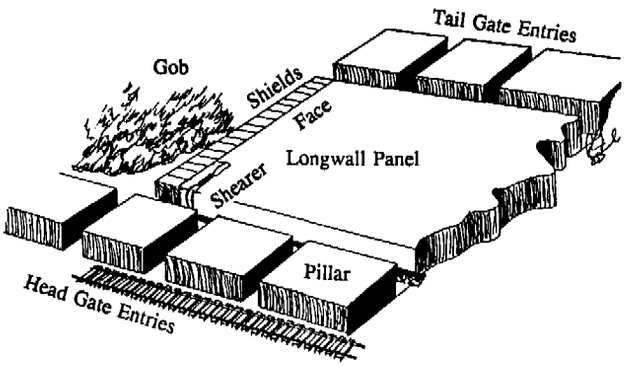



**Figure 4** Schematic drawing of an underground longwall operation. Courtesy: Greg Peiker.

In room-and-pillar mining operations, parallel drifts, or "entries," are driven into the coal seam. "Crosscuts" are driven at perpendicular or specified angles to the entries, spacing them as defined by the mine plan. This development technique creates a checkerboard of "rooms" and "pillars," which are simply interconnected underground tunnels. In areas where subsidence is permissible, the pillars may be extracted as an area is abandoned.

In longwall mining operations, entries and crosscuts ("gate entries") are created around a large block of coal. When the gate entries are fully developed, usually using continuous mining techniques, the longwall mining equipment is positioned to completely extract the large coal block. Because the entire block is removed, longwall mining results in the inevitable but predictable subsidence of the ground surface.

### 12.1.3 PREPARATION

Coal preparation is the process by which the run-of-mine coal is improved in quality to make it suitable for a given end use. Generally, during coal preparation the heavier waste material is separated from the lighter coal product. This process typically results in a relatively uniform particle size product, reduces the amount of ash

in the clean coal, and, depending on the geological occurrence, may reduce the sulfur content.

Most preparation plants incorporate the same fundamental techniques for improving coal quality based on heavy media separation techniques. Coal is initially crushed to a particle size that can be processed in the plant mechanical system. Once crushed, the coal is usually separated based on the size of the particles so that the most efficient preparation method can be applied for a given particle size based on coal washability characteristics established in the laboratory. Preparation plants may have both a coarse and fine coal circuit, with different methods of coal and refuse separation based on particle size.

There are a number of different types of equipment that are used in coal preparation, and nearly all rely on the differential densities of the coal and waste rock in the presence of water. In some circuits, reagents may be added to adjust the specific gravity or improve frothing of the water slurry, making the coal more amenable to flotation.

Coal preparation typically results in three end products: the clean coal, a coarse dewatered refuse, and a fine refuse slurry. Both the coarse refuse spoil material and the fine refuse slurry must be disposed of using environmentally sound methods. Preparation plants often have air emission point sources that must be in compliance with discharge requirements. Typical point sources in plants include crushers, stacks, and dust exhaust fans.

### 12.1.4 REFUSE DISPOSAL

Coal spoils and refuse can be generated from surface and underground excavations and also from the waste products of coal preparation. Overburden materials from surface mining operations are usually used to backfill the excavation to the approximate original contour. Underground mining operations will dispose of underground development waste in the mined-out workings to the extent possible or may have a designated waste rock disposal area at the surface.

Preparation plants usually produce the largest volume of refuse requiring surface disposal. The coarse refuse is a coarse rock product most often coming from the coarse coal circuit in the plant. This refuse is usually dewatered because it is coarse enough to be passed over dewatering screens prior to discharge from the plant. Fine refuse typically consists of the coarse refuse screen undersize material and water and any residual waste from the fine coal circuit.

Because it is produced in a slurry form, fine refuse disposal is usually a dominant component of the site environmental management program. Whenever a material is saturated, it must be stored in an environmentally sound manner within an engineered containment system. Fine refuse is most commonly stored in an impoundment where the slurry solid is allowed to settle to the bottom and the water is reclaimed from the pond surface. Because of the reclamation difficulties experienced at some mines with subaqueous disposal, some refuse disposal systems consider dewatered slurry storage.

It is important to remember that preparation plant refuse is the heavier material recovered from the coal seam. The specific gravity of coal commonly ranges between 1.0 and 1.3. Refuse usually is on the order of 1.8 or greater. This allows for effective heavy media separation at specific gravities in the 1.4 to 1.7 range. In addition to the non-combustible rock materials, if the coal seam contains pyrite and other heavy metals, the refuse would also be expected to contain pyrite and metals. Pyrite and other oxidizable sulfides have a propensity for acid-forming reactions that must be considered in evaluating waste disposal alternatives. These issues are more fully discussed in subsequent sections of this chapter.

## 12.2 COAL MINE REGULATION

### 12.2.1 SURFACE MINING CONTROL AND RECLAMATION ACT

SMCRA was promulgated by the United States Congress to assure that all surfaces affected by coal mining and processing operations are reclaimed to a condition that is at least as productive as it was before the mining activities. The Office of Surface Mining Reclamation and Enforcement (OSM) was established under the U.S. Department of Interior to administer the law and regulations established by SMCRA.

SMCRA pertains only to coal. It is the only federal legislation that is devoted exclusively to mined land reclamation and associated environmental studies and permitting. While other federal laws exist requiring reclamation of mined lands managed by public land management agencies (i.e., Forest Service, Bureau of Land Management), the reclamation requirements are only one aspect of the overall land management directives given to these agencies by Congress. Because the federal land management agencies receive their mined land regulatory authority through land management rather than regulatory directives, there is no provision within the law for delegating reclamation authority to individual state programs. Because SMCRA is intended to regulate and not manage coal mining, the regulatory program can be delegated to the state level provided a state program is at least as stringent as the federal program.

As with many federal environmental laws, SMCRA's provision which delegates to the states the administrative and enforcement functions under the Act has resulted in

substantial state participation. Most states with active coal mines or substantial coal resources have developed state regulatory programs patterned after SMCRA, which are reviewed and approved by OSM. OSM retains program-level oversight over state regulatory programs and can intervene in those cases where the state fails to adequately enforce the provisions of SMCRA. Because states have the option to make their individual programs more stringent than SMCRA, it is important to be familiar with any relevant state-specific criteria for regulating coal in addition to the basic requirements of SMCRA.

The following sections are not intended to fully describe all the permitting and environmental requirements of SMCRA. However, the intention is to give an overview of the environmental and permitting requirements of SMCRA and to supplement the environmental and permitting discussions included with other chapters of this handbook. Where practical, these sections point out areas where SMCRA requirements are unique or different from those usually enforced in the non-coal industry.

### 12.2.1.1 SMCRA Permit Content

Permit applications under SMCRA jurisdiction typically contain the same discipline-specific information as do non-coal permits. The key differences are in the level of regulatory prescriptivity under SMCRA and the fact that most non-coal regulatory programs are a result of state laws and regulations, with no federal program oversight. State non-coal programs typically require similar environmental resource data as well as operation and reclamation plans, but SMCRA prescribes a level of detail that often is presented in more general terms by its non-coal counterparts.

The SMCRA permit program can be generally divided into four regulated activities: exploration, surface mining, underground mining, and special mining categories. Each of these activities is discussed separately in subsequent subsections. SMCRA regulations are cited in Parts 700 through 955 of Chapter 30 of the Code of Federal Regulations (30 CFR). All CFR chapters are revised and updated annually. References made in this chapter to 30 CFR are from the 1993 publication.

#### *12.2.1.1.1 Exploration*

Coal exploration programs are regulated under 30 CFR Part 772. This section differentiates between those programs that will excavate greater or less than 250 tons of coal. All coal exploration programs, regardless of the volume of coal removed, are required to comply with the requirements of 30 CFR Part 815 of the Permanent Program Performance Standards for Coal Exploration. These standards include specific requirements for drill hole casing and/or plugging, access road maintenance and reclamation, topsoil handling and replacement, reclamation to approximate original contour, revegetation, surface water management and erosion control, protection of the hydrologic balance, and mitigation of potentially acid- or toxic-forming materials.

##### *12.2.1.1.1.1 Programs Removing Less than 250 Tons*

Operators intending to conduct coal exploration activities in which less than 250 tons of coal will be removed are required to file a Notice of Intent with the regulatory authority. To qualify for notice-level activity, the exploration must be outside of areas designated or determined to be unsuitable for mining (Section 12.2.1.3.3). The notice must state the anticipated duration of the exploration program and identify the owners and responsible parties. It must also include a narrative on the exploration program describing the location of drill holes and excavations and identifying the equipment to be used. The notice must also identify existing features, dwellings, water resources, and site improvements, and describe the methods to be used to reclaim surface disturbances and minimize adverse impacts to the environment. There is no agency approval required for notice-level disturbances.

##### *12.2.1.1.1.2 Programs Removing Greater than 250 Tons*

Exploration programs that will extract in excess of 250 tons of coal are required to file an exploration permit application. Like the Notice of Intent, an exploration permit application must also state the anticipated duration of the exploration program, identify the owners and responsible parties, and include a narrative on the exploration program describing the methods and equipment to be used for exploration and reclamation. A timetable for each phase of the anticipated exploration and reclamation program must be submitted along with information regarding the need and anticipated volume of coal to be produced.

Specific information is required on cultural and historic resources and threatened and endangered fish and wildlife species, as well as a description of the measures to be used to conform with the permanent performance standards of 30 CFR Part 875. Surface and mineral ownership must be identified and maps showing the area of disturbance, improvements, and proximate environmental resources must also be included.

The review and approval procedures for coal exploration permit applications are similar to those for other SMCRA permit applications (Section 12.2.1.1.5) in that there is a two-phase agency review for completeness and technical adequacy, and the final decision to approve or disprove is subject to the public

process. However, "the approval of a coal exploration permit may be based only on a complete and accurate application." Further, the regulatory authority must approve a complete and adequate application provided the applicant has demonstrated both compliance with the Part 772, Part 815, and any other applicable portions of SMCRA, and that the exploration program will not adversely affect threatened or endangered species or cultural and historic resources. These specific approval criteria leave less to the subjectivity of the regulatory agency and therefore should streamline the approval process for exploration.

#### *12.2.1.1.2 Surface Mining*

The minimum requirements for an application to conduct surface mining operations under SMCRA are defined in 30 CFR Parts 777, 778, 779, and 780. Parts 777 and 778 define the administrative, legal, and financial information required of the permit application and procedural information that is required for all non-prospecting permit applications. Parts 779 and 780 establish the specific operating and environmental data that must be included with the application package; the informational requirements of which are subsequently discussed in this section.

SMCRA requires that a permit applicant supply sufficient environmental data as to provide the regulatory authority an accurate description of the environmental resources that may be affected by surface mine development. In general, an applicant must provide pre-mine environmental data sufficient to quantify the effects of mine development and against which the success of the reclamation program can be measured. To this end, site-specific environmental resource data must be developed for all lands subject to mine development under the permit application

In considering the extent of environmental inventories, it is usually prudent to consider the maximum areal extent of the reasonably foreseeable mining activity and then add a "buffer zone" to allow flexibility when changes to the operating plan are necessary. SMCRA requires that each application include a description of the mining operation, the areal extent over which the activities will occur, and the size, sequence, and timing of each sub-area to be mined. Because operating plans may change over the mine life, and the final permit document must survive the test of time, it is prudent to develop baseline inventories well beyond the anticipated extent of surface disturbance.

SMCRA requires pre-mine environmental resource information on the presence and importance of cultural and historic resources; local weather conditions including precipitation, wind speed and direction, and temperature; vegetative communities including species, types, cover density, and habitat relationships; soil types, productivity levels and suitability of alternative topsoil; and pre-mine land uses. The land-use evaluation must include an assessment of the pre-mine condition, capability, and productivity, and it must identify any land use classifications that may be relevant under local law.

In addition to the required environmental resource discussions, ownership and permit boundaries, existing structures and improvements, anticipated areas to be affected by mine development, pre-mine surface configuration and slope must be adequately represented using maps, plans, and cross sections. Other information must be presented in a graphical format to adequately define the nature and extent of the coal and overburden to be mined, identifying the location and extent of any current or historic surface or underground mine workings and surface and ground water resources, and defining the location and design considerations for all spoil, waste rock, solid waste, impounding structures, water treatment, and pollution control facilities. In addition to the specific map requirements, permit application must include a verbal discussion regarding the maps that have been included with the application package.

All permit applications for surface mining operations must include a detailed description of the operation and reclamation plans for the site. In general, each operation plan must include a description of the anticipated mining activities and methods, production estimates, equipment schedules, and detailed discussions on the design, construction, use and closure of water and slurry impoundments, soil and overburden storage areas, preparation and transportation areas, waste storage and disposal, site improvements, and pollution control facilities. The operating plan must also include a blasting plan that addresses ground vibration and airblast issues, monitoring systems, and provisions for blasting near underground workings. In addition, each application must include an air pollution control plan and site-specific information on fish and wildlife resources, including a protection and enhancement plan.

Maps supporting the operation plan must show site improvements, anticipated disturbed area based on the mine development plan, areas of surety coverage, coal handling areas, locations of stockpiles, water diversions and conveyance structures, air pollution control facilities, waste sources, fish and wildlife enhancement facilities, locations for handling and storage of explosives, and the locations of water and waste storage facilities.

The reclamation plan must describe how the lands subject to surface mining will be reclaimed. Each plan must include a detailed timetable for each major phase of reclamation and an estimate of the cost of reclamation according to the reclamation plan defined in the application. Plans must be included for achieving the final proposed surface configuration, topsoil and subsoil handling, and revegetation. The revegetation plan must propose seed mixes, mulching techniques, irrigation plan

if appropriate, and the measures proposed for use in measuring revegetation success on completion of reclamation. Plans must also address any special measures for mitigating adverse geochemical characteristics in the coal and waste materials and the methods for sealing mine openings and drill holes.

Detailed resource-specific environmental information is required on local geology, surface water, and ground water resources. These resources are then coupled with an assessment of the geochemical characteristics of the materials that could potentially affect water quality and the containment facility design anticipated for these materials. These disciplines must then be evaluated as regards the cumulative impacts associated with mine development relative to the hydrogeologic regime. Based on these evaluations, a determination and quantification of the overall probable and cumulative hydrologic consequences are required for surface and ground water systems and the development of a hydrologic reclamation plan for mitigating adverse impacts to the hydrologic system.

Each reclamation plan must include detailed information on the design, construction, operation and reclamation of all ponds, impoundments, banks, piles, dams, embankments, diversions, and roads (Figure 5). A description of all site improvements and infrastructure must be included with the application. In addition, the overall reclamation plan must be shown to be adequate to meet a suitable post-mining land use.

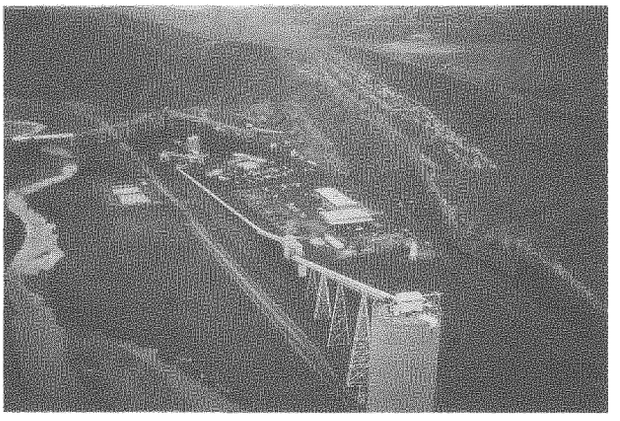


**Figure 5** Surface support facilities are arranged for both efficient mine support and adequate runoff and sediment control. Courtesy: Colorado Division of Minerals and Geology and Empire Energy Corp.

#### *12.2.1.1.3 Underground Mining*

Underground mining is regulated under SMCRA because of both the surface effects and the potential for hydrogeological impacts associated with underground activities. The minimum requirements for an application to conduct underground mining operations under SMCRA are defined in 30 CFR Parts 777, 778, 783, and 784. Parts 777 and 778 define the administrative, legal, and financial information required of the permit application and procedural information that is required for all non-prospecting permit applications. Parts 783 and 784 establish the specific operating and environmental data that must be included with the application package; the informational requirements that are subsequently discussed in this section.

As with surface mines, SMCRA requires that a permit applicant supply an accurate description of the environmental resources that may be affected by mine development. Pre-mine environmental data must be provided sufficient to quantify the mining affects and against which the success of the reclamation program can be measured. Therefore, site-specific environmental resource data must be developed for all lands subject to mine development under the permit application.

As discussed in Section 12.2.1.1.2, it is usually prudent to consider the maximum areal extent of the reasonably foreseeable mining activity and then add a "buffer zone" to allow flexibility when changes to the operating plan are necessary. This buffer often determines the limits of the permit boundary, and the anticipated mine plan determines the disturbed area boundary. Subsidence effects must be included within the disturbed area boundary. This area is typically determined by establishing the anticipated angle-of-draw and planning accordingly. The disturbed area boundary is the area for which surety is ultimately posted. The permit boundary typically delimits the area of any potential affect of the mining operation.

Those who perform underground operations must supply much the same pre-mine environmental resource information as do those who operate surface mines. This includes information on the presence and importance of cultural and historic resources; local weather conditions including precipitation, wind speed and direction, and temperature; vegetative communities including species, types, cover density, and habitat relationships; soil types, productivity levels, and alternative topsoil substitute material suitability; and pre-mine land uses. The land use evaluation must include an assessment of the pre-mine condition, capability, and productivity and identify any land use classifications that may be relevant under local law.

Maps, plans, and cross sections depicting relevant boundaries, existing structures and improvements, anticipated areas to be affected by mine development, pre-

mine surface configuration and slope must be adequately represented. In addition, information characterizing the coal interval and overburden to be mined, the location and extent of any current or historic surface or underground mine workings, and surface and ground water resources must be included. The location and design considerations for all spoil, waste rock, solid waste, impounding structures, water treatment and pollution control facilities are also an integral part of the permit documentation. Details of all road systems must be included along with measures to be taken to address hydraulic relief in roadways.

Underground mining plans must incorporate a detailed description of the operation and reclamation plans for the site with the permit application. In general, each operation plan must include a description of the anticipated mining activities and methods, production estimates, equipment schedules, and detailed discussions on the design, construction, use, and closure of water and slurry impoundments, soil and overburden storage areas, preparation and transportation areas, waste storage and disposal, site improvements, and pollution control facilities. The plan must also identify the location and condition of all existing structures and improvements. Furthermore, the structure must meet the requirements of the permanent performance standards of 30 CFR Part 817.

The reclamation plan must describe how the lands subject to the surface effects of underground mining will be reclaimed. Each plan must include a detailed timetable for each major phase of reclamation and an estimate of the cost of reclamation according to the plan. Plans must be included for achieving the final proposed surface configuration, topsoil and subsoil handling, and revegetation. The revegetation plan must propose seed mixes, mulching techniques, irrigation plan if appropriate, and the measures proposed for use in measuring revegetation success on completion of reclamation. Plans must also address measures to maximize coal recovery from the underground and any special measures for mitigating adverse geochemical characteristics in the coal and waste materials. They must also consider methods for sealing mine openings and drill holes.

Detailed resource-specific environmental information is required on local geology and surface and ground water resources. These resources must be evaluated in the context of their geologic setting and the geochemical characteristics of the materials that could potentially affect water quality. Containment facility design should also be factored into this evaluation. Overall consideration is then given to the potential cumulative impacts associated with mine development on the local and regional hydrogeologic regime. Based on these evaluations, a determination and quantification of the overall probable and cumulative hydrologic consequences are required for surface and ground water systems. A hydrologic reclamation plan must be developed to address any potential adverse effects identified by the hydrologic consequences evaluation.

Each reclamation plan must include detailed information on the design, construction, operation and reclamation of all ponds, impoundments, banks, piles, dams, embankments, diversions, and roads. A description of all site improvements and infrastructure must be included with the application along with a survey identifying the potential effects that subsidence may have on structures and on renewable resources. The subsidence information must demonstrate that no material damage to structures or renewable resources will occur. In addition, the overall reclamation plan must be shown to be adequate to meet a suitable post-mining land use.

Specific plans must be included with the permitting package for the protection of public parks and historic places, relocation or use of public roads, placement of underground development waste either inside or outside of the underground mine, subsidence control and fish and wildlife protection and enhancement. Operators of underground mines must also develop air pollution control plans.

#### *12.2.1.1.4 Special Mining Categories*

There are several types of coal mining operations that do not "fit" into the regulatory programs for exploration, surface mining and underground mining. These mining categories are usually regulated as a special category under SMCRA. These categories include experimental mining practices, mountaintop removal mining, steep slope mining, mining in alluvial valley floors, augering, and coal preparation facilities remote from the mine site. These categories are identified in 30 CFR Part 785. Performance standards for special categories are included in 30 CFR Parts 819, 820, 822, 823, 824, 825, 827, and 828.

Operators can apply for variances to the SMCRA requirement of reclaiming to approximate original contour where mining is being conducted on steep slopes. Variances can also be pursued under Part 785 to delay concurrent reclamation requirements for special sites having both surface and underground mining activity.

Probably the most common special category permit pursued by operators is for preparation plants not located within the mine permit area. The environmental information required in a permit application for these operations is similar to that required for the mining operations.

The special mining category subpart of SMCRA can be modified to include provision for state program primacy for special activities that would otherwise be included under a specific program regulation. For

example, anthracite surface mines in Pennsylvania and special bituminous surface mines in Wyoming are singled out as special mining categories. Without the special mining category provision, these activities would be regulated as surface mining operations. Under the special mining category language, SMCRA specifically requires that these activities comply with the approved state program. This allows some flexibility in the permanent program for site or area specificity, and a line of relief when the SMCRA regulatory language simply is inappropriate for a given situation.

#### *12.2.1.1.5 Permit Review and Approval Procedures*

Coal mine permit applications are reviewed using a two-phase process. The initial phase consists of a "completeness review," followed by a "technical adequacy review." Following completion of the technical adequacy review, the permit is drafted and a public comment period commences. Following completion of the public process, the permit is issued.

Upon receipt of an application, the regulatory authority conducts a "completeness review." During the completeness review, the application is checked to make sure that the provided information responds to each item required by SMCRA and the state delegate program. The completeness review is an administrative process whereby the agency determines whether each requirement is discussed in the application. The content of the application does not have to meet the reviewing agency's technical requirements to be determined "complete," (in fact, when an application is determined to be complete, it rarely is considered technically adequate) it simply must address the required information.

When the reviewing agency determines that an application is complete, typically the applicant is notified by letter. SMCRA requires that a regulatory authority review permit applications "within a reasonable time." Most state delegated programs, through rule-making processes, require that the completeness review be conducted within 30 days after receipt of the application. If any item required by SMCRA is not included with the application, the applicant is notified that the application is administratively incomplete. This re-starts the 30-day completeness review clock.

After being notified that the application is administratively complete, the permit applicant must place an advertisement in a local newspaper describing the proposed project and identifying where the public can review and comment on the proposed activities. The public notice must be published at least once each week for four consecutive weeks. Concurrent with the public notice, a copy of the application must be filed with the county recorder at the courthouse of the county in which the coal mining activity is proposed to take place for public review. Also, the regulatory agency must provide written notification of the application to all interested federal, state, and local government agencies.

Within 30 days after publication of the last public notice, written comments, objections, and requests for informal conferences may be filed with the regulatory authority.

Concurrent with the public notification process, the agency proceeds with the technical adequacy review. Having determined during the completeness review that the application contains "something" for each requirement under SMCRA, the information is then reviewed for technical merit. Again, the permit review time is left to the state delegate programs by SMCRA. Most state agencies have established a 90-day review allotment for technical adequacy.

The public comment period typically occurs concurrently with the initial phase of the technical adequacy review. As such, the comments, concerns and the results of any informal conferences can be factored into the technical review process. It is common to have one or more technical deficiency letters from the agency during the review process. When the application is determined by the agency to be both complete and technically adequate, the agency is then prepared to issue a decision.

The regulatory authority must notify the applicant, each person providing comments, and all interested government entities, including OSM, of its proposed decision. Within 30 days of this notification, any interested party may request a hearing on the reasons for the decision. Within 30 days following the hearing, the hearing authority must supply written findings and conclusions regarding the permit decision. Any decision can be subject to judicial review.

Prior to issuance of a permit, the applicant must post adequate financial assurances, usually in the form of a surety (Chapter 16). The amount of the surety is based on the estimated cost to execute the reclamation plan defined in the permit application. Surety amounts are calculated to reflect the cost of a third party performing the reclamation obligation. This amount presumably allows for the regulatory authority to conduct the reclamation activities if the operator were to default on its obligations under SMCRA.

Permits are issued for a five year permit term. During the permit term, at least one midterm review must be conducted to assure that the permit requirements and surety values are current. Failure to start up operations within three years of permit issuance automatically terminates the authorization unless an extension is granted by the regulatory authority.

### 12.2.1.2 Information Gathering

As discussed in the preceding sections, SMCRA permit

applications require a variety of environmental resource information to allow for adequate impact analyses. This section identifies some of the available resources where information and data can be obtained that may be useful in supporting a permit application. Most SMCRA permit programs will require a substantial amount of detail in these site assessments. It is most common to retain individuals with specific qualifications in the resources being evaluated to conduct the site-specific investigations.

#### *12.2.1.2.1 Climatological and Air Quality Data*

Climatological information is collected by the National Oceanic and Atmospheric Administration (NOAA) and the State Climatologist Programs. Each state has a State Climatology Program that participates with NOAA in building the NOAA database. While the State Climatologist may have a more comprehensive record, NOAA also has the summary records necessary for permitting purposes.

NOAA has climatological stations at numerous locations throughout each state, most commonly in the more populated areas. These stations are monitored for various climatological data and are published in several publications that are available in local libraries. Also, NOAA can provide climatological data in digital format for a fee.

The protection of air quality and the permit program for emission sources is under the purview of the U.S. Environmental Protection Agency (EPA) pursuant to the Clean Air Act. Most states have delegate programs for administering the EPA program. State air quality programs are usually included within the state health, ecology, environmental, or natural resources departments. All states are included within a particular EPA region which has oversight on the state program. If a state does not have an approved delegate program, the applicable EPA region will have the primary permitting responsibility for air quality programs (Chapters 3 and 4).

Both the EPA and state air quality program can be resources for obtaining local air quality information. The operator of any permitted emission source is required to have submitted information on air quality. That information typically is available for public review and copying at the agency office. Air quality monitoring data may be available for proximate sites that will supplement any site-specific data that may be developed.

Site-specific meteorological and air quality information can be developed by installing monitoring equipment on site. Most commonly, this equipment will measure precipitation, wind speed and direction, and temperature on an intermittent or continuous basis. Meteorological stations are often required to collect data identifying the background and operational levels of airborne particulates, under the Clean Air Act. Most often, particulate concentrations are measured using a PM-10 monitoring station to measure respirable air particulates less than 10 microns in size. The state air quality program staff will usually be able to provide a listing of qualified meteorological consultants if outside assistance is necessary.

#### *12.2.1.2.2 Surface and Ground Water Hydrology*

There are a number of sources available for gathering data and information on surface and ground water resources. Information may be gathered through library research and university contacts. The U.S. Geological Survey conducts numerous studies and analytical programs on surface and ground water resources, and they are available to the public. Some states have a state geologist or geological survey programs, and the results of their investigations are publicly available.

Most states have EPA delegate programs for water pollution control which can be attributed to the Clean Water Act. Also, most states have an agency responsible for surface and ground water appropriations, well drilling and testing, and impounding structures. Almost everything submitted to a state or federal agency is available for public review. Therefore, data can usually be obtained from these agencies regarding any known production or monitoring wells that exist, water quality and quantity data, and any analytical or interpretative reports that may have been submitted by others for nearby areas. Also, information on aquifer characteristics, quality, productivity, and availability for appropriation can usually be obtained. Some states have water management subdivisions where local watermasters can be identified by contacting the state office.

The U.S. Army Corps of Engineers is responsible for regulating impacts to waters of the United States under the provisions of Section 404 of the Clean Water Act. Any activity requiring excavation or placement of fill into waters will require a permit from the Corps. The Corps, therefore, is often a good resource in obtaining design data and technical information on stream flow and development programs in surface waters. Also, many regional Corps offices develop base maps identifying candidate wetland areas within their jurisdiction. The Corps files, like nearly all regulatory agency information, are available to the public for inspection and use on request.

#### *12.2.1.2.3 Soils and Vegetation Information*

Preliminary information on local soils and vegetation can be obtained through research in local libraries and conservation groups. In some areas, there are research

facilities that may be affiliated with local colleges and universities or functioning as private enterprises that may have relevant and available information on soils and vegetation. Public land management agencies, like the Forest Service and Bureau of Land Management, will typically have information on soils, vegetation, and rangeland productivity that is available to the public on request. Also, the Soil Conservation Service (SCS), within the U.S. Department of Agriculture, is a good resource for soil and vegetation information as SCS surveys typically identify the vegetation communities associated with particular soil types.

A typical SCS soil survey will cover a particular demographic area over which the detailed survey is conducted. SCS conducts detailed field investigations and creates maps for each report. Reports typically include detailed descriptions of individual soil units; an evaluation of the uses and management of each soil type, including capability groupings, use potential, estimated vegetation yield, engineering considerations, physical and chemical properties; and discussions on the formation and classification of the soil units. In addition, detailed maps delineating the various soil types are included on orthophoto maps. The map units directly correlate to the soil descriptions included with the survey.

SCS mapping is accomplished over a large area, and, although the surveys provide very valuable information, they often lack the site-specific details for adequately documenting pre-mine conditions. Ground proofing over the specific permit area boundary to supplement SCS data and confirm accuracy is usually well advised. The regulatory authority, SCS, and public land management agencies can usually advise as to some good technical consultants in the disciplines of soils and vegetation if additional assistance is required.

#### *12.2.1.2.4 Fish and Wildlife Resources*

The U.S. Fish and Wildlife (USFW) Service has a number of regional offices throughout the United States. The USFW maintains records on fish and wildlife species and the presence of threatened or endangered species within each regional jurisdiction. On written request, USFW will usually respond with a listing of species expected within a given area and also identify potential sensitive species that may also be present.

State and local fish and game departments are usually good resources for information on species presence, diversity, enumeration, summer/winter range habits, and productivity. The state agencies are generally not affiliated with the USFW so the information gained from one agency may not be duplicative of information from another. Also, public land management and permitting agencies like the U.S. Forest Service, Bureau of Land Management, and Corps of Engineers often have staff specialists and relevant records available to the public on fish and wildlife resources.

#### *12.2.1.2.5 Cultural and Historic Resources*

Section 106 of the National Historic Preservation Act requires that the impacts to historic and cultural resources be assessed and addressed on all projects under the jurisdiction of a federal agency. Cultural and historic resource information and the status of a specific land parcel may be available from the State Historic Preservation Office (SHPO). Every state has a SHPO, but the office may be nested within another state department that may not sound like a historic preservation office. For example, in Colorado, SHPO is within the Department of Higher Education - Historical Society Division; in Arizona, it is within the State Parks System.

Cultural resource information can also be obtained by researching at local libraries and universities. Because all federal decisions must comply with the Act, consultation with federal agencies such as the U.S. Army Corps of Engineers, the Forest Service, the Bureau of Land Management Federal, and other federal permitting agencies are good candidate sources for identifying existing cultural resource information. It is noted, however, that some site-specific information may only be available to qualified archaeologists to minimize despoilage of identified historic sites in the field. SHPO and the regulatory authority can usually provide a listing of qualified consultants available for hire should outside assistance be required.

### 12.2.1.3 Coal vs. Non-Coal Permitting

There are many differences in coal and non-coal permitting. As previously mentioned, there is no federal oversight for non-coal programs. Because there is no federal program for non-coal, the following discussions are based on the general trend of most state programs regulating non-coal mines. While these general trends are apparent in most states with substantial mining activity, the topics discussed may not be appropriate for all circumstances.

#### *12.2.1.3.1 Approximate Original Contour*

Probably the most significant difference between surface coal reclamation requirements and those for non-coal mines is the requirement for reclamation to the approximate original contour. SMCRA requires that only under special circumstances is a mine operator allowed to reclaim to a configuration other than the approximate pre-mine contour.

Coal seams are typically tabular and continuous. It is very clear where the seam starts and stops, which allows for complete excavation of the resource upon mining.

Because of the nature and configuration of coal seams, the coal can be completely extracted during surface mining in a manner that facilitates the continuous backfilling of the excavated overburden into previously mined areas as the mining advances.

By contrast, non-coal ore bodies come in all sizes and shapes. Ore deposits often do not lend themselves to economic concurrent backfilling as does coal excavation. The economic recoverability of the minerals being mined from non-coal deposits is usually driven by the market price. As the commodity price goes up, material that was previously waste may become ore. Backfilling exposed mineralization based on today's market price may not be the best alternative for conserving the mineral resource.

#### *12.2.1.3.2 Subsidence*

The environmental and reclamation requirements for underground mines are generally similar to those required of non-coal mines. However, non-coal programs typically deal with subsidence on a case-by-case basis rather than having a prescriptive method for determining acceptable or unacceptable levels of surface subsidence from underground mines. SMCRA deals directly with subsidence, but the subject is one of controversial legal interpretation.

In general, SMCRA requires that the area of potential subsidence be determined during the pre-mine permitting process. For those areas subject to potential subsidence, the angle of draw must be determined based on site-specific conditions including geology, rock strength, and overburden thickness. The angle is projected to the surface to delineate the area potentially affected by mine subsidence. All structures and renewable resources within the area of potential subsidence must be surveyed in detail to quantify their pre-mine condition. The mine operation and reclamation plan must then be able to demonstrate that no material damage to structures or renewable resources will occur. Design techniques for underground mine subsidence abatement are presented in Chapter 6.

#### *12.2.1.3.3 Unsuitability*

Unlike their non-coal counterparts, coal mining activities have been expressly excluded from certain areas considered unsuitable for mine development under SMCRA. Although many of these areas would be very difficult or even fatally flawed for development of non-coal mining activities, there is no express, universally applicable, similar exclusion for non-coal operations. However, such unsuitability criteria have been hotly contested between the industry and environmentalists in recent legislative processes germane to non-coal mining. It is probable that unsuitability language will be included in future federal legislation for non-coal mining.

Unsuitability criteria for coal mining are defined in 30 CFR Part 761 and should be referenced in conjunction with the following discussion. In all cases, the areas determined to be unsuitable for mining are subject to valid existing rights. These rights must have been in place as of the effective date of SMCRA on August 3, 1977. Areas excluded from coal mining include:

- Lands within the boundaries of the National Park System, National Wildlife Refuge System, National System of Trails, National Wilderness Preservation System, Wild and Scenic River System, and national recreation areas;
- Lands within the boundaries of any national forest;
- Lands where mining will adversely affect any publicly owned park or which are included in the National Register of Historic Places; and
- Lands within 100 feet of any public road, 300 feet of any occupied dwelling, 300 feet of any public building or park, 100 feet of a cemetery.

From a practical perspective, new coal mining operations will not likely be allowed to infringe on the boundaries of the above-cited exclusion areas. For lands proximate to dwellings or buildings, there are provisions for arrangements with landowners that can potentially allow mining to be conducted.

The exclusion in national forest lands is an interesting contrast between coal and non-coal operations. A substantial portion of national forest land is open to mineral entry for hardrock mining. Many surface mining operations have been successfully developed within these boundaries. The exceptions to the unsuitability criteria for surface coal mines on forest lands are predicated on the absence of significant recreational, timber, economic or other values. Forest lands absent these values are rare, so coal mining is most often effectively excluded by SMCRA where its hardrock counterparts may be allowed to develop at the same location.

In addition to the specific areas deemed unsuitable under SMCRA, 30 CFR Parts 762, 764, and 769 establish specific criteria for the designation of other areas as unsuitable by the regulatory authorities.

### 12.2.2 FEDERAL MINE SAFETY AND HEALTH ACT

Both surface and underground coal mines are regulated by the Mine Safety and Health Administration (MSHA) under the Federal Mine Safety and Health Act (36 CFR Parts 1-199). This section is not intended to be a comprehensive review of MSHA requirements, as they focus on the health and safety aspects rather than

environmental protection. However, there are some specific requirements relevant to facilities that have a bearing on the environmental condition and permitting.

#### 12.2.2.1 Refuse Piles

Both OSM and MSHA have requirements for the design, construction, and operation of coal refuse piles. Because refuse piles can be subject to spontaneous combustion, the piles must be constructed so as to mitigate against such hazards. Where refuse is placed over exposed coal or with historic refuse, a clay interface must be constructed to physically separate the new refuse from the other material. Refuse must be placed in lifts and compacted in such a manner as to minimize air flow through the pile. Also, a refuse pile cannot be constructed to impound water or impede drainage.

While the MSHA requirements are intended to mitigate against health and safety hazards associated with potential spoil fires, the mandated procedures result in activities that also reduce the potential for acid-forming reactions. As discussed in Section 12.4.2.1, minimizing air permeability and water contact with the refuse will also reduce the overall potential for reactive refuse to produce acid drainage.

In addition to the environmental obligations under SMCRA for refuse piles, a facility operating an active refuse pile must be in compliance with specific MSHA requirements that in some aspects duplicate the SMCRA requirements, but for health and safety rather than environmental reasons. Prior to construction, the operator of a planned refuse pile must submit a specific design and construction plan and file an abandonment plan. As mentioned in Section 12.2.1.1 and its subsections, SMCRA also has specific requirements for the design, construction, and reclamation of refuse piles. In addition, an annual report must be submitted to MSHA describing the construction history and information regarding the specific location and configuration of the facility.

#### 12.2.2.2 Water, Sediment and Slurry Impoundments

Plans for the design, construction, and maintenance of large impounding structures must be submitted to MSHA before construction is begun. Abandonment plans are also required prior to closure and reclamation of each impounding facility. As in the case of the refuse piles discussed in Section 12.2.2, MSHA and SMCRA have similar design and informational requirements, but their review perspectives are different; MSHA is concerned with health and safety, and SMCRA is concerned with protecting and restoring the environment.

Impounding structures must be monitored on a regular basis by persons determined to be qualified by MSHA. Results of the monitoring program and specific operational discussions must be developed and submitted to MSHA on an annual basis, under the direction of a registered professional Engineer.

#### 12.2.2.3 Coal vs. Non-coal Regulation

MSHA has rigorous programs for regulating and enforcing both coal and non-coal mining in the United States. While the metal and non-metal mine regulatory program is strict, the coal mining program is far more detailed, probably due to the presence of hazardous mine gasses and explosive dusts that require the use of specialized equipment and the fact that the coal and wastes produced can spontaneously combust and/or burn if exposed to heat sources. For perspective, in the 1993 Code of Federal Regulations, the coal mine health and safety regulations are covered in 389 pages (30 CFR, Subchapter 0, Parts 70, 71, 74, 75, 77, and 90), and metal and non-metal mine health and safety requirements are covered in 163 pages (30 CFR, Subchapter N, Parts 56 and 57).

Because of the environmental relevance, the focus in preceding sections was only on the waste disposal issues regulated under MSHA. Coal mine refuse piles and impounding structures are substantially regulated by MSHA. Their non-coal counterparts are largely unregulated by MSHA. While non-coal MSHA programs include consideration for operator safety, stable highwalls, and slopes, there are no specific design, construction, monitoring, and abandonment requirements for mine wastes and impoundments similar to those required of the coal industry.

## 12.3 ENVIRONMENTAL CONSIDERATIONS

The purpose of this section is to define some of the more significant environmental considerations associated with coal mining, processing, and usage. It is not intended to be comprehensive, but it provides an overview of the key environmental media that have the potential to transport contaminants and identifies the types of contaminants associated with coal mining and usage that may be found in the environment.

### 12.3.1 AIR
**by R. B. Finkelman**

About 90% of the coal mined in the U.S. is burned, principally to generate electricity. The coal combustion process produces large quantities of waste products that may be released into the atmosphere. Most of what is seen emitted from the smoke stacks of utility boilers is harmless water vapor (steam). However, the emissions

do contain small but significant amounts of atmospheric pollutants. Among these pollutants are sulfur and nitrogen oxides, carbon dioxide, mineral and coal particulates, trace elements, and trace amounts of organic compounds. Each of these air pollutants has different effects on human health and the environment. Fortunately, there are various ways in which these effects can be mitigated. The following discussion is, in part, based on material appearing in Schobert, 1987.

#### 12.3.1.1 Sulfur Emissions

Sulfur in coal occurs principally as pyritic sulfur and organically-bound sulfur. Other sulfur forms (sulfate and elemental) are commonly trace constituents in coal. Regardless of the form, sulfur is oxidized during coal combustion and forms various gaseous sulfur oxide compounds.

These sulfur oxides have a broader environmental impact than any other combustion product of coal. Sulfur's undesirable effects have been known for more than 100 years. In 1880, the deaths of approximately 1,000 people in London, England were attributed to sulfurous gases produced by the combustion of coal (Chiras, 1989). One of the more obvious, but less significant impacts is the obnoxious odor of gaseous sulfur compounds. Sulfur dioxide can be absorbed in the lining of nasal passages where it is converted to sulfuric acid causing a burning sensation. Sulfuric acid also can coat respirable dust particles that are taken into the lungs causing severe breathing problems.

In the atmosphere the sulfur oxides can combine with water and form sulfurous and sulfuric acids. The deposition of these acids causes corrosion or decomposition of many materials such as limestone, marble, iron, and steel. The deterioration of building facades and irreplaceable monuments is one aspect of this worldwide problem. Flushing of the sulfur oxides from the air by precipitation (acid rain) can lead to acidification of lakes and soils, weakening or killing plants and animals.

The U.S. has been very successful in reducing sulfur emissions from coal combustion. There are several ways in which sulfur emissions can be reduced. These include cleaning coals by physically removing the pyritic sulfur prior to combustion; combustion gas scrubbing to remove gaseous sulfur compounds after combustion but prior to release of the gases to the atmosphere; and switching from the use of high-sulfur to low-sulfur coals. Several new coal cleaning and combustion technologies designed for even more efficient removal of sulfur are currently being tested.

#### 12.3.1.2 Nitrogen Emissions

Virtually all of the nitrogen in coal is organically-bound. During coal combustion, nitrogen is oxidized to form several gaseous oxide compounds. However, most of the nitrogen oxides produced and emitted during coal combustion come from nitrogen in the air reacting with additional oxygen at high temperatures. These products contribute to the formation of smog and they react with oxygen in the presence of light to produce a variety of materials that cause eye and respiratory irritation. As with sulfur oxides, nitrogen oxides combine with moisture in the air to make nitric acid. When the nitric acid is flushed from the air by precipitation, it contributes to the acidification of surface waters and soils.

Technology is available that will reduce the amounts of nitrogen oxides produced during coal combustion or will enhance their decomposition prior to release. Methods are being tested to remove nitrogen oxides from the combustion gases.

#### 12.3.1.3 Carbon Dioxide

All fossil fuels (coal, petroleum, natural gas, coal-bed methane, oil shale) are carbon based. The combustion process produces substantial amounts of carbon dioxide, primarily a harmless gas. It is believed that accumulation of carbon dioxide and other "greenhouse gases" in the atmosphere may disrupt the global climate (McCabe and others, 1994). When the earth radiates heat, the heat energy is given off in the infrared region. Carbon dioxide and water vapor absorb the infrared energy preventing it from radiating back into space, thus accumulating heat in the atmosphere and raising earth's temperatures. An increase in global temperatures can have profound effects on precipitation, crop yields, and sea level. This is still a highly controversial topic and there is no consensus among scientists as to the consequences of increased atmospheric carbon dioxide due to fossil fuel combustion.

There are no current commercial technological innovations that will significantly reduce the amounts of carbon dioxide produced and emitted from fossil fuel combustion. If the greenhouse effect is deemed to be a real threat to global climate, then the use of non-fossil fuel energy sources, such as nuclear power, will have to be increased substantially.

#### 12.3.1.4 Particulates

Coal generally contains from 5 to 20 weight percent of mineral particles. During combustion most of the minerals are transformed into dust-sized glassy particles and, along with some unaltered mineral grains and unburned carbon, are emitted from the smoke stacks. These particles contribute to the smog problem, are eye and respiratory irritants, and act as substrates for the deposition of sulfuric and nitric acid.

Current pollution control technology can remove about 99% of the particulates in the combustion gases. Improved coal cleaning procedures and pollution control technology promise to be even more efficient in reducing the amounts of particulates produced by coal combustion.

#### 12.3.1.5 Trace Elements

All coal contains small concentrations of trace elements. Most of these elements are associated with the minerals in coal but some are organically-bound (Finkelman, 1993). Some of these elements can be harmful to human health and the environment. The 1990 Amendments to the Clean Air Act cite about a dozen trace elements as potential hazardous air pollutants. These elements include antimony, arsenic, beryllium, cadmium, chromium, cobalt, manganese, mercury, nickel, lead, selenium, and radionuclides (e.g. uranium). Although these elements are present in small concentrations in coal, the vast amount of coal burned annually mobilizes tons of these pollutants.

Deposition of these pollutants downwind from power plants can lead to high trace element concentrations in soils and uptake by plants. The pollutants can retard plant growth or enter the food chain causing adverse health effects in animals and humans (Adriano, 1986).

Existing pollution control devices can remove as much as 99% of the trace elements (except for mercury and selenium) from the combustion gases. Substantial amounts of mercury and, to a lesser extent, selenium are emitted with the combustion gases. There are a number of ways to reduce trace element emissions due to coal combustion. These include switching to coals with lower trace element contents, selectively mining those parts of the coal bed having lower trace element contents, cleaning the mined coal, and using pollution control devices such as fabric filters, electrostatic precipitators, and combustion gas scrubbers.

#### 12.3.1.6 Organic Compounds

The coal combustion process is not 100% efficient. Several percent of the carbon is not burned and commonly is carried along with the combustion gases. Under combustion conditions this carbon can react to form small amounts of polycyclic aromatic hydrocarbons (PAH). Certain PAH compounds are known carcinogens and are cited in the Clean Air Act Amendments as hazardous air pollutants. The U.S. Environmental Protection Agency is currently conducting tests to determine the amounts and possible impacts of PAH emitted from coal-burning power plants. Various pollution control devices efficiently remove particulates, including unburned carbon, from the combustion gases. Modifying the boiler operating conditions can reduce the amounts of PAH produced.

### 12.3.2 WATER
**by C. A. Cravotta III**

Water is needed for revegetation and chemical reactions and as a product carrier to transport coals and wastes in the preparation plant and to the refuse disposal areas. Generally, an excess of water is a concern in humid regions, and a deficiency of water is a concern in arid regions. Excess water can cause erosion, slope failure, and offsite transport of contaminants; deficient water can impair revegetation efforts. Precipitation and other inflows of water to a site can be lost as evapotranspiration, surface runoff, and ground-water outflow or seepage from a site. Even in humid regions, potential evapotranspiration can exceed precipitation seasonally, causing drought conditions in soil and shallow spoil. Such conditions can concentrate soluble, metallic-sulfate salts within the plant-root zone. On the other extreme, storms and sustained precipitation can produce saturated conditions, runoff, and ground-water seepage which can lead to dissolution of minerals and transport of acid, sulfate, and toxic metals to aquatic ecosystems.

#### 12.3.2.1 Quantity and Quality

The quantity and quality of surface and ground water at a site can vary temporally and spatially. Variations in water quantity are influenced by weather, geology, and drainage characteristics at a site. Variations in water quality are influenced by many interdependent factors, including the flow paths and flow rates of water and the relative abundance and distribution of acid-forming and alkaline-forming minerals in overburden, mine spoil and coal left in the ground. Many of these factors can be affected by mining and engineering practices that alter the distribution of, and contact between, water and reactive minerals.

The chemical composition of water at a site generally is related to that of the coal and overburden and reflects the extent of mineral weathering along flow paths. For example, pre-mining seeps from shallow zones (less than 10 m) in the Northern Appalachian coal field commonly yield waters that are dilute and poorly buffered. Relative to deeper zones, reactive minerals in shallow zones have been depleted by weathering, which can increase porosity and permeability and decrease water residence time (Brady and others, 1996). Hence, water and rock samples from outcrops and shallow overburden may not reflect the composition of deeper overburden and coal. Ground water from deeper zones, such as hill cores, commonly is more alkaline and mineralized than that from shallow zones; alkalinity in pre-mining ground water may indicate the presence of carbonate minerals that may or may not be

encountered by boreholes used for overburden sampling.

Water samples from surface and underground mine discharges commonly are extensively mineralized because unweathered, reactive minerals are exposed by mining. In backfilled surface mines, regardless of mining methods used, spoil tends to be inverted relative to its stratigraphic sequence in bedrock; unweathered material commonly is placed near the land surface, which can promote oxidation and other weathering reactions. The quality of water from surface mines generally reflects the composition and reactions in exposed overburden materials in the backfill. However, the quality of water from underground mines generally reflects the composition and reactions in exposed seat and roof rocks and coal pillars. Subsidence features and fractures associated with underground mining also can expose overburden to weathering and can intercept surface waters, potentially dewatering streams.

Acidic, mineralized water can be produced by the accelerated oxidation of iron-sulfide minerals that are exposed to oxygen, water, and bacteria during and after mining. Pyrite ($FeS_2$) and, less commonly, marcasite ($FeS_2$) and greigite ($Fe_3S_4$) are the primary sulfur-bearing minerals in coal and overburden; secondary iron-sulfate minerals also can be important reactants contributing to the formation of acidic water. Oxidation of iron sulfides can be rapid in humid air even if oxygen concentrations are substantially reduced from atmospheric concentrations (Hammack and Watzlaf, 1990).

Acidic water (pH less than 4) from coal mines typically has elevated concentrations of sulfate (greater than 500 mg/L), the predominant anion instead of bicarbonate or chloride, and elevated concentrations of iron, aluminum, manganese, magnesium, and calcium as major cations (greater than 100 mg/L). Because most cations are relatively soluble under acidic conditions, elevated concentrations of potentially toxic metals (greater than 0.1 mg/L) including cadmium, chromium, copper, lead, nickel, and zinc also are common in acidic discharges. However, concentrations of nutrients, including nitrogen compounds, phosphorus, and potassium typically are not elevated relative to background water from unmined sources (Dugas and others, 1993). Additions of nutrients to spoil, as fertilizer or sewage sludge, to promote revegetation has potential to promote bacterial catalysis of acid-forming reactions .

Acidic water can be neutralized by reactions of the water with carbonate, aluminosilicate, and hydroxide minerals in coal-bearing rocks. The most acid-reactive minerals are the carbonates: calcite ($CaCO_3$), dolomite [$CaMg(CO_3)_2$ ], and siderite ($FeCO_3$). Carbonates can be present as individual mineral grains and as cementing agents in limestone, dolostone, sandstone, siltstone, and shale. Dissolution of calcium- and magnesium-bearing carbonate minerals produces alkalinity (bicarbonate, $HCO_3^-$). However, dissolution of siderite, because of oxidation and hydrolysis of iron, can produce acid (Cravotta and others, 1990). Calcium, magnesium, iron, and manganese may substitute for one another in calcite, dolomite, and siderite. Hence, carbonate minerals, notably siderite, can be important sources of iron and manganese in mineralized, alkaline water.

#### 12.3.2.2 Characterization and Mitigation Strategies

SMCRA requires potential coal mining operations to collect baseline information on hydrology and on surface- and ground-water quality at the proposed mine site (Section 12.2.1.1 and its subsections). Also, a water-quality monitoring program must be developed that includes surface- and ground-water stations upgradient and downgradient from the proposed disturbance. Even when not required for permitting, the baseline information is useful for planning appropriate waste management. Knowledge of the depth to the water table in the vicinity of mining is necessary to determine both the costs of potential required dewatering operations and the most appropriate locations for any required selective placement of pyritic waste. (See Section 12.3.3 for a discussion of how to predict the acid producing potential of waste.)

Segregation of pyritic strata during mining and then burial of this material in compacted pods, which are encapsulated with alkaline materials, below the plant root zone in backfill has potential to reduce water-quality degradation at surface mines. Placement of pyritic materials in compacted pods above the water table and installation of limestone-filled diversion structures within backfill can minimize transport of acid and oxidation products and can add alkalinity to recharge water (Geidel and Caruccio, 1984). Placement of pyritic materials below a permanent water table in backfill to minimize oxidation commonly is not practical because oxidation takes place during and after mining, before the water table rebounds, and because of seasonally thin saturated zones (Cravotta, 1994, Cravotta and others, 1994).

The addition of limestone or other alkaline additives to spoil, to promote the subsurface production of alkalinity, can be an effective method to abate acid discharges. However, large quantities of limestone and deep incorporation of alkaline additives, to be above and below pyritic zones in the spoil, may be needed.

### 12.3.3 WASTE
**by L. H. Filipek**

Waste is created during mining of coal and during preparation (cleaning) of the mine product. During surface mining, large quantities of overburden rock, commonly called "spoil" or "gob," are backfilled into

previously mined portions of the pit. In contrast, underground mines produce relatively small amounts of waste that may be disposed of either inside or outside the mine. Much of mine production from both surface and underground operations is cleaned in preparation plants to reduce impurities that can be sources of air pollutants when the coal is burned. (These pollutants are discussed in Section 12.3.1.) The refuse from the cleaning operations is disposed of within disturbed portions of the permit area. If a mining company has several neighboring mines, one active site is usually selected for preparation refuse disposal.

### 12.3.3.1 Baseline Characterization

Both the mine spoil and the preparation refuse can contain pyrite and other minerals of potential environmental concern. In the refuse, sulfur contained in pyrite and some metals, including cadmium, chromium, mercury, nickel, lead, and zinc, can be concentrated by factors of about three to ten compared with raw coal (NRC Committee, 1979). During the course of mining, the most common environmental problem associated with coal mine spoil or preparation refuse is drainage that is acidic or contains unacceptably high concentrations of metals, as discussed in Section 12.3.2. (In rarer circumstances, drainage can be unacceptably alkaline.) Both planning and practice for waste stabilization and reclamation must be adequate to minimize environmental impacts.

SMCRA requires potential coal mining operations to provide information on the hydrology, geology, and geochemistry of potential future spoil and refuse for permitting purposes (Section 12.2.1.1 and its subsections). This information can include depth to the water table; baseline surface- and ground-water quality; geologic logs of test holes drilled through the coal and overburden; lithologic descriptions, including rock types, degree of weathering and color; locations and characteristics of joints and faults; stratigraphic correlations of all strata and estimates of relative volumes of each lithology; descriptions of sulfide and carbonate minerals; and acid-base accounting on representative rock samples of each lithology.

#### *12.3.3.1.1 Acid-Generating Wastes*

Acid-base accounting is a means of determining whether waste material, in this case spoil or refuse, can produce acid drainage. The acid production potential (AP), sometimes called maximum potential acidity (MPA), is a function of the amount of iron sulfides present, as discussed in Section 12.3.2. The acid neutralization potential (NP) is mainly a function of the calcium and magnesium carbonate content.

The Sobek calculation method is most commonly used for acid-base accounting. This method assumes that all sulfur in the material is in the form of pyrite ($FeS_2$) and that the neutralizing component consists entirely of calcium carbonate. In calculating AP, a conversion factor of 31.25 is used to convert weight percent total sulfur to the equivalent weight of calcium carbonate needed to neutralize the acid, in grams per 1,000 grams (g/kg). This conversion allows a direct comparison between AP and NP values. The value of 31.25 assumes an open system in which all carbon dioxide formed in the neutralization process is lost to the atmosphere. However, in a closed system, the conversion factor should be doubled, to 62.5 (Cravotta and others, 1990). In any real situation, the value could range between these two extremes.

Several criteria have been recommended by various researchers regarding the interpretation of acid-base accounting results. One criterion relates to the net neutralization potential (NNP), which is the difference between the NP and the AP (NNP = NP - AP) of a sample. Originally, Sobek suggested that an NNP of -5 g/kg would be sufficient to mimic the slightly acid soils commonly found in the East, based on agronomic considerations. However, many mines meeting this guideline have produced acidic drainage. Several studies have indicated that prediction of water quality becomes uncertain as NNP approaches zero (NNP between about -20 and +20 g/kg) for drainages from both coal and metal mines (Erickson and Hedin, 1988; Lapakko, 1992; Brady and Cravotta, 1992). That is, the waters from mines within this range sometimes are acidic.

Use of the conversion factor of 31.25, rather than a higher value, could account for some of the discrepancies. An additional problem with employing the NNP is that it sometimes represents a relatively small difference between two large numbers. A more conservative criterion involves the ratio of neutralization potential to acid production potential (NP/AP). If the NP/AP ratio is less than one, then the material is considered an acid generator. Other researchers have found that mine sites with NP/AP ratios less than about 2.4 usually produced acid drainage; whereas, those with ratios above 2.4 generally did not (diPretorio and Rauch, 1988).

Three additional factors are likely to account for the lack of predictability as NNP approaches zero or the NP/AP is between about 1 and 2.4:

- As mentioned previously, acid-base accounting typically measures total sulfur under the assumption that all sulfur is in pyrite or other forms that can generate acid. In many cases, a significant percentage of the sulfur is in non-acid producing sulfate and/or organic sulfur forms. Use of total sulfur would thus overestimate the acid producing potential of the material.
- Acid-base accounting is a "static" test, which means

it measures the maximum amount of acidity and alkalinity produced, assuming all acid producing and neutralizing components will react to completion. In real weathering situations, the carbonates commonly dissolve relatively rapidly; whereas the sulfides may oxidize more slowly. In such cases, drainage is initially alkaline but eventually turns acidic. Sulfide oxidation itself promotes carbonate dissolution. Eventually acid conditions may develop if carbonates become depleted along the flow path or become "armored" by precipitation of iron oxides. Also, the two opposing mineral components may not be in close proximity, so that acid and alkaline waters may be produced from different areas within the same spoil pile. As discussed in Section 12.3.2, the stratigraphic sequence within a spoil pile is typically inverted or randomly mixed and is thus quite different from that of the overburden strata prior to mining.

- For most mine sites, the details of stratigraphy and the variability of pyrite and carbonate occurrences within the coal and overburden are not well enough known to choose a truly representative suite of samples before mining begins. A representative suite of lithologies must be available for testing in order to develop an accurate volume or tonnage-weighted average of the material characteristics by rock type and lithology. Composite samples of each lithology from drill cores is a good first step. However, composites give no indication of the variability within a lithology. In the absence of such detailed knowledge, a large number of individual samples must be collected to ensure statistical validity. The required number of samples is seldom, if ever, collected due to the prohibitive cost.

Various partial extraction tests have been developed to look at individual sulfur forms, such as sulfate sulfur, pyritic or sulfidic sulfur, and organic sulfur. These tests can give a more accurate measurement of the amount of sulfur in a sample that has potential to produce acid. However, the extractions may not be exact because mineral crystallinity and element substitutions can affect a mineral's solubility. Also, sulfates are typically considered non-acid-generating, even though some sulfates can, in fact, generate acid.

Several "kinetic" or "dynamic" tests have been developed to simulate the weathering environment and investigate the relative dissolution/reaction rates of the carbonates and sulfides. These tests are often recommended or required when acid-base accounting results indicate a NNP between about -20 and +20 g/kg. The common types of tests include humidity cells, columns, shake flask tests, Soxhlet reactors, and bacterial tests. Each test is designed for a specific purpose. For example, humidity cell and column tests are designed to mimic dry spoil piles. Shake flask tests can mimic undrained slurry impoundment of fine refuse. Soxhlet tests use elevated temperature to speed up the oxidation process. Bacterial tests use an inoculum of sulfur-oxidizing bacteria and may be combined with other kinetic tests.

The kinetic tests have been shown to be better predictors than acid-base accounting when NNP approaches zero. However, all the kinetic tests are significantly more expensive than acid-base accounting, and, except for the Soxhlet reactors, they require considerable amounts of time, typically a minimum of 10 weeks to over a year. Finally, they cannot investigate the effects of variations in lithology and flow path on drainage water quality. Such effects can only be addressed in tests on the scale of small spoils piles.

#### *12.3.3.1.2 Sampling*

The development of an appropriate, cost-effective sampling strategy requires a better knowledge of the roles of depositional and post-depositional environments in the formation and concentration of pyrite and carbonates than is presently known. Experience in the Eastern United States has shown that acid or metal-rich drainage from the same coal seam in adjacent mines is one of the best indicators of potential acidic drainage at a proposed mine, most likely because of similar paleoenvironments at both sites. Caruccio and others (1977), working in eastern Kentucky, and Hornberger and others (1981), working in Pennsylvania, suggested that knowledge of the paleodepositional environment of coals and associated strata could be used to predict whether a coal mine would produce acidic drainage. The Caruccio group reported that acid mine drainage was associated with back-barrier and lower delta plain strata, but not with upper delta plain strata. The Hornberger group suggests that shales deposited in a brackish environment are more likely to be rich in pyrite and poor in carbonates than either freshwater or marine shales and are thus more likely to produce acid drainage if they are present as roof rock. Additional research is presently underway by scientists in federal and state government agencies and universities to develop models using the paleodepositional environment of the coal and overburden to predict the water quality from a future coal mine.

Section 12.4.2.1 discusses waste management techniques to mitigate potential acid drainage from spoil piles or refuse impoundments. These include selective placement techniques to segregate high-pyrite overburden; addition of neutralizing amendments, such as limestone, phosphate, or coal ash; addition of organic matter to inhibit oxidation and/or surfactants that act as bactericides to the bacteria that oxidize pyrite; and encapsulation in compacted spoil or local fine-grained soils. The geochemical effectiveness of various

amendments can be tested using some of the kinetic tests, such as columns or humidity cells. The chemical effectiveness of local soils and/or local rock units to attenuate metals and acid from waste drainage can also be tested using columns or sequential batch tests (Houle and Long, 1980).

If acid drainage already exists at a site, active and passive treatment methods are available to bring the water quality into compliance. The most common active methods are addition of lime or sodium hydroxide, which can be costly if the water must be treated "in perpetuity." Passive constructed wetlands (Section 12.4.2.3.4) have low maintenance costs but must be properly designed, based on the flow rate and chemistry of the water to be treated and the climate.

## 12.4 MITIGATIVE DESIGN TECHNIQUES

Many environmental issues can be mitigated by front-end planning and design. However, unless site and waste characteristics are factored into the design strategy, the overall environmental management program goals may be defeated. Site characteristics such as geology, hydrogeology, surface hydrology, and soils are the receiving media into which pollutants are released. The geochemical behavior of the materials and wastes produced by the mining operation on these receiving media is a fundamental component of the design process.

Engineering designs are typically intended to contain or isolate waters and/or wastes that may otherwise adversely affect the environment. In this regard, the design can be considered the intermediary between the waste and the receiving media. To disregard either waste or site characteristics in the design process will likely undermine the overall environmental management program goals.

This section is intended to introduce some design concepts that may be appropriate for mitigating impacts to the environment. It is not intended to be comprehensive, and is certainly not intended to suggest that these concepts are appropriate in all circumstances.

### 12.4.1 MINE PLANNING AND DESIGN

Drainage control is probably the most significant mitigative design technique practiced in mine planning. For surface mines, preparation plants, and surface facilities supporting underground mines, effective sedimentation control measures must be practiced at all times to avoid adverse impacts to receiving waters. Typical sediment control structures include sediment ponds and basins, filter fabrics, straw bales, and rock gabions.

With the 1987 Amendments to the Clean Water Act, the U.S. Environmental Protection Agency has developed guidance documents for the control of sediment from disturbed areas. While coal mine sediment control is excluded from the purview of the Clean Water Act requirements due to federal oversight under the OSM program, the documents provide a good reference as to the planning and design for sediment control. It is noted, however, that effluent from sediment ponds is subject to the requirements of the National Pollutant Discharge Elimination System (NPDES) permit program under the Clean Water Act.

Underground mines can intercept ground water systems, requiring water handling to maintain dry working areas. In these cases, mine planning is extremely important, not only from an environmental perspective, but also from the cost of water handling perspective. In designing mine water collection and dewatering systems, consideration should be given to the overall mine development goals, geologic exposure at accumulation areas (so that adverse geochemical reactions are minimized in these areas), retention times, and settling characteristics. Settling of particulates in underground sumps is usually preferred over outside settling or filtering prior to release. Off-site discharges from underground mines and sumps must meet NPDES discharge requirements.

Some underground mines use backstowing techniques for disposal of development wastes. Where mine wastes are being disposed of in the underground, the geochemistry of the wastes and the hydrogeological condition of the disposal area are of paramount importance. Disposal methods may vary depending on whether the waste has the potential to generate acid and whether ground water will be present over the long term. Both MSHA and OSM or its state delegate program have jurisdiction over underground backstowing practices. A discussion on mitigative strategies for potentially acid-generating materials is included in Section 12.4.2.1.

SMCRA has very specific requirements for protecting water resources and restoring impacted resources. Detailed hydrologic inventories and technically adequate hydrologic reclamation plan must be developed as part of the front end planning in order to obtain permits to operate (Section 12.2.1.1 and its subsections).

### 12.4.2 REFUSE DISPOSAL AND WATER MANAGEMENT

Preparation plant refuse disposal areas often are among the largest disturbed during a mining operation. As discussed in Section 12.1.3, plant refuse is usually produced as wet coarse refuse and a fine refuse slurry. Section 12.3.3 points out that plant refuse is typically more concentrated in metals and acid producing potential than the raw coal because the pyrite and other metals are usually contained in the waste rock rather than the coal product.

#### 12.4.2.1 Acid Mine Drainage

Acid-forming reactions in mine wastes require three components: oxidizing conditions, water, and reactive rock. Sulfides exposed to oxidizing conditions will react with water to form sulfuric acid in the off solutions. If the reactive refuse is exposed to oxidizing conditions without coming into contact with water, there is no transport medium to cause environmental degradation. Therefore, the goal of an acid drainage mitigation plan is either to mix potentially reactive refuse with net neutralizing materials to the extent that the mass abates acid forming reaction or is net-neutralizing, or to minimize the potential for water and/or air to come into contact with the reactive refuse.

Waste characterization (Section 12.3.3) is normally accomplished to represent the reasonably foreseeable mine life for permitting purposes (Section 12.2.1.1). When the total volumes of anticipated acid-generating and acid-consuming wastes have been determined, the most appropriate alternative for handling of the acid-generating wastes over the long term can be determined.

Free pyrite is a common component of acid-generating coal refuse. For coarse refuse, the pyrite is usually disseminated among the overall gob mass. Placement of coarse refuse is most often accomplished by truck dumping. Assuming the plant feed is a relatively homogenous blend, this also results in a comparatively homogenous gob that has similar acid-generating characteristics throughout the mass.

There are many alternatives for mitigating acid-forming reactions in gob piles. Some, used singularly or in combination, may include compaction to minimize the permeability of both air and water through the pile; capping with a low-permeability, non-acid forming material such as topsoil or borrow; amendment of acid-generating materials with neutralizing agents such as lime or phosphate either as a surficial layer, as periodic layers, or intermixed within the pile; placement of oxygen-consuming materials such as organics to promote anoxic conditions; and establishing positive drainage on the outer surface to promote surface runoff and minimize infiltration.

Fine refuse is most commonly pumped to a refuse disposal facility in slurry form. As slurry is placed into a disposal facility, there is a natural tendency for beaching of the coarser, heavier particle sizes near the point of deposition. Conversely, the finer, lighter particles tend to flow away from the distribution source. This is an important aspect to consider in developing an acid mitigation program, as the pyrite material is among the heavier particles and will tend to deposit nearer to the distribution source (Nawrot, 1993). Depending on the pyrite occurrence in the refuse, there may be zones of acid-generating materials near the discharge point and non-acid-generating material at points further out (i.e., separation by specific gravity).

As with coarse refuse, there are a number of strategies for abating acidic reactions in fine refuse disposal facilities. Some may include adding neutralizing materials, such as lime, to the slurry discharge (selective placement may be accomplished by using a coarser lime product such as limestone to selectively deposit the neutralizing agent near the discharge source where the pyrite tends to deposit); capping with a low-permeability, acid consuming material such as soil or borrow to minimize air and water infiltration; creating positive drainage from the facility, or at least off of the acid-generating refuse, to minimize air and water infiltration.

The cover design for acid-generating waste is driven by the need to minimize the potential for water infiltration into the sulfide zone. To this end, acid mitigation strategies are often designed as multi-layer systems of varying thicknesses and permeabilities to minimize infiltration and promote runoff and lateral drainage. A seepage model can then be used to predict the potential for seepage from the system.

An easy-to-use model that is publicly available, free-of-charge (there may be some reproduction charge for the software documentation) from the U.S. Environmental Protection Agency (EPA), is the Hydrologic Evaluation of Landfill Performance (HELP) model (U.S. Army Corps of Engineers). This model simulates water infiltration through layered soil and synthetic liner systems and allows the estimation of components such as evapotranspiration, percolation, storage changes, and lateral drainage. The model may be an appropriate simulation of unsaturated mine waste disposal systems because it evaluates the hydraulic characteristics of placed materials within unique layers based on physical properties such as permeability, soil moisture capacities, and drainage layer configurations. There are other seepage models available that may also be appropriately applied; the HELP model is identified here because it is available to the public at little or no cost.

#### 12.4.2.2 Anticipating Reclamation

During front-end planning for any mine facility, reclamation requirements should be anticipated and included in the design. The final slopes for coarse refuse piles should be gauged during the placement process so that significant post-mine grading is not necessary. Materials can be placed at the reclamation slope during active operations, or benches can be incorporated with angle-of-repose slopes. Benched slopes can be constructed into the waste-placement plan to the final reclamation slope when measured from toe-to-toe. This method requires a minimum amount of surface grading to construct the final reclamation slope.

Impounding structures must be designed for long-

term stability, both during the operational and post-closure phases. Some refuse impoundments may be closed in a non-impounding manner when refuse can be capped. This will usually change the operational design stability assumption and may require re-evaluation to demonstrate the structural integrity of the facility for reclamation. Usually, dewatered and capped facilities are more stable than their water-impounding counterparts.

Fine refuse reclamation can be problematic when placed into the disposal area in a saturated condition. Entrained water in the stored refuse can cause liquefaction as reclamation caps are placed, resulting in a need for additional cap construction material that may not have been anticipated by the reclamation plan (Filas and Zmudzinski, 1993). If coarse refuse was expected to be used as a cap material, as it often is, material shortages can problematic after the plant is shut down because there is no longer a source of additional coarse refuse.

Dewatering stored fine refuse in a refuse storage facility can be accomplished in several ways. The simplest method is to anticipate the reclamation requirements during the storage facility design phase and provide a means of hydraulic relief suitable for the refuse being stored. With some coals, an underdrainage layer at the pond bottom can provide an effective means of relief; other coals will blind a drainage layer, rendering it ineffective for dewatering. Therefore, it is important to understand the physical characteristics of the refuse for facility design.

Managing the slurry distribution from multiple discharge points around the perimeter of the facility may result in a more dense stored refuse. Some slurries can be effectively managed to form a gently sloping beach toward a localized water reclaim area. Storing refuse as a solid beach rather than a liquid slurry has some distinct advantages:

- Reducing the volume of entrained moisture in the refuse results in higher stored densities in the facility;
- Higher stored refuse density will require less volume in the storage facility to store the same amount of refuse (i.e., lower embankment heights, less construction material); and
- Non-saturated refuse has less potential for liquefaction, making it more amenable to reclamation cap placement.

When slurries are stored in a saturated condition, there may be little or no strength characteristics in the stored refuse solid. In these cases, it usually is necessary to stabilize the surface or improve the strength properties of the stored refuse to facilitate capping. These procedures are typically costly.

The surface may be stabilized by overlaying the fine refuse with a suitable-strength material to allow the cap to "float" on the refuse surface. A geotextile layer, or a gravel or polyethylene drainage net sandwiched between geotextile layers, may be appropriate to establish a suitable hydraulic break between the low-strength fine refuse and the cap material. High tensile strength materials such as Tensar (Tensar Corporation, Morrow, GA) may be appropriate either singularly or in combination with geonet. Consideration for hydraulic relief is important to stabilization designs because the surcharge imposed by capping will tend to liquefy the fine refuse below.

The strength properties of stored fine refuse may be enhanced by dewatering. Where the storage facility design does not allow for hydraulic relief, the use of drainage systems may be appropriate. Wick drains (Nilex, Englewood, CO) may be installed vertically into the fine refuse mass. These drains are designed on the premise that surcharging a load on saturated material will force the pore water into the vertical drain for pressure relief. The weight of the surcharge (cap material) forces the water in the drain to flow "uphill" and out of the drain at the surface, thereby consolidating the stored refuse and improving strength characteristics.

In addition to stabilizing stored fine refuse, reclamation alternatives should always consider the ability to mitigate against any potential adverse chemical reactions and also provide for adequate stormwater management and control. Ideally, these considerations can be incorporated into the front-end design and operating practices with minimal impact to the coal washing operations. Mitigation techniques are often costly when applied after the operations are terminated.

Consideration should always be given to the surety requirements (Section 16.4.1) and other financial advantages associated with accomplishing the reclamation concurrent with the mining operation. Whenever possible, contemporaneous reclamation should be practiced. Development and operation plans that include a commitment to ongoing reclamation during the operational phase typically have the following cost advantages over those that address the reclamation obligations at the end of operations:

- Reduced surety requirements due to the activities accomplished as part of the operational commitments.
- Reduced maintenance cost associated with controlling sediment from unreclaimed disturbed areas.
- Reduced equipment mobilization cost due to equipment availability on-site during operations.
- Reduced capital cost for reclamation by absorbing reclamation cost as an operating cost.

### 12.4.2.3 Water Treatment

As discussed in Section 12.4.2, acid drainage is a common water quality issue for coal mines. Acid drainage is a solution of sulfuric acid and iron sulfate, with iron in the ferrous and/or ferric form. It typically has elevated concentrations of manganese and may contain varying concentrations of other heavy metals.

Most conventional treatment methods use an acid neutralizer, such as lime or caustic soda. An aeration/oxidation step is often added in the treatment process to oxidize any reduced iron. The oxidized iron will precipitate as a ferric hydroxide at pH's above 4, whereas the reduced iron requires a pH of at least 8 to precipitate. The cationic metals are less soluble in basic than acidic solutions and tend to co-precipitate with ferric hydroxide so the neutralization/aeration process tends to precipitate the metals (EPA, 1983).

#### *12.4.2.3.1 Conventional Lime*

The conventional lime treatment process typically includes at least five basic treatment steps: collection, neutralization with lime, aeration, settling and/or sedimentation, and sludge disposal. The ferric hydroxide sludge produced from acidic solutions is a gelatinous mass with very low solids content, often less than one percent. Dewatering the sludge by settling, centrifuging, or filtering is required to reduce the sludge volume and thus the cost of disposal, as well as to salvage water for reuse.

The major considerations with conventional lime treatment are the large sludge volumes generated, the maintenance costs associated with periodic removal of calcium sulfate scale build-up, and the potential of the sludge to be classified as a hazardous waste. Sludge with high concentrations of potentially toxic elements such as arsenic, lead, and cadmium may not pass the Toxicity Characteristic Leaching Procedure (TCLP) (U.S. EPA Method 1311) due to the ferric hydroxide floc formed with this method.

#### *12.4.2.3.2 High Density Sludge*

The chemistry of the high density sludge (HDS™) treatment process is the same as for conventional lime treatment. However, a portion of the sludge is recycled into the lime reaction vessel where the lime is adsorbed on the surface of the existing sludge particle. This seeding process results in a more crystalline-like sludge that is easier to dewater and may have a solids content on the order of 30% or more, thereby reducing the costs associated with sludge handling and disposal.

In additional to reduced sludge management cost, other advantages of the HDS™ process are the minimization of calcium sulfate scaling and the very efficient use of lime. Finally, the sludge may be more resistant to leaching by the TCLP test. The process was developed by the Bethlehem Steel Corporation and is now sold under patent by TETRA Technologies, Inc.

#### *12.4.2.3.3 Electrocoagulation*

Electrocoagulation uses an electrochemical process to precipitate iron and other metals from the waste water. In many cases, the precipitate is a less reactive form of hydrous ferric oxide than that precipitated using the lime process. Accordingly, the electrocoagulation precipitate may pass the TCLP test (thus classifying it as a non-hazardous waste) when the equivalent lime precipitate will not.

In the electrocoagulation process, an electrical charge is applied to the water being treated. The charge destabilizes ions and other charged particles and causes them to coagulate, forming larger, heavier particles. The particles are then removed by filtering, clarifying, or centrifuging. Typically, little or no pH adjustment is required for precipitation. Typically, water with an initial pH of 3 will have a final pH of about 5 with this process. If the final pH is lower than that required for discharge, a neutralizing agent must also be added.

#### *12.4.2.3.4 Passive Treatment*

Wetlands and bogs have long been recognized as nature's method of improving water quality. Passive water treatment using constructed wetlands is essentially a man-made simulation of the natural processes occurring in the environment (Figures 6 and 7). The design of a passive treatment system simply embellishes on those natural removal processes occurring in nature to improve the efficiency of the overall system and minimize the surface area required to accomplish effluent goals.



**Figure 6** Passive treatment of coal mine drainage using constructed wetlands. Courtsey: Tennessee Valley Authority.

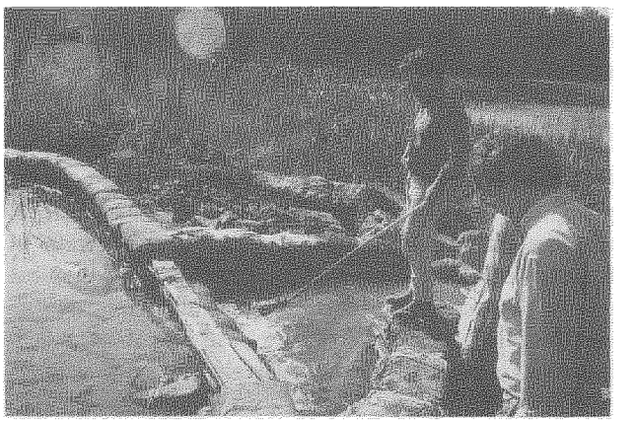


**Figure 7** Sampling of effluent discharge from passive treatment system. Courtsey: Tennessee Valley Authority.

Bacterial reduction of sulfate and iron and precipitation of metal sulfides are the important chemical processes in anaerobic passive treatment. The process essentially reverses the reactions that occurred to produce the acid drainage. Reactive sulfides from the mine react with air and water to form acidic drainage under oxidizing conditions; the anaerobic reducing zone in the passive treatment environment generates sulfides under reducing conditions as the solution passes through the system. The result is an accumulation of sulfide precipitates within the anaerobic zone which would otherwise be carried in the effluent.

In an anaerobic system reduction occurs in the subsurface, so subsurface flow through the wetland is critical to effective treatment. Also, sustained inundation of substrata must be accomplished to minimize the potential for future acid-forming reaction and subsequent remobilization of metals. Accordingly, the wetland must be appropriately engineered. Engineered anaerobic systems have exhibited successful results in pH improvement and metal removal on a number of mine discharges (Hammer, ed., 1989; Wildeman and others, 1991; Filas and Wildeman, 1992).

The dominant process treating acid drainage in a surface flow aerobic wetland is oxidation of iron and precipitation of iron hydroxides. Aerobic wetlands require sufficient alkalinity in the water to keep the pH from falling as a result of the hydrolysis of iron. An anoxic limestone drain can sometimes be installed before the wetland to add alkalinity and raise pH if no iron (III) is present in the initial drainage. This type of wetland treatment works best on coal mine drainages with low concentrations of other heavy metals. While anaerobic systems have successfully reduced iron and manganese concentrations in some cases, these metals have not been consistently removed using anaerobic wetlands. Work with aerobic wetlands on coal mine drainages has successfully and consistently removed iron and manganese to acceptable regulatory levels (Brodie, 1991),

### 12.4.3 FLY ASH DISPOSAL

Some coal sales contracts may include provisions for the mine to receive and dispose of the combustion by-products associated with burning their coal. The solid waste produced from the burning of coal is referred to as fly ash. It consists of the non-combustible solid component in the clean coal shipped to the power plant. As discussed in Section 12.3.3, it usually contains elevated concentrations of heavy metals because metals are concentrated in the non-combustible wastes by the burning process. Fly ash is typically alkaline and when fly ash is stored as a slurry, the rounded uni-size particles can settle at a relatively low density and high moisture content which is usually more subject to liquefaction. The alkaline slurry is also very prone to scaling and other pipeline problems.

Some fly ash may also have pozzolanic properties. Coupled with the typically low permeabilities, there may be some potential for its use as a grout or backfill material in underground areas prone to subsidence. There may also be a potential for use as a low permeability liner and/or additive to coarse refuse construction material. Permeabilities ranging from $3 \times 10^{-7}$ to $1 \times 10^{-9}$ cm/sec have been measured for fly ash (Burkhalter, 1987). Mixing fly ash with fine sand typically increases the permeability, but testing has shown that even mixed ash and sand can have permeabilities averaging $1.4 \times 10^{-7}$ cm/sec; still within liner permeability criteria.

Incorporating fly ash into any refuse management program requires the determination of the waste characteristics. It is important to evaluate the effects of adding the alkaline, metal-rich fly ash to the coal refuse, especially if the refuse is acid generating. Waste characteristics should be assessed, using a tonnage-weighted average of each constituent or other representative techniques, based on the anticipated plant throughput and the volume of fly ash the mine has agreed to take. This allows for an assessment of the geochemical characteristics of the mix to be determined and understood relative to the overall site environmental management goals.

#### 12.4.3.1 Construction Material Additives

Ash additions to coarse refuse or other fill materials for embankment construction or reclamation caps may have dual advantages. The pozzolanic properties of fly ash may reduce the permeability of the embankments and caps while at the same time add buffering capacity to the stored waste. Coarse refuse is usually the most common

construction material at coal mines. When coarse refuse construction materials have the potential to generate acid, adding a strongly alkaline fly ash may tend to buffer acidic reactions in the materials.

As with any soil amendment, the addition of ash to candidate construction materials can affect the strength properties of the combined material. Thus, in addition to the characterization testing that must be performed to understand the potential environmental impact aspects, physical testing must also be conducted to define the engineering strength properties of composite materials.

### 12.4.3.2 Liner Systems

Because of the pozzolanic properties and low permeability characteristics of some fly ash, there may be opportunities for using it as a low permeability liner or as an additive to local soils during refuse disposal area construction. The resulting low permeability soil may then function as a liner beneath the slurry impoundment. Above the fly ash liner, it may be appropriate to consider a drainage layer to reduce the hydraulic head on the soil liner to reduce the potential for metal mobilization in basin seepage.

Using fly ash as an impoundment basin soil amendment may require a demonstration that the refuse storage system will not adversely affect ground waters. This would typically be evaluated by testing the local soil's ability to attenuate contaminants (Section 12.3.3) and by evaluating the efficiency of the pond liner system.

### 12.4.3.3 Underground Backfill

Underground mines may allow the use of fly ash as a backfill to minimize subsidence. It may be feasible to mix ash with coarse refuse and pneumatically or hydraulically backfill to stabilize areas where long-term subsidence is an issue. Consideration for underground backfilling would also require characterization testing as previously discussed.

## 12.4.4 RECLAMATION
**by K. G. Whitman**

There are unique opportunities for the successful reclamation of the disturbances created by coal mining activities (Figures 8 and 9). Two of these are the ability to limit the soil storage interval, thereby enhancing opportunities for regrowth from the applied soil, and the ability to return the site to approximately the original topography. Because of the nature of seam mining, operators are able to remove soil a few hundred feet in advance of the pit and store it or place it directly on an area of concurrent reclamation. Generally, the storage interval can be managed to maximize potential for preservation of seed and microbial sources in the soil.

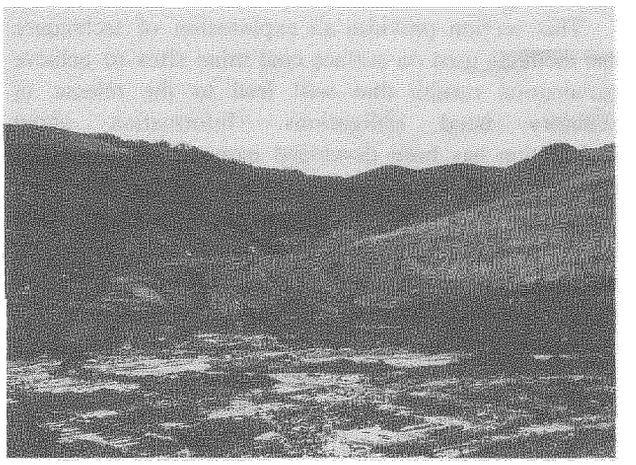


**Figure 8** The pre-reclamation disturbed area at the Seneca Mine has limited utility to support the planned post-mining land use as wildlife habitat. Courtesy: Colorado Division of Minerals and Geology.



**Figure 9** The reclamation program at the Seneca Mine has restored mined land to attractive use as wildlife habitat and wetlands. Courtesy: Colorado Division of Minerals and Geology.

After three to five spoil rows have accrued behind the active pit, regrading to approximate original contour can begin without interfering with on-going mining operations. Spoil material is recontoured and graded to

adhere with approved reclamation plans, thus meeting the regulatory goal of returning the character of the original topography and insuring drainage without excessive erosion.

This section provides an explanation of techniques and methods used on surface coal mine sites to achieve reclamation results that will lead to the release of statutory bond obligations. Information about reclamation has been developed extensively, especially since the late 1970's. Much formal research has been conducted. In addition, most coal mine operating staffs have developed their own catalog of data, based on observations in the field. Much of the body of reclamation knowledge is site specific. Climate, site chemistry, geology, soils, topography and the judgments of the relevant regulatory agencies are all important considerations when selecting reclamation methods.

### 12.4.4.1 Surface Grading and Shaping

Surface grading and shaping is accomplished using dozers on spoil peaks and earth-mover/scrapers, once the angles are reduced. Graders are used for smoothing and shaping the surfaces when recontouring is nearly completed.

SMCRA requires that mined land be returned to approximate original contour. Approximate original contour is defined in 30 CFR 701.5. "Approximate original contour means that surface configuration achieved by backfilling and grading of the mined areas so that the reclaimed area, including any terracing or access roads, closely resembles the general surface configuration of the land prior to mining and blends into and complements the drainage pattern of the surrounding terrain, with all highwalls, spoil piles and coal refuse piles eliminated..." A plan for backfilling and regrading is a required part of a mine permit. An approach to developing a backfilling and grading plan follows.

#### *12.4.4.1.1 Assess the Pre-mining and Post-reclamation Contours*

In order to return mined lands to their post-mining land use, pre-mining cross-sections are evaluated to aid in the selection of post- reclamation slope and drainage configurations. Of critical importance to post-reclamation slopes is the overburden balance. To insure a reasonable slope angle at the final highwall, maintaining an overburden balance for the life-of-mine is necessary. Average pre-mining slopes can be determined using representative corridors from base maps obtained from standard aerial photo mapping. A corridor, as differentiated from a random section, is aligned so that the section extends from the top of a ridge, for instance, through the valley bottom and up to the next ridge. This process accounts for the entire slope of the valley-to-crest sequence. The process reflects actual slopes and guards against the misrepresentation of slopes which may occur from random sections (that may cut through the side of a hill, for example).

#### *12.4.4.1.2 Determine the Post-Reclamation Surface*

Computer technology aids greatly in the development of the reclaimed surface. A CADD-aided or similar system can be used to calculate the volume of overburden and coal in each pit. Accounting for the loss of volume (from coal) and the increased volume (from overburden swell), the new material volume can be "placed" into the previously mined pit by the computer. A pre-graded map is then plotted. Reduced slope angles and shapes of slopes are generated based on information from the contour assessment.

Careful analysis should be given to the shape of the slopes. Recontoured slope segments will be either concave, convex, flat, or straight. A concave slope below a straight slope will result in sediment deposition. A preferred slope profile is convex-straight- concave. Concave slopes at the toe of a hill are an effective mechanism for sediment deposition.

#### *12.4.4.1.3 Develop the Regraded Spoil Plan*

A map of the final regraded surface is a helpful field tool to insure reclamation objectives are achieved. Surveyed elevations taken during the regrading process and compared to the map will insure that grading is within a reasonable margin of the developed post-reclamation contours.

#### *12.4.4.1.4 Assess the Post-Reclamation Slopes*

An evaluation of the results of recontouring efforts and their adherence to reclamation goals should be conducted. These goals may include: 1) leaving the slopes with angles that are lower than angle of repose, 2) providing drainage, 3) ensuring the reclaimed surfaces will support the post-mining land use, and 4) returning the approximate original contour.

#### *12.4.4.1.5 Consider the Final Highwall*

Final highwall reclamation generally requires the movement of large volumes of material. Some difficulties may be encountered while trying to achieve low enough slope angles without using borrow material, blasting the final highwall, or using some other method for accounting for any material shortages. An alternative that has been considered by some states is to leave final highwalls, creating cliffs and enhancing habitat for cliff-using species such as birds of prey, large predators, and

small mammals. While this reclamation practice is not common, it may be appropriate for certain habitats and surroundings.

### 12.4.4.2 Seed Bed Preparation

Reclamation success is dependent upon the preparation of a seed bed which will support the germination and subsequent establishment of revegetation species. Although site specific conditions will dictate on-the-ground reclamation practices, these procedures may apply in principle to most areas.

#### *12.4.4.2.1 Soil Salvage*

Soil salvage operations are conducted in advance of the active pit, at facility areas and at other areas of planned surface disturbance (Figure 10). Prior to the removal of soil, a soil survey is needed to define the soil resource. Soil surveys include the review of vegetation and geologic information, the review of aerial photos, the excavation of soil test pits. Soil pits are dug at representative locations based on vegetation, topography, and geology. Information about soil chemistry, soil horizons and depth, and physical characteristics are recorded. Soils are then categorized into units. Each unit will have a soil depth associated with it. This three-dimensional data is often entered into a CADD or GIS system. Soil volumes are calculated and soil maps with salvage depths are generated. Removal depths are staked on the ground with grade stakes. Soil is removed with scrapers or a loader/haul truck combination.



**Figure 10** Topsoil is excavated prior to surface disturbing activities. The material is stockpiled for later use in reclamation. Courtesy: Brad Walker and Cyprus Yampa Valley Coal Company.

#### *12.4.4.2.2 Stockpile Monitoring*

Soil is deposited at a stockpile location or, in some cases, placed directly on a regraded area. Stockpile locations are selected to minimize disturbance to the soils. If possible, soil should be located such that it will not have to be moved again prior to application to a reclaimed area. Soil stockpiles which are mound-shaped with low slope angles are less vulnerable to erosion. Soil stockpiles are seeded with a quick stabilization mix, which may include annual "cover-crop" species or fast-growing perennial grasses.

A life-of-mine soils balance is needed to insure the soil resource is used evenly throughout the mine life. A spreadsheet program can be used to monitor "deposits" and "withdrawals" from the soil stockpiles, calculated from scraper load counts or surveys.

Stockpiles should be evaluated prior to application to determine the soil's suitability to support vegetation. Possible parameters for analysis may include: pH, electric conductivity, saturation percentage, texture, nitrate, phosphorous, potassium, sodium absorption ratio, and any problem constituents such as boron and selenium. Stockpiles may require fertilizer or other amendments.

#### *12.4.4.2.3 Preparation of Regraded Spoil*

Generally, graded spoil is ripped on the contour with a dozer or blade to a depth of three feet or more. This loosens the compaction and creates a roughened surface for the contact with the soil, preventing soil from slipping along the contact.

#### *12.4.4.2.4 Soil Replacement*

Soil is replaced using scrapers or a loader/haul truck/grader combination to a specified depth determined by evaluating pre-mining soil depths and budgeting for the mine life reclamation acreage. Grade stakes can be used to keep track of application depths. An equipment traffic plan should be developed to minimize the number of times equipment must traverse freshly applied soil. Soil is then chisel plowed or disk plowed along the contour. Soil may be "rolled" with a roller harrow or cultipacker for an even surface, depending on the seed bed roughness and homogeneity that is desired.

### 12.4.4.3 Revegetation

SMCRA requires permittees to establish vegetation that is "diverse, effective and permanent; comprised of species native to the area, or of introduced species where desirable and necessary to achieve the approved post-mining land use...at least equal in extent of cover to the natural vegetation of the area, and capable of stabilizing

the soil surface from erosion." Seeding methods and seed mixes are selected with this mandate in mind.

Species for seed mixes are selected after evaluating the pre-mine vegetation communities, soil conditions, species availability, climate, and land use. Regulations generally call for seeding at the next possible seeding season after soil application. This practice conserves soil from water and wind erosion and may prevent the influx of weeds.

#### *12.4.4.3.1 Seed Mixes*

The selection of species for a seed mix is a site-specific activity. A good local or regional seed supplier is important to insure that the species varieties selected are adapted to the area. Depending on pre-mine plant communities, most seed mixes contain grasses, forbs, and shrubs. Shrubs may be planted in a separate seeding, as well. Seeds are usually sold on a pure live seed (PLS) basis.

PLS = % Germination x % Purity

Purity and germination information is shown on the seed tag of commercial seed. The PLS value indicates what percentage of the bag of seed is actually viable seed. Some native shrubs and forbs as well as custom collected seed can have PLS values of less than 60%. Therefore, it is important to determine how many live seeds per unit (e.g. square foot) are desired so the proper bulk seeding application rate can be calculated. For example:

If 10 pounds (PLS) of Sideoats grama with a germination of 78% and a purity of 90% is to be planted,

.78 x .90 = .70, then,

10 lbs. PLS ÷ .70 = 14.3 pounds of commercially bagged seed is needed to achieve 10 pounds of pure live seed.

#### *12.4.4.3.2 Seeding Methods and Cultural Practices*

Several combinations of seeding methods and cultural practices can be used on reclaimed areas:

*Fertilization.* Standard Nitrogen-Potassium-Phosphorous fertilizers can be used to enhance soil which has lost nutrient viability during the storage interval or is naturally low in a particular element.

*Amendments.* To correct major chemical problems in soils or underlying overburden materials, amendments (such as lime for some problem soils) can be applied prior to seeding.

*Mulch.* The use of mulches and cover or nurse crops has many advantages such as decreased effects from wind and water erosion, development of micro-habitats for better germination, reduction in colonization by weedy species and more. The seeding of a nurse crop usually involves seeding an annual, such as oats, and later interseeding the permanent seed mix. Straw mulches can be spread with modified farm bale spreaders or specialized mulching equipment and crimped into the soil with a crimping implement. The crimper bends the straw pieces in half and then mechanically pokes the bent straw into the soil. Long stems are important for the most effective mulch. Mulch should be considered a seed source and, therefore, free from weeds or other undesirable or highly competitive species.

*Drill Seeding.* Seed mixes are most commonly applied by the use a drill seeders. Rangeland drills or modified farm seed drills are both effective. Drill seeders can be purchased with discrete boxes designed for specific types of seeds. Some reclamation seed is "fluffy" and is not conductive to seeding through a conventional grass drill. These special seed boxes may contain agitators or large-diameter seed tubes or other specialized adaptations. Roller/cultipacker implements have the ability to plant seeds at shallow depths, which is very desirable due to the germination requirements of some reclamation species. These implements are less sturdy, in general, than a rangeland type drill seeder.

*Hydroseeding.* Seed may also be applied to reclaimed areas in an aqueous slurry. A mixture of seed, water, a tactifier, and sometimes a dye are sprayed on to the reclaimed area from the ground or air. This method works well for steep slopes or other areas where equipment access is a problem. Seeds may have met their requirement for germination shortly after application because of the presence of water.

*Broadcast Seeding.* Some species with very shallow planting depth requirements respond best to hand broadcasting.

### 12.4.4.4 Irrigation

The goals for use of irrigation must be evaluated carefully to insure that the purpose for using irrigation on reclaimed areas is not to develop vegetation that would not ordinarily be adapted to an area. This is assuming, of course, that the revegetation goal is a return to native rangeland, for example, and not a specialty use such as a golf course or other non-native result. Generally, irrigation is used to simulate favorable precipitation for germination and/or establishment, thus contributing to the chances of reclamation success. Most operators have found, however, that if conditions are

extremely unfavorable following an initial planting, several reseedings are more cost effective than irrigation.

Irrigation of reclaimed areas requires a suitable water source and a large capital-intensive distribution network of pumping systems, pipes, nozzles, sprinkler heads or drip heads, and operating and maintenance labor in order to be effective. Studies over the last 10-15 years have failed to demonstrate conclusively that irrigation improves reclamation success. Some of the concerns surrounding the use of irrigation include: 1) water quality may cause chemical changes in the soil which affect germination, 2) irrigation may select for water-loving plants at the expense of adapted, more drought-tolerant ones, 3) irrigation may have a negative impact on fungus-root associations which help drought-tolerant plants take up water, and 4) other cultural practices such as mulching, fertilizing and using fresh soil may be much more effective at a lower cost.

### 12.4.4.5 Enhancements

The prescribed post-mining land use often dictates the need to enhance reclaimed areas beyond the application of seed through a farm implement. For example, the creation of wildlife habitat is often needed. Some reclamation enhancements may include:

#### *12.4.4.5.1 Shrub Plantings*

The creation of areas with higher density shrubs or "shrub islands" will provide cover and food sources for mammals and reptiles. Shrubs can be transplanted using bare- or containerized-root-hardened nursery stock (Figure 11). Shrub density may also be increased by broadcasting the shrub mix in selected areas with optimal moisture characteristics, perhaps during the winter.

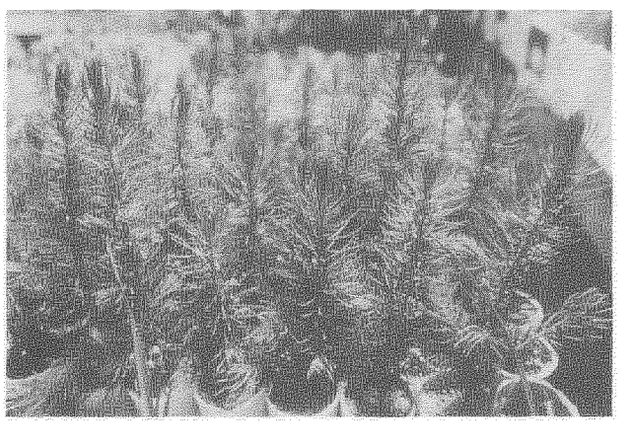


**Figure 11** Containerized shrubs are sometimes planted to enhance revegetation efforts. Courtesy: Cyprus-AMAX Minerals Inc.

#### *12.4.4.5.2 Rock Piles*

Stacks or piles of large, competent rocks may provide habitat for small mammals and nesting birds. Piles must be constructed such that predator species have difficulty scaling the pile.

#### *12.4.4.5.3 Drainage Reconstruction*

The design of the final configuration of drainages requires attention to pre-mine properties of the channels. The reconstructed channel should be similar with regards to channel width, depth, gradient, length, and materials to that of the pre-mine segment in order to avoid headcutting and scouring of the channel. Sediment transport characteristics should also be in keeping with the adjacent reaches.

#### *12.4.4.5.4 Cliffs/Highwalls*

Operators of mines which had many cliff formations prior to mining may consider leaving partial highwalls for raptor habitat. Highwalls are generally a much more suitable habitat for large birds of prey than are rock piles because of their height and inaccessibility to predators. Although this practice is more common to non-coal mining reclamation programs than it is to coal, it may offer a higher and better use of land features in certain ecosystems. Both Wyoming and New Mexico have reportedly approved highwall cliffs for raptor habitat as a suitable post-mining land use for coal mines.

#### *12.4.4.5.5 Impoundments*

Fresh water impoundments may enhance wildlife habitats and may be desired if livestock grazing is identified as a post-mining land use. Small embankments, similar to typical livestock ponds, require low maintenance and create little risk to downgradient land users. These ponds may help offset losses of pre-mine wet areas.

#### *12.4.4.5.6 Fencing*

If livestock grazing is a post-mine land use, agencies, allotment holders, or land owners may request fencing as a part of the reclamation plan. Fencing may also be needed to keep livestock and wildlife away from reclaimed areas while they are becoming established.

#### *12.4.4.5.7 Viewshed Management*

If the mining project is located in a visually sensitive area and can be viewed from public highways, roads, trails, or campgrounds, enhancements that address the visual offense may be required. Areas can be enhanced in a variety of ways specific to the site, such as by painting

roadcuts to match the surrounding weathered bedrock.

### 12.4.4.6 Methods to Determine Reclamation Success

Establishing with the regulatory agency that a reclaimed area is successful is important because it means the release of a company's long term obligation to a site and the release of bond monies. There are many schools of thought regarding the best way to determine reclamation success. Two reasons for monitoring the progress of vegetation on reclaimed areas are:

1) To evaluate the effectiveness of reclamation methods. This information may directly help in modifying seeding rates, species selection, time of planting, and equipment used. This interim monitoring of reclaimed areas is useful in evaluating the progress of reclamation during the conventional ten-year bonding phase.

2) To demonstrate that a reclaimed area is successful and ready for release from the bond obligation.

The types of monitoring discussed below will be useful for both needs. These methods represent only a few possibilities for monitoring scenarios.

#### *12.4.4.6.1 Seedling Density*

During the first and two subsequent growing seasons following a planting, small plots (20 cm x 20 cm) are placed at intervals of about 2 meters, along several randomly located 50-meter transects. Within each plot, seedlings are counted and recorded according to lifeform (perennial grass, annual grass shrub, forb, weed). Densities are calculated and expressed as plants per $m^2$. During the initial growing season, this method identifies which species germinated following seeding. The two subsequent monitoring periods will be a valuable comparison in terms of changes in relative occurrence of lifeforms.

#### *12.4.4.6.2 Cover*

Cover is an important measurement of the success of reclaimed territory because it can be directly compared to pre-mine control or reference areas. Several other statistical tests, such as diversity, can be produced from cover data. Generally, cover data are gathered by direct methods, using grids or points, or estimates are made following visual observation. Both methods can yield the percentage of vegetative cover and the percentage of relative cover of life forms or species.

#### *12.4.4.6.3 Production*

Production, sometimes called biomass, is the weight of the vegetation within a representative number of plots. All the vegetation in the plots is usually clipped and bagged by species, then dried and weighed.

#### *12.4.4.6.4 Shrub Density*

Depending on the size and distribution of shrubs, shrub density can be measured on reclaimed areas using discrete plots or belt transects. Belt transects (1M x 50M) are good for large shrubs. Shrubs are counted within the belt. Results are calculated and expressed as shrubs per square meter.

#### *12.4.4.6.5 Record Keeping*

Perhaps one of the best tools for insuring reclamation success is a database that holds detailed information about the treatments that reclaimed areas received. The database should contain information in the following categories:

Area name
Reclaimed vegetation type
Acres
Location (coordinates)
Slope
Aspect
Seeding date
Seed bed preparation
Soil depth
Seed mix
Seeding method
Fertilizer (type, amounts, date of application)
Mulch (type, source, amount, method, date of application)
Irrigation (amount, source, dates of application)
Precipitation/Evaporation
Temperature (high/low)
Special plantings/enhancements (date, type, source, location)
Soil application method
Soil stockpile number
Date of interseeding
Interseeding mix
Weed spray (method, type, amounts, date)
Type of surface preparation

### 12.4.4.7 Bond Release

To be released from bond obligations, reclaimed areas must be "at least equal in extent of cover to the natural vegetation of the area; and ... be compatible with the approved postmining land use; have the same seasonal

characteristics of growth as the original vegetation; be capable of regeneration and plant succession; be compatible with the plant and animal species of the area;" and be predominantly native (Section 6.6).

Vegetation criteria for determining reclamation success are generally negotiated as a part of a mine permit. The criteria will probably include 1) vegetative cover statistically similar to pre-mine vegetation (i.e., reference areas), and 2) the presence of all pre- mine lifeforms (cool season grasses, warm season grasses, annual grasses, shrubs, legumes, forbs, trees) within specified cover ranges. For example, a mine permit may specify the following relative percent cover:

5%-35% forbs
15%-70% cool season native grasses
5%-30% warm season native grasses
5%-25% shrubs

This method insures that the reclaimed area is not dominated by a single species or lifeform, and these criteria are not impossible to achieve as are other criteria proposed, such as diversity indices based on reference area cover data. Often, duplication of pre-mine plant communities is not necessarily the best possible result for reclamation, because overgrazing, overuse in recreational activities, or other factors had led to deterioration of the original land condition. This "lifeform ranges" method also allows for the selection of desirable climax or late seral species, regardless of the status and condition of the pre-mine community.

## 12.5 CONCLUSION

This chapter has provided an overview of the environmental and regulatory picture pertaining to coal mining in the United States. It is by no means comprehensive, but rather intended to give the reader an overview of the specific environmental issues pertaining to coal operations and the unique regulatory purview under which the industry operates. There are many other chapters in this Handbook that go into more depth regarding some of the environmental issues identified in this chapter, which should be referenced in concert with these discussions. Other publications that address the technical aspects of coal mining and preparation (Cassidy ed., 1973; Leonard ed., 1991; Hartman ed., 1992) are available to embellish some of the ideas presented in this chapter.

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# Chapter 13

# ACID MINE DRAINAGE AND OTHER MINING-INFLUENCED WATERS (MIW)

edited by R. L. Schmiermund and M. A. Drozd

## 13.1 INTRODUCTION

**by R. L. Schmiermund**

The origins of the phrase "Acid Mine Drainage" (AMD) are obscure but it was probably first used to describe the low-pH effluent from certain underground mine workings. In view of its common use today as a descriptive phrase applied to most types of mining-influenced waters, the term is inadequate due to its limited scope and consequently is often misleading. The more recent modification, "acid rock drainage" (ARD), de-emphasizes the obvious genetic relationship of mining to the vast majority of such waters but is unfortunately no more inclusive than its predecessor.

The objective of this chapter is to provide an overview of the characteristics of natural waters affected by mining activities (exclusive of direct contributions and discharges from milling and other beneficiation operations) and to briefly discuss the geochemical processes relevant to those characteristics. Such waters include groundwaters that enter underground workings and exit via surface openings or are pumped to the surface, groundwaters that enter pits or surface excavations and contribute to surface water courses, meteoric precipitation which, in the course of becoming runoff or recharge to surface water bodies, contacts pit faces, ore and waste-rock piles or tailings piles. Many such waters are indeed acidic with pHs significantly less than 7.0, thus giving legitimacy to the term "AMD." The fact that all these generic rock-water interactions may also take place, with similar impacts to water quality, in the absence of mining validates the term "ARD". Indeed, situations occur where ore bodies naturally outcrop at the surface and are actively weathering and impacting surface water courses. One such example is the Vangorda base-metal massive sulfide orebody near Faro, Yukon Territories. Others are described by Runnells et al. (1992) and Plumlee et al. (1993). These situations are rare compared to those where mining has been directly responsible for modifications of water quality.

Low pH is not a universal characteristic of natural waters influenced by mining. Drainage from mines may also be neutral or basic, and the most environmentally serious aspect of some drainage may be not be its low pH, but rather its heavy metal content, iron or aluminum content, sulfate or arsenate content or suspended solids. To give the impression that low pH is a universal characteristic of mining-related waters, or that low pH is the only characteristic of concern, is misleading to the general public and may impair the ability of the mining industry to evaluate situations and plan for economically viable mining operations. Taken together, these points argue for a more accurate term such as "mining-influenced-water(s)" (MIW(s)). Such a term invites a definition of the nature and extent of the influence rather than simply declaring, in an automatically negative and perhaps erroneous way, that the characteristic of greatest concern is low pH. While the inconvenience of a new term and acronym is acknowledged, the benefits appear sufficient to justify its adoption and use.

Figure 1 schematically illustrates five important and generally undesirable characteristics of MIWs and the relationships of AMD and ARD. Any given MIW may possess none, one or more or all of these characteristics - thus they should be regarded as potential characteristics for any given MIW. While certain characteristics are unquestionably genetically related, the geochemical processes that give rise to and/or tend to mitigate each characteristic will be discussed separately. Each characteristic requires a different approach to prediction, monitoring and control. MIW issues are common to virtually every type of mining operation, regardless of mining method, commodity or type of ore body, although some deposits, mine locations and climates result in minimal concerns.

A significant literature is available on the subject of MIW (typically referred to as "acid mine drainage") but a great portion is disseminated among an unusually large number of journals, publications of various government agencies and difficult-to- obtain conference proceedings. A recent and ongoing focus of the U.S. Geological

Survey has been to establish guidelines for the prediction of MIW characteristics of new mining operations based on ore-body types (Smith (1994), Plumlee et al. (1993), Ficklin et al. (1992)). Current activities of the U.S.G.S. Mine Drainage Interest Group may be found via http://water.wr.usgs.gov/mine/home.html. Gray et al. (1994) provides additional evidence of efforts to place the prediction of MIW quality in the context of economic geology evaluations of mining properties. A cooperative of various Canadian government agencies and mining companies has established Mining Environment Neutral Drainage (MEND) to coordinate a large volume of research on MIW situations in that country (http://www.emr.ca/mets/mend/). A particularly useful overview of MIW issues is presented by the British Columbia Acid Mine Drainage Task Force (BCAMDTF, 1989).

## 13.2 POTENTIAL CHARACTERISTICS OF MINING-INFLUENCED-WATERS

### 13.2.1 GENERAL

Natural surface and subsurface waters may be affected by mining operations in a variety of ways, leading to a range of chemical and physical characteristics. A thorough knowledge of these characteristics is critical to cost-effective environmental compliance and management and not infrequently has significant impacts on mine planning. Investigations of existing MIW situations should initially seek to define and quantify those characteristics, without preconceptions and as completely as possible, both in absolute terms and relative to an applicable background. Similarly, spatial and temporal variations in chemical and physical characteristics should be established. Investigations such as baseline studies and environmental impact analyses for planned mining operations, which frequently include existing MIW situations, are poorly served by focusing only on regulated constituents rather than seeking to fully characterize waters. Not only do regulations change over time, but requirements for understanding water systems in the context of treatment or utilization typically escalate as a project goes forward. The cost of 'doing it right the first time' is usually trivial compared to the cost of dealing with incomplete information about characteristics and the resultant indecision or the possibility of incorrect decisions at a later time.

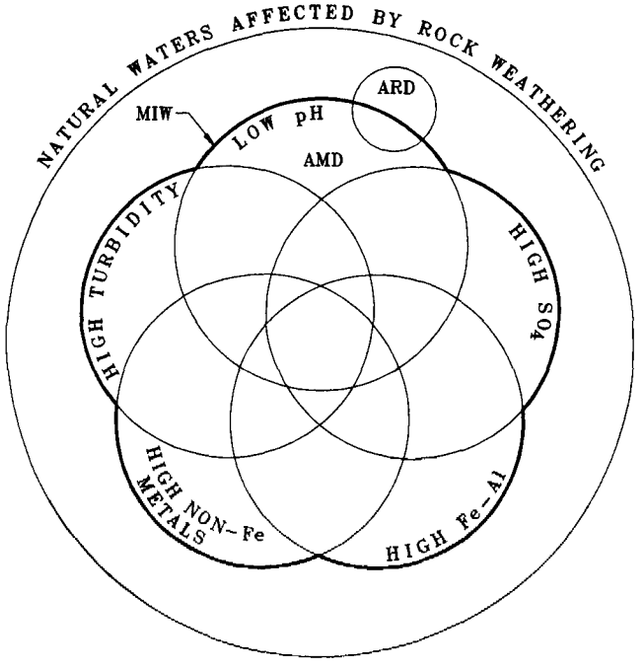



**Figure 1a** Venn diagram illustrating the five potential characteristics of MIW discussed in this chapter and the relationships of AMD and ARD to MIW. Note that MIW is a subset of all waters affected by rock and mineral weathering and that AMD is a subset of MIW. ARD includes AMD and acidic non-MIW waters.

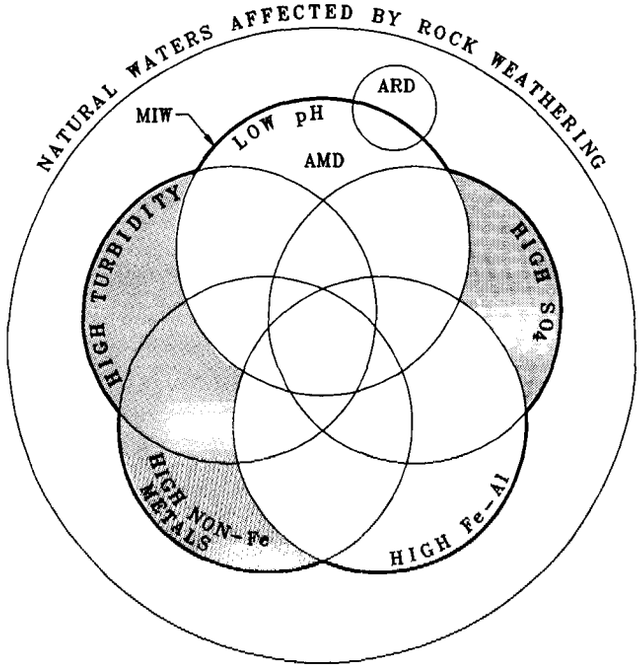



**Figure 1b** Example illustrating a non-acidic MIW with high sulfate, turbidity and elevated heavy metals (e.g., neutralized water with suspended ferric oxyhydroxide and elevated copper, pH = 6, Eh = +800 mV, Cu = 6 mg/L, Fe < 0.001 mg/L).

Anticipating potential effects of a mining operation on natural water quality characteristics is considerably more difficult than characterizing existing conditions. The topic is not discussed here but the reader is referred to EPA (1994) for a survey of general materials-testing methods and predictive models and Scharer et al. (1994) for a review of models applied to tailings. Documented characteristics of local MIW can provide valuable guidance for prediction of future conditions. If local MIW situations are present, are thoroughly understood and can be logically shown to be relatable in certain ways to proposed operations, it may be possible to predict something useful - even if it is only the worst-case scenario. Literature searches for MIW cases related to similar deposits or analogous unit operations may also produce valuable clues but in the end, site-specific knowledge is required because of the many factors involved in determining the characteristics of MIW.

Table 1 presents an assortment of selected MIW analyses which serve as illustrations of the characteristics discussed here. At first glance it is obvious that there is little consistency in the type of geochemical data collected or reported. In general, incomplete or partial analyses and incomplete documentation appear to be the rule rather than the exception.

## 13.2.2 FIVE COMMON CHARACTERISTICS OF MIW

The MIW characteristics that are most consistently of concern are elevated pH and heavy metal concentrations, thus it is useful to consider their ranges. Ficklin et al. (1992) and Plumlee et al. (1993) discuss and classify MIW from some 25 identified and geologically classified metal mines in the Colorado Mineral Belt and include six MIW-like waters related to un-mined metal deposits. Their MIW classification is based on pH and the content of combined non-ferrous metals. As shown in Figure 2, pH varies from less than zero to slightly greater than 8.0 and combined dissolved metals (Zn+Cu+Cd+Co+Ni+Pb) range over five orders of magnitude. This pH range is not inclusive of all MIW given the observations of -3.0 pH values at Iron Mountain, California (Alpers and Nordstrom, 1991). Smith et al. (1994) show that the concentration variations for individual metals may be even more pronounced (seven orders of magnitude) than is the case for combined metals. Certain deposit types appear to have consistent MIW characteristics while MIWs for other types vary widely. The data clearly supports the fact that not all MIW is acidic and that unacceptably high metal concentrations are not necessarily associated with low pH.

Although pH and concentrations of heavy metals as discussed above are clearly important, and often the most important, characteristics of MIW, the analyses listed in Table 1 illustrate the preponderance of other components in most MIW, some of which (eg. $SO_4^=$, Fe, and Al) are subject to compliance criteria in some cases. Dissolved iron and aluminum typically occur in significantly higher (10 times to 100 times) concentrations than the heavy metals mentioned above (Smith et al., 1994). These two metals are worthy of separate consideration as a characteristic of MIW, not merely because of their higher concentrations, but also because they have distinct geochemical characteristics. Frequently iron and aluminum in MIWs cause pronounced visual effects such as the formation of "yellow-boy" and, in some cases, influence the behavior of heavy metals. Other metals such as the alkali earths Ca and Mg, and the alkali metals Na and K may also occur in greater concentrations in MIWs but are typically not of environmental concern *per se* but may limit some uses of MIW and in some cases are tied to toxicity indices for other metals (e.g., Zn toxicity as a function of hardness).

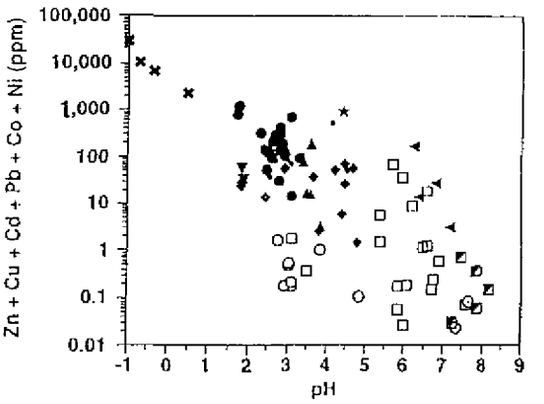



**Figure 2** Variations in pH and metal content of Colorado Mineral Belt MIW. Different symbols represent different genetic types of mineral deposits with different mineral assemblages, host rocks or alterations. (after Smith *et al.*, 1994).

Anion concentrations also represent important characteristics of MIWs and, as is the case of $SO_4^=$ and As (which occurs as $H_2AsO_4^-$ or $HAsO_4^=$), some have associated compliance criteria. Since sulfur, as sulfide, is associated with the majority of the mineral phases that represent the sources of metals in MIWs, and since relatively few natural processes remove sulfate from surface or ground waters (i.e., $SO_4^=$ behaves conservatively), it is logical that its concentrations would typically exceed those of metals (X000 mg/L are not uncommon). This conservative aspect of sulfate geochemistry also dictates that elevated sulfate is typically the most pervasive and persistent characteristic

**Table 1** Chemical analyses of selected mining-influenced waters

| | SOURCE | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH (field) | units | 6.8 | 2.96 | 7.84 | -1 | 1.8 | 4.4 | 7.7 | 6.2 | 3 | 3.2 | 8.15 | 2.65 |
| Acidity | mg/L as H2S | | | | | | | | | 342 | | | 305 |
| Eh (field) | mv | 280 | 500 | 250 | | | | | | | | | 840 |
| DO | mg/L | | | | | | 7.5 | 7.5 | | | 10 | | |
| Condtivity | uS | <100 | 2100 | 1170 | | 38000 | 980 | 2800 | | 1780 | | 3036 | 1274 |
| TDS | mg/L | | 2568 | 1220 | | | | | | 1260 | | | |
| TSS | mg/L | | 0.6 | 419.6 | | | | | | | | 54 | |
| Temp | C | 5 | 13 | 14 | 42 | | | | | | | 10 | 6 |
| Sulfate | mg/L | 19 | 1520 | 720 | 760000 | 130000 | 640 | 1200 | 1800 | 817 | 2000 | 1400 | 950 |
| Chloride | mg/L | 2 | 0.5 | 1.4 | | | | | | 22 | | 16.2 | |
| Alkalinity | mg/L as CaC | 27.2 | <1 | 73 | | n.d. | n.d. | 330 | | <1 | n.d. | 401.4 | <1 |
| Fluoride | mg/L | | 0.28 | | | | | | | 0.1 | | 1.08 | |
| Ca (Tot/Dis) | mg/L | /9.8 | 96.6/ | 280/249 | /279 | | | | | 119/ | /400 | 180/ | /36 |
| Mg (Tot/Dis) | mg/L | /2.5 | 6.73/ | 23.8/23.9 | /437 | | | | | 68/ | /110 | 122.5/ | /26 |
| Na (Tot/Dis) | mg/L | /2.4 | 3.6/ | 2.6/2.1 | /416 | | | | | 17/ | /19 | 410/ | /0.79 |
| K (Tot/Dis) | mg/L | | 1.68/ | 2.14/1.79 | /194 | | | | | | /4 | 26.5/ | /2.4 |
| Si (Tot/Dis) | mg/L | /6.11 | | | /14 | | | | | 10/ | | 6.4/ | /5.6 |
| Fe (Tot/Dis) | mg/L | /<0.02 | 63.16/ | 22.4/0.07 | /111000 | /28000 | /2.4 | /0.02 | /87 | 15/ | /37 | 0.13/ | /27 |
| Al (Tot/Dis) | mg/L | /<0.05 | 43.71/ | 0.66/<0.05 | /1420 | /5400 | /2.6 | /<0.1 | /0.2 | 29/ | | | /19 |
| Ag (Tot/Dis) | mg/L | | 0.003/ | 0.004/0.00 | /2.4 | | | | | | | | |
| As (Tot/Dis) | mg/L | /<0.001 | 0.039/ | 0.156/<0.0 | /340 | /15 | | | | | /0.12 | <0.005/ | |
| Cd (Tot/Dis) | mg/L | /0.0002 | 0.422/ | 0.054/0.02 | /211 | /3 | /0.29 | /0.001 | /0.12 | | | 0.0002/ | |
| Co (Tot/Dis) | mg/L | | | | /5.3 | /16 | /0.02 | /0.02 | /0.12 | | | 0.004/ | |
| Cu (Tot/Dis) | mg/L | 4.95/3.2 | 4.6/ | 0.11/0.04 | /4760 | /460 | /2.4 | /0.001 | /0.27 | | /5.4 | 0.011/ | |
| Pb (Tot/Dis) | mg/L | /<0.02 | 0.04/ | 2.71/0.02 | /11.9 | /<0.2 | /0.01 | /<0.005 | /0.15 | | | 0.0115/ | |
| Mn (Tot/Dis) | mg/L | /0.01 | 36.84/ | 40.9/30.4 | /22.9 | | | | | 10/ | /31 | 0.05/ | /5.3 |
| Ni (Tot/Dis) | mg/L | | 0.13/ | <0.01/<0.0 | /3.7 | /21 | /0.04 | /0.02 | /0.19 | | | | |
| Zn (Tot/Dis) | mg/L | /0.04 | 72.77/ | 14.5/8.87 | /23500 | /390 | /69 | /0.11 | /170 | | /9.6 | 0.042/ | |

n.d. = not detected xxx/yyy = total (unfiltered) concentration / dissolved (filtered) concentration

SOURCES:

1 - Chalcopyrite massive sulfide, preCambrian meta sediments, Osceola Tunnel drainage, 0.45 um, Ferris Haggarty Drainage Study, Adrian Brown Associates 321A/94083

2 - Acid-sulfate altered Au-bearing stockwork, northern Peru, tunnel drainage, undisclosed data source

3 - Limestone-hosted Pd/Zn massive sulfide manto, northern Peru, tunnel drainage, 0.45 um, undisclosed data source (pH at ore face <3)

4- Richmond Mine, Iron Mountain, CA , tunnel drainage, 0.1 um, Alpers and Nordstrom (1991)

5 - Acid-sulfate epithermal Au deposit, Blackstrap Mine, Summitville, CO, dump drainage, 0.1 um, Plumlee et al. (1993)

6 - Limestone hosted Pb-Zn-Ag manto deposits, Yak Tunnel, Leadville, CO, tunnel drainage, 0.1 um, Plumlee et al. (1993)

7 - Gold-Telluride vein deposit, Carlton Tunnel, Cripple Creek, CO, tunnel drainage, 0.1 um, Plumlee et al. (1993)

8 - High-sulfide carbonate hosted, Wellington Mine, Breckenridge, CO, tunnel drainage, 0.1 um, Plumlee et al. (1993)

9 - Anthracite coal mine-affected creek, Shamokin Creek at Weighscale, PA , presumed unfiltered, Hem (1985)

10 - Quartz-sulfide Au veins in metasediments, Argo Tunnel, tunnel drainage, 0.45 um, Idaho Springs, CO, Stewart and Severson, 1994

11 - Bituminous coal strip-mine effluent after settling pond, Zowada Pit, Big Horn Mine, Sheridan Co., WY, presumed unfiltered, Dettmann et al. (1976)

12 - Bituminous coal underground mine effluent, Babb Ck. watershed near Morris, PA, 0.45 um, Crouse and Rose (1976)

of MIWs (Webster et al.(1994) provides an example of sulfate persistence). Arsenic, although occurring in ore deposits as mineral arsenides and sulfides (sometimes abundantly) and is most commonly present as an oxyanion in solution (Welch et al. (1988) and Hem (1985), it is typically not as concentrated in MIW as sulfate and does not behave conservatively as does sulfate. Dissolved arsenic concentrations, in general, are similar to metal concentrations.

A final important characteristic of MIW is total suspended matter and resultant turbidity. This characteristic is highly variable, both spatially and temporally, and a strong function of the geochemistry of iron and, to a lesser extent, aluminum. Significant concentrations of iron are possible under low-pH conditions, but iron may also be transported in MIW at higher pHs as suspended ferric oxyhydroxide (FeOx) solids. Low-pH MIW is typically very clear because all constituents, including iron, are in solution. Progressive neutralization of pH and/or oxidation of MIW causes amorphous FeOx to precipitate as initially sub-micron sized material that remains in suspension, thus causing turbidity. As the precipitated particles continue to grow and aggregate they eventually reach a critical mass and settle out of the water column, thus reducing turbidity. Turbidity is an important characteristic of MIW, not only because it is regulated in some cases, but also because FeOx precipitate has a large surface area and a well documented facility for adsorption of metals and arsenate. Thus, when FeOx suspensions are present, some portion of otherwise dissolved components of MIW may be associated with suspended matter and not detected in filtered water samples. When FeOx suspensions eventually leave the water column, metals may go with them and form part of the temporarily immobile substrate of streams that can be remobilized under different flow conditions.

## 13.3 GEOCHEMICAL PROCESSES RELATED TO THE CHARACTERISTICS OF MINING-INFLUENCED-WATERS

Each of the characteristics of MIW discussed in Section 2 may be related to one or more geochemical processes that either give rise to or attenuate a characteristic feature. Although there is considerable overlap in attributing MIW characteristics to geochemical processes (e.g., one process may be responsible for multiple characteristics), each characteristic is unique in one or more ways so that the presence or absence of any one characteristic feature is not a guarantee of the presence or absence of any other characteristic feature. In short, the evolution of MIW is a complex site-specific function of parent materials and prevailing conditions.

### 13.3.1 pH, ACIDITY AND ALKALINITY CONTROLS

#### 13.3.1.1 Definitions and Analytical Issues

The terms pH, acidity and alkalinity are very commonly used in relation to MIW issues and merit a brief discussion. Understanding the analytical aspects of these and all chemical quantities are extremely important and the burden of QA/QC should never be assumed to lie entirely with the analytical laboratory.

The hydrogen ion activity ($[H^+]$), expressed as pH (pH = -log$[H^+]$), is a straight-forward *intensity* attribute of all aqueous solutions but may be incompletely understood. For example, the commonly used pH-scale ranges from 0-14 pH units, but these limits are only an artifact of common use. Although uncommon, waters in nature may have pH values outside this range: acidic MIW is one situation where this occurs. Neutral pH (pH ≈ 7.00) is merely the point at which $[H^+] = [OH^-]$ and should not automatically be assumed to be the "background" pH of a natural water as most natural water have a pH between 6 and 9. Waters are commonly referred to as being "acidic" or "basic" when their pH is below or above neutral pH, respectively, but "acidic" in this context should not be confused with "acidity".

Acidity and alkalinity are *capacity* attributes of aqueous solutions and neither are exclusively related to pH. Acidity is the capacity of a solution to consume hydroxide ions and any reaction or component (including proton) that accomplishes this is a contributor to acidity as illustrated by the following Equations. High acidity represents a resistance toward neutralization and a facility for corrosion.

$$OH^+ + H^- \rightarrow H_2O \qquad (13.3.1.1\text{-}1)$$

Alkalinity is the capacity of a solution to consume protons and may also be illustrated by Equation 13.3.1.1-1 but most often interpreted in terms of the inorganic carbon reactions shown in Equation 13.3.1.1-3. However in metal-rich MIW, reactions of the type illustrated by Equation 13.3.1.1-4 may be the predominant sources of alkalinity.

$$\begin{aligned} CO_3^= + H^+ &\rightarrow HCO_3^- \\ HCO_3^- + H^+ &\rightarrow H_2CO_3^0 \end{aligned} \qquad (13.3.1.1\text{-}3)$$

$$Al(OH)_n^{(3-n)} + nH^+ \rightarrow Al^{3+} + nH_2O \qquad (13.3.1.1\text{-}4)$$

It is important to recall that neither acidity nor alkalinity are absolute quantities as are $[H^+]$, pH or concentrations of a metal or sulfate. They are strictly operationally defined by the analytical procedure - in

effect they represent bench tests conducted under specified conditions. In the case of alkalinity, the typical reporting units (mg/L as $CaCO_3$) are based on the assumption that inorganic carbon is the only source of alkalinity, which, as stated above may well not be the case for MIW. It is preferable to request the analytical laboratory to also report alkalinity in terms of the raw experimental data (e.g., x ml of acid of N normality was used to obtain a specified endpoint pH). Such data may then be used by the geochemist to correctly interpret the characteristics of MIW. Refer to Standard Methods for the Analysis of Water and Wastewater (Greenberg et al., 1992) for these and other analytical procedures.

### 13.3.1.2 Sulfide Mineral Oxidation and Production of Acidity

Sulfide minerals, especially the most common of all sulfide minerals, pyrite ($FeS_2$), are at the heart of most MIW problems. Sulfide minerals represent the form in which most base metals occur in nature, iron-sulfide minerals (pyrite, pyrrhotite, marcasite) and other sulfides are common associates of important non-sulfide ore minerals (e.g., native gold), and iron-sulfides are commonly associated with coal and the rock sequences that host coal.

Pyrite, marcasite and pyrrohotite form and are stable under chemically reducing, typically anoxic conditions and consequently are inherently and thermodynamically unstable in the presence of the earth's atmosphere and surface environment. It is pyrite's response to this instability that gives rise to elevated concentrations of protons, iron and sulfate in many MIWs and initiates processes that produce other characteristics. In the overall sense, the reactions related to this instability are referred to as "oxidation" although the process is far more complex than simple oxidation. The wide range of rates at which pyrite succumbs to this inherent instability, and the intricate relationship of those rates to environmental variables attests to the complexity of the overall process. There is a vast literature on the subject of pyrite oxidation which can only be alluded to here. The reader is referred to and Alpers and Blowes (1994) for a recent collection of relevant articles, and to Evangelou and Zhang (1995), de Hann (1991), Lowson (1982), Nordstrom et al. (1979), Rogowski et al. (1977), Singer and Stumm (1970) and Barnes and Romberger (1968) for reviews of and a perspective on the subject.

Processes associated with the oxidation of pyrite are summarized in Figure 3 and have been divided into initiation and propagation steps. The initiation step requires molecular oxygen in a aqueous or humid (Borek, 1994) environment and apparently can proceed by two different paths including dissolution of pyrite with subsequent microbial-assisted oxidation of sulfide sulfur or by direct oxidation of pyrite to sulfate (Stumm and Morgan, 1981). Although both initiation steps ultimately results in aqueous solutions with three of the common characteristics of MIW (increased $H^+$, $SO_4^=$ and $Fe^{2+}$) it does not account completely for field observations of stoichiometry or kinetics associated with pyrite weathering. For example, the overall initiation reaction (Equation 5) only produces two moles of protons for every mole of pyrite oxidized and thus does not account for observed acidities and pHs.

$$FeS_{2,py} + \frac{7}{2}O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \qquad (13.3.1.2\text{-}5)$$

As an aside, the initiation reaction (Equation 5), although an incomplete description of acidity production during pyrite weathering, is the basis for calculating Acid Producing Potential (APP) from total sulfur determinations (i.e., it is the basis of the 31.25 factor commonly used in such calculations) and for interpreting Acid-Base Accounting results. Thus, Acid-Base Accounting methods do not take into account the all-important propagation phase of pyrite weathering discussed below.

The propagation phase of pyrite weathering involves the oxidation of $Fe^{2+}$ to $Fe^{3+}$ and the subsequent oxidation of additional pyrite by $Fe^{3+}$. Oxidation of ferrous iron in a sterile (abiotic) environment proceed very slowly under acid conditions and would probably be the overall rate-limiting reaction for pyrite weathering. Acidic mine drainages might never be produced under such conditions. However, certain microorganisms that thrive in dark, acidic environments with very minor amounts of oxygen, derive energy from the oxidation of ferrous iron and thus catalyze the reaction and increase rates of $Fe^{3+}$ production by five or six orders of magnitude over abiotic rates. The organism thought to be chiefly responsible is the acidophilic, obligate chemotroph, Thiobacillus ferrooxidans bacteria. Depending on the prevailing pH environment, $Fe^{3+}$ may either attack additional pyrite (Equation 6, the overall propagation phase reaction) or form ferric oxyhydroxides or jarosite. Both processes liberate additional protons and contribute to acidity in the system.

$$14Fe^{3+} + FeS_2 + 8H_2O \rightarrow 15Fe^{2+} + 2SO_4^{2-} + 16H^+ \qquad (13.3.1.2\text{-}6)$$

### 13.3.1.3 Neutralization and Acquisition of Alkalinity

Neutralization refers to raising the pH of acidic MIWs and thus altering one of its distinguishing characteristics.

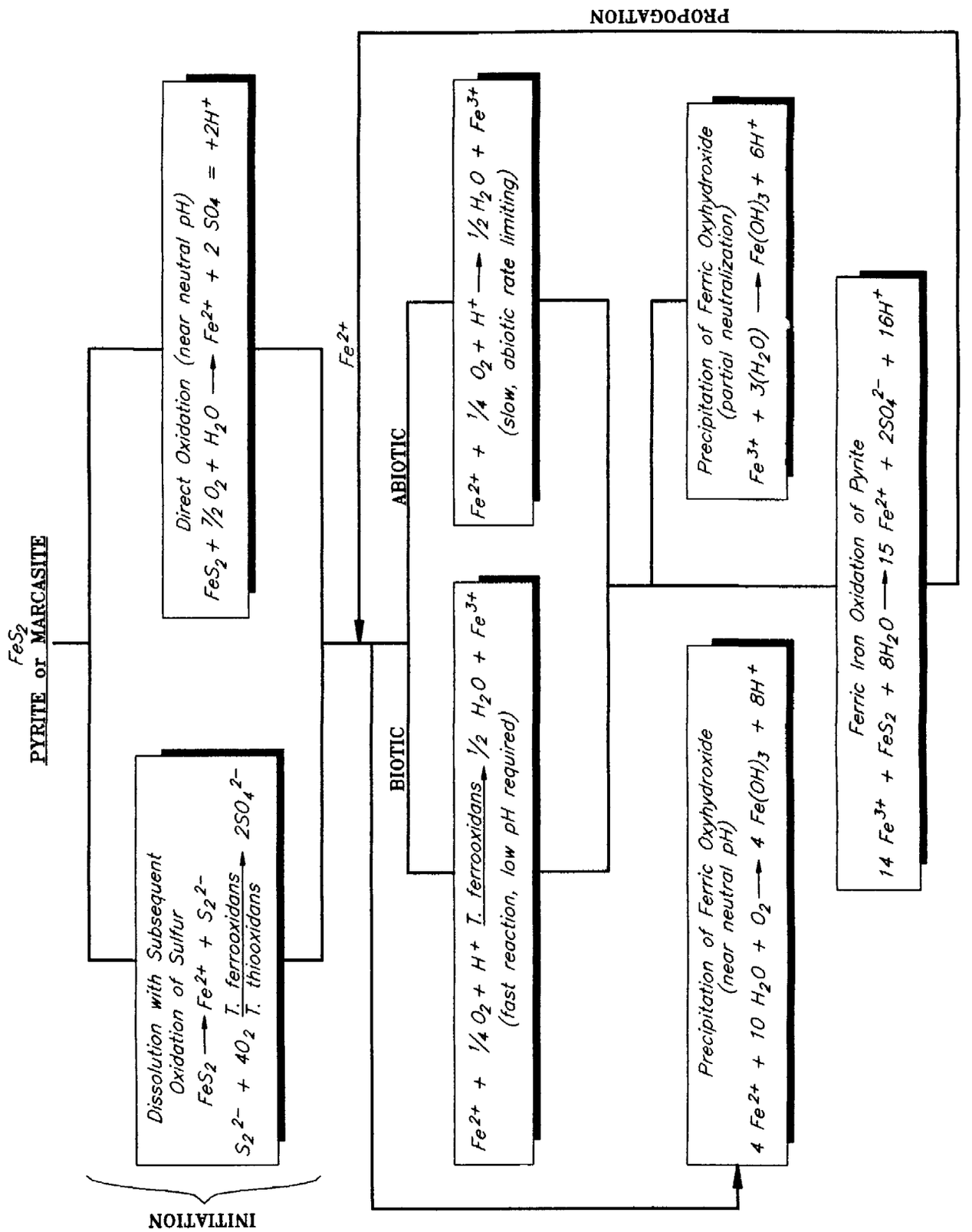



**Figure 3** Flow chart of major reactions and pathways involved in weathering of pyrite.

However, other important alterations may occur in concert with raising the pH, depending on the extent of the neutralization.

When acidic MIWs flow away from the environment in which they were created (typically sulfide mineral-rich) they may be exposed to rock types capable of reacting with the aqueous products of sulfide oxidation, especially the protons. The resultant neutralization gives rise to MIWs that are no longer acidic but may still contain dissolved metals. Extensive neutralization, in conjunction with oxidation may also cause metals to precipitate as hydroxide or oxy-hydroxide solids, sometimes causing significant turbidity.

Rocks containing carbonate minerals (e.g., calcite) are typically thought of as agents of neutralization but the process may also occur in the presence of silicates, especially feldspars. Carbonate minerals generally dissolve completely in acidic solutions (congruent dissolution) but feldspars frequently dissolve incongruently resulting in some of the original components being solubilized and the remainder forming a new solid phase such as a clay mineral. Carbonate minerals also react rapidly (relative to silicates) but their effectiveness in neutralization reactions will be controlled by available surface area per unit volume of MIW and may be compromised by "armoring" of the carbonate surfaces. Armoring occurs when low-solubility secondary solid products of neutralization (e.g., ferric oxyhydroxides) coat the carbonate surfaces and limit further reactions. The exact products of incongruent silicate dissolution, and thus the extent of neutralization by silicates, are highly dependent on the chemical environment. Consequently the net effect of MIW contact with silicates changes as the composition of the MIW changes along its flow path. Both congruent and incongruent dissolution reactions result in decreases in solution proton concentrations as well as increases in dissolved components, some of which in-turn can consume protons. Such components constitute alkalinity.

Alkalinity is defined operationally as described above in Section 13.3.1.1 but is also equivalent to the sum of constituents that can consume protons less the protons already present as generally shown in Equation 7. A MIW may acquire components of alkalinity by dissolution of rocks and minerals or by mixing with waters containing alkalinity. The effectiveness of contact with rocks for neutralizing acidic pHs and supplying alkalinity is a function of reaction rates as discussed by Sherlock et al. (1995). Carbonate minerals typically have considerably higher reaction rates and are therefor more effective in neutralizing MIW. The effectiveness of mixing for neutralization on a volume-for-volume basis can be assessed by performing simple titrations of the two subject waters.

$$\begin{aligned} Alkalinity = & \\ & -[H^+]+[OH^-]+[HCO_3^-]+2[CO_3^{2-}] \\ & +[NH_3]+[HS^-]+2[S^{2-}] \\ & +[HSiO_3^-]+2[SiO_3^{2-}]+[B(OH)_4^-] \\ & +n[Me(II)(OH)_n^{2-n}]+n[Me(III)(OH)_n^{3-n}] \end{aligned} \quad (13.3.1.3\text{-}7)$$

Results of MIW contact with various minerals (i.e., the extent of neutralization) may be predicted through the use of a variety of geochemical computer codes. Simplistic models assume complete reactions of some mass of rock with a unit volume of MIW (a situation analogous to adding lime to a stirred reactor) but are unrealistic predictors of many situations. Similar assumptions are made in Acid-Base Accounting calculations. More comprehensive models would take into account effective surface areas, diffusion rates, reaction rates, boundary layers and other aspects of mass transport. Such models are difficult to apply in real-world cases such as the flow of MIW through a tunnel driven in limestone or meteoric precipitation percolating through a waste rock pile.

### 13.3.2 SULFATE AND ARSENATE CONCENTRATIONS

An elevated sulfate concentration is perhaps the most consistent characteristic of MIW because the majority of cases involve oxidation of sulfide minerals. Figure 3 show the production of sulfate during the oxidation of sulfide minerals and it is clear that each mole of pyrite must ultimately produce two moles of sulfate. Protons are also produced but, as described in Section 13 3.1.2, neutralization can negate this characteristic. Since pyrite and other sulfides are abundant in most metal mining environments, the concentrations of sulfate in the associated MIW will not be source limited. Rather the concentrations will reflect the effectiveness of sulfide mineral oxidation and the volumetric discharge of water from the site of the oxidation and any subsequent dilution.

The limited number of chemical mechanisms that remove sulfate from MIW solutions is also a reason for the common occurrence of elevated sulfate. Gypsum ($CaSO_4 \cdot 2H_2O$) and secondary iron sulfate minerals like jarosite that can form from the oxidation of pyrite are far too soluble to effectively decrease sulfate concentrations in MIW (Cravotta, 1994). The approximately conservative nature of sulfate in MIW streams provides a basis for assessing and tracing the fate of non-conservative components, especially metals. For example, a downstream decrease in sulfate concentrations

can frequently be ascribed to dilution. Other components that decrease to a greater extent in the same reach of stream may be assumed to be attenuated by one mechanism or another (e.g., precipitated along with ferric-oxyhydroxide particles or sorbed onto bed sediments).

Arsenic is included here with sulfate in light of the tendency for arsenic to form complexes with sulfide sulfur and thus to form arsenic sulfides including orpiment ($As_2S_3$) and realgar ($As_2S_2$) and metal sulfarsenides such as arsenopyrite (FeAsS). In addition, the oxidized form of arsenic (As(V)) as arsenic acid hydrolyses to form oxyanions (e.g., $H_2AsO_4^-$, $HAsO_4^{-2}$) as does sulfuric acid and there appears to be a limited solid solution series between scorodite ($FeAsO_4 \cdot 2H_2O$) and jarosite. Selenium, antimony and possibly tellurium could be logically included in this characteristic but will not be discussed here.

Oxidative weathering of arsenopyrite is probably the most common source of arsenic in MIW and occurs under less oxidizing conditions than does pyrite oxidation (Marsden and House, 1993). Arsenopyrite is actively oxidized by $Fe^{3+}$, as is pyrite, but the rate is greater than that for pyrite for $[Fe^{3+}]$ greater than about 10 mg/L (Rimstidt et al., 1994).

Arsenic in MIW is often limited by the availability of arsenic (unlike sulfate) in the source material and by attenuation mechanisms. Scorodite is likely the most common secondary arsenic mineral and has low solubility under near-neutral pH conditions (Dove and Rimstidt, 1985). Sorption/co-precipitation of arsenic oxyanions onto positively-charged ferric-oxyhydroxide surface is well documented mechanism for removal of arsenic from acidic waters and may effectively limit arsenic concentrations in many MIW situations (Smith et al., 1992 and Gulens and Champ 1979). A tendency for arsenic to associate with ferric oxyhydroxides reinforces the importance of characterizing MIW with respect to turbidity as an indicator of the behavior of suspended ferric oxyhydroxides.

### 13.3.3 IRON AND ALUMINUM CONCENTRATIONS

Iron and aluminum associated with MIW often give rise to its most visible characteristic in the form of intense ochreous ferric oxyhydroxide "yellow-boy" staining of stream beds and conspicuous accumulations of white aluminum oxyhydroxides. The extremely low solubilities of these compounds under near-neutral conditions results in the persistence of such discoloration long after a MIW source ceases to be active.

Elevated iron concentrations are an obvious byproduct of the oxidation of pyrite or any other iron sulfide (see Figure 3). The salient aspects of aqueous iron chemistry are conveniently described by Eh-pH and solubility diagrams such as those presented by Hem (1985) which illustrate the instability of pyrite under oxidizing conditions at all pHs. Upon dissolution of pyrite, iron enters the aqueous environment as ferrous iron (Fe(II)) in the form of $Fe^{2+}$ which is stable over a relatively wide range of Eh-pH conditions. As discussed in Section 13.3.1.1, in the presence of molecular oxygen and acidic conditions $Fe^{2+}$ may be abiotically oxidized to ferric iron (Fe(III)) in the form of $Fe^{3+}$, or its hydrolysis products $FeOH^{2+}$ or $Fe(OH)_2^+$ (depending on pH). $Fe^{3+}$ may also be photo-reduced to $Fe^{2+}$ - a mechanism that may be especially important in high altitude, where ultraviolet radiation is more intense (Waite and Morel, 1984).

Rates of $Fe^{2+}$ oxidation are dramatically enhanced by Thiobacillus ferrooxidans. Concentrations of dissolved iron, ferrous or ferric, are controlled by the precipitation of one or more ferric oxyhydroxide or oxyhydroxysulfate solid phases that have large stability fields in Eh-pH space. Under very acidic (e.g., less than pH = 1) and oxidizing conditions, significant concentrations (thousands of mg/L) of dissolved Fe(III) are possible in solutions in equilibrium with $Fe(OH)_3$, but under similar oxidizing conditions at pH 5, iron solubility is limited to 0.005 mg/L. Under less oxidizing conditions, where $Fe^{2+}$ predominates over $Fe^{3+}$, the same solubility variations occur over only two pH units but very large concentrations of iron are possible at higher pHs (e.g., 1000+ mg/L at pH 4, Eh < 0.4 V). Smith et al. (1994) reports dissolved iron concentrations in a variety of 0.1 mm filtered-MIW samples to be a strong function of pH and to range between 0.0001 mg/L (pH 7-8) and 100,000 mg/L (pH <0).

Precipitation of Fe(III) solids from MIW is of considerable importance for aesthetic reasons, as a control on iron concentrations and as a potential control on other metal concentrations via sorption and co-precipitation. The mineralogy of these precipitates is quite complex and ranges from distinct phases such as goethite (aFeOOH) through less-well crystallized ferrihydrite ($Fe_5HO_8 \cdot 4H_2O$) and schwertmannite (also known as "mine drainage mineral" or MDM, $Fe_8O_8(OH)_6SO_4$) and others to essentially amorphous ferric oxyhydroxides (Murad et al., 1994). Seemingly a common attribute to all Fe(III) precipitates in MIW situations is their initially very fine particle size and tendency to form suspensions. Depending on aqueous environmental conditions these particles aggregate or flocculate and settle out of the water column or remain as colloid-sized particles and are preserved in suspension for long periods of time (Schmiermund and Ranville, 1996).

The mineralogy, fine particle size and associated large surface areas of freshly precipitated Fe(III) solids contribute to sorption/co-precipitation of heavy metals, resulting in metal enrichment of these solid phases (Bowell and Bruce, 1995). Transportation of suspended

iron oxyhydroxides and associated heavy metals can represent a significant mode of metal mobility in MIW and one that differs in important ways from transport as dissolved metals. Flocculated material may result in the transfer of heavy metals to the stream bed and thus attenuate the metal flux from MIW sources but future floods may re-suspend the bed sediments causing increases in downstream metal fluxes in the absence of increases in MIW output. Colloidal material with sorbed MIW-derived heavy metals may transport those metals long distances (hundreds of kilometers) in concentrations exceeding that of the dissolved fraction (Kimball et al., 1995).

Aluminum is included with iron as a potential characteristic of MIW for a variety of reasons including its similar tendency to form oxyhydroxides and oxyhydroxysulfates in acid-neutralized environments and its potential to cause aesthetic degradation of MIW-affected waterways. Aluminum is also included with iron because, like iron, there is generally a readily available source for aluminum, albeit one that is very different from the iron sulfide minerals that give rise to iron in MIW. Aluminum in MIW is derived from acidic weathering of host rock and gangue minerals associates with many ore deposits and clay minerals in the enclosing sedimentary rocks of coal seams. Feldspars, micas and secondary clay minerals are generally unstable in strongly acidic environments and represent the primary sources of aluminum to MIW.

The aqueous chemistry of aluminum is extremely complex and prone to misunderstanding due in part to the tendency of aluminum to form dissolved polymeric species and colloidal macromolecules requiring special sampling and analytical handling to interpret correctly (Hem and Robertson (1990) and Sposito (1996). Smith et al. (1994) reports dissolved aluminum concentrations (in 0.1 mm filtered samples) to be a strong function of pH and to range between 0.01 (pH 7-8) and 10,000 mg/L (pH <0) in a variety of MIW. The control on aluminum solubilities in natural waters is generally thought to be amorphous ($Al(OH)_3$) although Nordstrom (1982) has proposed aluminum sulfate and hydroxysulfate as possible controls in acidic sulfate solutions. To the extent that amorphous $Al(OH)_3$ does control aluminum solubility, it would be expected that acidic MIW would form $Al(OH)_3$ precipitates upon neutralization and that dissolved aluminum concentrations would approach their minimum (< 0.001 mg/L) between pH 5 and 6. Kimball et al. (1994) and Crouse and Rose (1976) found this to be the case in a MIW-affected stream during artificial neutralization experiments and natural field conditions, respectively. In contrast, the solubility limit imposed by $Al(OH)_3$ at pH 4 is close to 100 mg/L. As in the case of ferric oxyhydroxides, aluminum oxyhydroxides may be present as suspended matter in the water column adding to turbidity.

### 13.3.4 HEAVY METAL CONCENTRATIONS

Elevated concentrations of one or more heavy metals are characteristic of MIW from virtually all metal mines and represent threats to downstream aquatic life forms as well as to humans through direct consumption and agricultural and aquacultural bioacumulation (an example is provided by King, 1995). (Heavy metals in this context is taken to be all non-ferrous transition metals and the main group metals except aluminum, including Ga, In, Tl, Sn, Pb, Bi, Po and the actinides Th and U.) The vast array of metallic mineral deposits, their inherent metal contents and mineralogy and environmental signatures are described by du Bray (1995). In general, any metal present in a mineral deposit is subject to incorporation in MIW under certain geochemical conditions.

The majority of primary metal-bearing phases commercially mined are sulfides and, as such, are inherently unstable under oxidizing conditions as is pyrite. Their oxidation mechanisms are also analogous to that of pyrite but reaction rates may be very different and are typically slower than that of pyrite as shown by Rimstidt et al. (1994). Most low-solubility secondary minerals of transition metals are carbonates or hydroxides and are unstable at low pHs due to their tendency to react with protons. Consequently, the highest aqueous concentrations of many metals in MIW are associated with oxidizing, acidic conditions as is evident from the data of Smith et al. (1994). However, this correlation does not imply that acidic or extremely acidic pHs, are necessary for a MIW to carry significant (with respect to regulatory limits and/or environmental health and safety limits) metal loads.

In ordinary (non-MIW) natural waters, heavy metals, as well as iron and aluminum, are typically thought of as trace metals as compared to the much more abundant alkali and alkali earth metals (Ca, Mg, Na and K). Many exceptions to this generality exist as can be seen from the examples provided by Hem (1985). However, in MIW, especially acidic ones, certain heavy metals may be present in major dissolved concentrations and in extreme cases (e.g. Iron Mountain, CA, see Alpers et al. (1992)) equaling or exceeding those of iron or aluminum and the alkalis and alkali earth metals.

Controls on heavy metal concentrations in MIW is a complex issue and is highly metal-specific and site-specific. Initially (at the point of MIW formation), the abundance of metal-bearing mineral phases as well as their solubilities and rates of dissolution control the concentrations of heavy metals. As waters evolve in response to increased contact with country rock, the atmosphere and other waters, changes in metal complexation may take place, precipitation may occur and sorption reactions are possible. In general, these reactions serve to attenuate metal fluxes. In many

situations a clear understanding of the processes is required to prevent inadvertent worsening of an existing situation by future activities.

### 13.3.5 TURBIDITY AND SUSPENDED MATTER

Turbidity is the ability of a water to disperse and absorb light so as to prevent straight-line transmission and is caused by suspended particles greater than about one nanometer in diameter. Turbidity is a in-field measurable parameter and is directly related to visual appearance of a water. Total suspended solids is a laboratory-measured parameter and has the distinct disadvantage, relative to turbidity, of involving sample storage. During storage, reactions, such as precipitation and flocculation, may occur and irreversibly change the sample relative to field conditions. Particles relevant to MIW include macromolecular through colloid-sized particles of iron and aluminum oxyhydroxides, macroscopic particles of flocculated metal oxyhydroxides and other compounds maintained in suspension by turbulence and normal suspended clays and silts due to erosion.

Turbidity and total suspended solids are important characteristics of MIW because they may have associated regulatory MPLs and because of their relevance to transport of heavy metals and arsenic and their obvious impact on iron and aluminum concentrations. The importance of collecting both unfiltered and filtered water samples cannot be overemphasized in this connection. Furthermore, distinguishing between total and dissolved iron and aluminum requires filtration through at least a 0.1 mm filter. The 0.45 mm filter media typically used for this purpose is inadequate and has absolutely no relevance to aqueous chemistry.

Depending on local regulatory requirements, either or both total and/or dissolved metal concentrations may be relevant. Turbidity may define where certain metal-attenuation reactions are occurring in a MIW watercourse and provide important clues for remediation planning and criteria for water use. Careful attention should be given to prevailing definitions of maximum permissible limits (MPLs) that may or may not address filtered versus unfiltered concentrations or prescribe filtration procedures. Regardless of regulatory requirements, an accurate characterization that is necessary for a functional understanding of MIW chemistry requires that the distinction be made.

## 13.4 MIW REMEDIATION COSTS

**by M. A. Drozd**

### 13.4.1 BASIC ESTIMATION ASSUMPTIONS

For the purpose of estimating the cost of treating MIW under various treatment schemes, all economic analyses will use the same base assumptions. The material to be analyzed will be 2.5 million tons of waste with 0.5% pyrite present along fracture planes exposed by blasting. Approximately 50% of the pyrite will be on exposed surfaces. It is assumed that the reactive portion of the material will take 50 years to be depleted and no further acid potential above natural geologic levels will be present after that time. The rainfall for the area is 8 inches per year and approximately all of this material will be spread evenly over each year's period. This assumption is valid if you consider that most pits will produce ground water. The area of surface run-off is 100 acres. The water quality of the effluent is:

| Parameter | Concentration |
|---|---|
| pH | 3.2 |
| $Fe^{+2}$ | 10.0 g/l |
| $Fe^{+3}$ | 1.0 g/l |
| $Al^{+3}$ | 15.0 ppm |
| $Cu^{+2}$ | 1.0 ppm |

No arsenic or selenium are present in the ore. Treatment of the water exiting from the property prior to cessation of mining is treated and discharged by ordinary chemical treatment methods except in the case of bio-remediation. Solution impoundment is minimal so that surface evaporation is not considered. All sludge produced is solid waste requiring disposal at a licensed land fill at a cost of $0.75 cubic foot (about $50 per ton at density of 65 lbs/ft$^3$). The transportation cost is included in the disposal cost. Project life is seven years.

### 13.4.2 CHEMICAL TREATMENT

#### 13.4.2.1 Chemical Treatment Estimate

The water flow from the project is:

100 acres x 0.75 feet per year = 75 acre-feet of water

75 acre-ft x 325,851 gal/acre-ft = 24,438,825 gal/yr

24,438,825 gpy / 365 d/y / 1440 min/day = 46 gpm

The treatment process used is a two stage hydroxide precipitation followed by pH modification to 8.5 for release. Lime is used for pH modification in the form of lime water and milk of lime. Sludge density technology, such as HDS, is used along with drying of the sludge. Extrusion drying is utilized to further compact the material. Aluminum removal is accomplished at a pH

level of 7.8., while copper and iron removal requires a pH level of 9.0. Clarification of the material is accomplished by the HDS system and a small sampling pond (115' x 115' @ depth of 11' with 3 to 1 side slopes) containing approximately 5 days retention with 2' of freeboard. The project will operate for 7 years with 43 years of additional treatment.

### 13.4.2.2 Capital Cost Estimate

| | |
|---|---|
| Plant Feed Holding Pond - 75' x 75' x 8' (including excavation, double lining, 60 mil HDPE, monitoring system and engineering) | $15,000 |
| Feed pump (2 pumps) | $10,000 |
| Plant Holding Tank (10'∅ x 10') | $15,000 |
| Treatment Tank 1 (5'∅ x 5') (Rubber Lined) | $5,000 |
| Agitator (Stainless Steel) | $1,000 |
| Treatment Tank 2 (5'∅ x 5') | $4,000 |
| Agitator (Stainless Steel) | $1,000 |
| pH Adjustment Tank (5'∅ x 5') (Rubber Lined) | $5,000 |
| Agitator (Stainless Steel) | $1,000 |
| Building (50' x 25' x 15' eave height) | $63,000 |
| Lime Water Tank (10'∅ x 10') | $15,000 |
| Lime Water Pump | $1,500 |
| Agitator | $5,000 |
| Milk Of Lime Tank (6'∅ x 6') | $6,000 |
| Agitator | $1,000 |
| Milk of Lime Pump | $2,500 |
| Sulfuric Acid Pump | $2,000 |
| Sump Pump | $8,000 |
| Dryer | $15,000 |
| Clarifier (High Capacity 4' Diameter) | $20,000 |
| Lime Bin and Feeder | $50,000 |
| Piping | $10,000 |
| Speciality Concrete Work and Concrete Coating | $17,000 |
| Electrical | $20,000 |
| Instrumentation | $20,000 |
| Structural Steel | $20,000 |
| Lab Furniture and Equipment | $50,000 |
| Internal Carpentry | $12,000 |
| Erection Cost | $35,000 |
| Miscellaneous Equipment | $15,000 |
| Finished Solution Holding Pond (110' x 110'x 11') | $25,000 |
| Engineering | $23,000 |
| Subtotal | $493,000 |
| Contingency (25%) | $123,000 |
| **Total Capital Cost** | $616,000 |

### 13.4.2.3 Chemical Treatment Operating Costs

#### *13.4.2.2.1 Labor (Yearly)*

| | |
|---|---|
| 2 men per shift @ $12.00/hr & 40% burden and 25% support $21.00/hr x 2 men x 24 hr/d x 365 d/yr | $367,900 |

#### *13.4.2.2.2 Power (Yearly)*

Power Requirements 50 KVA
Power Cost (including Demand) $0.06/KWH
50 KVA x 24 hr/d x 365 d/y x $0.06/KWH $26,300

#### *13.4.2.2.3 Chemicals, Maintenance and Consumables (Yearly)*

| | |
|---|---|
| Lime Consumption - 10,625 lbs/day | |
| Lime Cost/lb - $0.05/lb | |
| Lime addition cost | $193,900 |
| Sulfuric Acid | $500 |
| Flocculent | $2,000 |
| Maintenance and Supplies | $36,500 |
| Propane | $5,000 |
| Other Supplies | $9,000 |
| Sludge Disposal Costs - $50/ton | |
| Sludge production - 5,124 tons per year | |
| Disposal cost | $256,200 |
| Yearly Cost | $503,000 |
| Contingency (25%) | $126,000 |
| **Total** | $626,000 |

#### *13.4.2.2.4 Total Yearly Chemical AMD Treatment Operating Costs*

| | |
|---|---|
| Labor | $368,000 |
| Power | $26,000 |
| Chemicals, etc. | $626,000 |
| **Total** | $1,020,000 |

#### *13.4.2.2.5 Surface Reclamation Costs*

Topsoil placement and re-vegetation efforts will cost $2,400 per acre for side slopes and $1,800 per acre for top surfaces of heaps and dumps. Total tons of ore mined are 3.5 million tons. Ore tonnage is 1,000,000 tons. The mining method is open pit mining. The waste to ore ratio is 2.5 to 1. The pit occupies 12 acres. The waste dump, at maximum capacity, occupies 25 acres. The pad and plant area occupies 43 acres. An additional 20 acres is disturbed for roads, ore storage, laydown areas and offices. The total site disturbance to be reclaimed is 100 acres. The sludge generated during mine water treatment does not pass a TCLP (toxic leach characterization procedure) test and must be disposed in a licensed landfill. The waste dump material density is 120 lbs/ft$^3$ and ore density (on the heap) is 100 lbs/ft$^3$. The total disturbed mine surface area subject to reclamation is 100

acres. The road, ore areas, shops, offices and borrow areas will be reclaimed with the pads. The annual precipitation for the area is 8 inches per year.

| | |
|---|---|
| Top Surface Contouring and Topsoil Placement Cost | $2,500/acre |
| Top Re-vegetation Costs | $1,800/acre |
| **Total Cost/acre** | $4,300/acre |

| | |
|---|---|
| *Cost Estimate:* | |
| Re-vegetation 100 acres x $4,300/acre | $430,000 |
| Surface grading | $420,000 |
| Heap Detoxification | $400,000 |
| **Total** | $1,250,000 |

| | |
|---|---|
| *Total Reclamation Cost:* | |
| Water Treatment Plant Capital | $616,000 |
| Water Treatment Operating Cost for 50 yrs | $51,000,000 |
| Surface Reclamation | $1,250,000 |
| **Total Reclamation Cost** | $52,866,000 |

*(All closure cost estimates are shown with as much cost detail as possible to allow manipulation of the values for site specific parameters.)*

### 13.4.2.3 Semi-passive MIW Treatment Cost Analysis

#### *13.4.2.3.1 Semi-Passive Treatment Scheme*

The semi-passive treatment scheme includes reducing "bog" inoculated with sulfate reducing bacteria (anaerobic pre-treatment), Anoxic Limestone Drain (pH modification), SRB treatment structure (metal removal), and constructed wetlands (metal, BOD and toxin polishing). All pond structures are underlain with a double PVC liner and with inter-liner leak detection. The PVC liner is covered with 2' of dirt. Internal treatment requirements, such as hay and manure fill, etc., are built on top of the dirt fill. Each structure is built with a smaller by-pass facility to allow for cleaning and maintenance. Maintenance of the biological structures is preformed by an outside contractor. The contractor is responsible for maintaining all bacterial cultures and doing all bacterial culturing tests. The service supplies two bacterial re-augmentations per year for each system. Additional re- augmentations are billed at $7,500 each. The cost of this service is $90,000 per year. All material removed from the structures must be disposed in a solid waste facility (cost $50/ton). ALD's are renewed every three years, SRB are renewed every 10 years, and the constructed wetlands is renewed every 12.5 years. Renewal involves removal and disposal of spent material and complete replacement of consumable material. All structures are excavated to allow pooling and overflow movement of the treated solution. Solution flow design allows up to 250% excess to flow into the system except in the by-pass mode. Any flow in excess of the 250% (or 46 gpm when in the by-pass mode) will be diverted into an overflow pond and pumped back to the system when possible. The overflow pond will have a single liner and a capacity of 25% of the annual precipitation (approximately 6 million gallons).

#### *13.4.2.3.2 Pre-Treatment SRB Pond Cost Estimate*

| | |
|---|---|
| Pre-treatment SRB Pond - 75' x 75' x 8' (including excavation, double lining, 40 mil PVC, monitoring system and engineering) | $25,000 |
| 3500 cubic feet of peat, manure and hay installed | $10,000 |
| Cement work and gravel packing for inlet and outlet structures and drain piping | $25,000 |
| Initial culture isolation, pilot work and initial inoculation | $40,000 |
| Construction management, design engineering quality assurance | $20,000 |
| **Subtotal** | $120,000 |
| Contingency (25%) | $30,000 |
| **Total** | $150,000 |

#### *13.4.2.3.3 Anoxic Limestone Drain Cost Estimate*

Pond structure for 115,000 cubic feet of limestone, 100' x 175' 12 deep. Structure includes a geotextile, 60 mil HDPE top and coated pre-stressed concrete baffle walls sealed with bento-mat. A recording flow device is placed on the in-flow and exit to monitor flow characteristics of system. The structure is entirely excavated, and the pond's side slopes are 3 to 1. $192,500

| | |
|---|---|
| 11,500 tons of limestone @ $45/ton | $517,500 |
| Ancillary by-pass ALD (all costs included) | $50,000 |
| Flow metering system and remote alarms | $15,000 |
| **Subtotal** | $775,000 |
| Contingency | $195,000 |
| **Total** | $970,000 |

#### *13.4.2.3.4 SRB Treatment Cost Estimate*

SRB treatment structure consists of a pond with internal baffling that can how the solution with 250% excess flow (flood conditions). Design utilizes upflow design.

| | |
|---|---|
| Pond - 250 x 250 x 12' including double 40 mil PVC liner, leak detection system. Internal free standing pre-stressed concrete baffles. | $195,000 |
| Organic substrate @ $1.75 per $ft^3$ | $775,000 |
| Engineering, Procurement and Construction Management | $75,000 |
| By-pass system all costs included | $250,000 |
| Quality Assurance | $15,000 |
| **Subtotal** | $1,310,000 |
| Contingency | $328,000 |
| **Total** | $1,638,000 |

#### *13.4.2.3.5 Constructed Wetlands Cost Estimate*

Six acres (24,300 $m^2$) of constructed wetlands will be built to polish the water exiting the SRB/ALD/SRB system. The TVA estimated a constructed wetland cost from $3.58 to $32.03 per square meter, in 1986. A mid-point cost of $17.80 and a ten year inflation factor of 33% (2.9% per year) would give a 1996 estimated cost of $23.67 per square meter.

| | |
|---|---|
| 24,300 $m_2$ @ $23.67 | $575,000 |
| By-pass System | $125,000 |
| **Total** | $700,000 |

#### *13.4.2.3.6 Annual and Recurring Cost Estimate*

| | |
|---|---|
| Contract maintenance | $90,000 |
| per year for 50 years | $4,500,000 |
| *ALD renewal (every 3 years)* | |
| Limestone ($517,500 x 17) | $8,789,000 |
| Limestone disposal (11,500 tons x $50 x 17) | $9,775,000 |
| *SRB renewal (every 10 years)* | |
| Substrate ($775,000 x 5) | $3,875,000 |
| Substrate disposal ($0.75/$ft^3$) x 5 | $1,650,000 |
| *Renewal of constructed wetlands (every 12.5 years)* | |
| Renewal cost ($575,000 x 4) | $2,300,000 |
| Spent wetlands material disposal (5,000 tons) 5000 x $50/ton x 4) | $1,000,000 |
| **Total maintenance and recurring costs** | $31,889,000 |

#### *13.4.2.3.7 Surface Reclamation Costs*

Topsoil placement and re-vegetation will cost $2,400 per acre for side slopes and $1,800 per acre for top surfaces of heaps and dumps. The total ore/waste mined tonnage is 3.5 million tons. Ore tonnage is 1,000,000 tons. The mining method is open pit mining. The waste to ore ratio is 2.5 to 1, and the pit occupies 12 acres. The waste dump at maximum capacity occupies 25 acres. The pad and plant area account for 43 acres. An additional 20 acres is required for roads, ore storage, laydown areas and offices. The total site area subject to eventual reclamation is 100 acres. The road, ore areas, shops, offices and borrow areas will be reclaimed with the pads. The sludge generated during mine water treatment does not pass a TCLP (toxic leach characterization procedure) test and must be disposed in a licensed landfill. The waste dump material density is 120 $lbs/ft^3$ and ore density (on the heap) is 100 $lbs/ft^3$. An additional area of 20 acres is associated with biological treatment.

| | |
|---|---|
| Top Surface Contouring and Topsoil Placement Cost | $2,500/acre |
| Top Re-vegetation Costs | $1,800/acre |
| **Total Cost/acre** | $4,300/acre |
| *Cost Estimate:* | |
| Re-vegetation 120 acres x $4,300/acre | $516,000 |
| Surface grading | $420,000 |
| Heap Detoxification | $400,000 |
| **Total** | $1,336,000 |

#### *13.4.2.3.8 Estimated Total Semi-passive Treatment Cost*

| | |
|---|---|
| *Capital Costs* | |
| Pretreatment SRB | $150,000 |
| ALD | $970,000 |
| SRB Treatment | $1,638,000 |
| Constructed Wetlands | $700,000 |
| Operating Costs | $31,889,000 |
| Surface Reclamation | $1,336,000 |
| **Total** | $36,683,000 |

### 13.4.2.4 MIW Material That Has "Gone Acid"

#### *13.4.2.4.1 Isolation Scheme*

The MIW material location in the waste dump is not exactly known. Consequently, all material will have to be moved to a new location. No infrastructure is present on site since the MIW production was discovered during post closure monitoring. All work is done by a contractor. The MIW material is identified using wipe tests on the material and sight observation by a geologist. Any questionable material will be moved to the isolation area. Material moving costs are $4.00 per yard. Contract geologists are retained at $70,000 per year and are retained by the original operators to provide quality assurance. A contract reclamation superintendent is hired at $100,000 per year. Truck, office and sundry costs are $200/day. Work proceeds 250 days per year and only eight hours per day (during daylight).

Closure design utilizes the open pit that was not back filled. The pit contains water derived from ground water flowage and precipitation. The ground water movement has been hydrologically shown to be relatively slow, and would safely allow sub-aqueous disposal of the material. A drainage system is designed for the pit bottom to allow additional pit water pump down, if design parameters prove incorrect. Heap material has started to "go acid". Isolation design allows for capping of the material in-place. All previous re-vegetation work must be removed and redone.

The ore is only 28.6% of the material mined. All the waste material cannot be back-filled into the pit. Non-acid producing material will be moved to a new surface disposal area to be covered and re-vegetated. Each cubic yard of waste weighs 1.6 tons. The time period for the new closure procedure is two years. During the reclamation work a portable water treatment plant will treat all on site precipitation. Water treatment plant rental is $25,000 per month, and holding pond construction costs are $65,000. Water treatment capital costs are the same as the Chemical Treatment estimate. Engineering and design for an approved treatment plan requires one year and costs $500,000. Upon state approval of permits, the waste dump is neutralized and the bacteria are killed using a bactericide. The bactericide usage is maintained throughout the closure work. The treatment plant is returned when the bacteria are killed. The ponds are used for the neutralization of the waste dump. Capping of the heaps commences as soon as possible upon receiving approval of the remediation plan. The reclamation work done during closure will cost $1,250,000.

#### *13.4.2.4.2 Heap Reclamation Costs*

Heap closure includes adding a bactericide to the heap prior to capping. Capping is done by removing all topsoil from the heaps. The side slopes of the heap are graded 5 to 1 where possible. Excess material is removed for screening and pH modification. The re-graded surface is then compacted and smooth graded. The heap is covered with a rough surface HDPE liner underlain by a 10 oz. geotextile. The liner is then covered by fines (-1/2") screened from the heap material. The +1/2" material is then placed on top of the fine material as a root barrier. The top soil is replaced on the root barrier.

| | |
|---|---|
| Bactericide Treatment $700 per acre | |
| Heap Area - 8 acres x $70 | $6,000 |
| Remove topsoil | $25,000 |
| Heap material removal 100,000 yards | $400,000 |
| Grading | $66,000 |
| Screening | $50,000 |
| HDPE liner | $292,000 |
| Geotextile | $32,000 |
| Replacing screened material($3/yd$^3$) | $300,000 |
| Replace topsoil and modify pH | $35,000 |
| Re-vegetation ($1,800 per acre) x 8 | $15,000 |
| **Subtotal** | $1,221,000 |
| Contingency (25%) | $305,000 |
| **Total** | $1,526,000 |

#### *13.4.2.4.3 Mine Waste Remediation*

| | |
|---|---|
| *Water treatment - for one year* | |
| Mobile plant rental $25,000/month | $300,000 |
| Water treatment labor and power | $460,000 |
| Water treatment chemicals | $503,000 |
| Pond construction | $65,000 |
| Topsoil removal | $162,000 |
| Bactericide treatment and stabilization ($1,200 per acre) x 25 acres | $30,000 |
| Caustic neutralization of waste dump | $576,000 |
| Geologic Quality Assurance | $280,000 |
| Site Supervision | $100,000 |
| 1,562,500 cu yd moved | $6,250,000 |
| Compaction | $260,000 |
| Capping of Pit Liner 40 mil PVC | $1,020,000 |
| Root barrier | $1,800,000 |
| Fine cover | $484,000 |
| Topsoil replacement/pH modification | $200,000 |
| Re-vegetation ($1,800/acre) x 25 | $45,000 |
| *Non-acid producing waste dump - area 8 acres* | |
| Surface preparation | $350,000 |
| Re-vegetation ($4,300/acre includes grading) | $35,000 |

| | |
|---|---|
| Pit underdrain | $100,000 |
| EPCM | $500,000 |
| **Subtotal** | $13,520,000 |
| Contingency (25%) | $3,370,000 |
| **Total** | $16,890,000 |

#### *13.4.2.4.4 Total Reclamation Cost Estimate for Post-closure Remediation*

| | |
|---|---|
| Chemical costs | $1,020,000 |
| Heap Closure | $1,526,000 |
| Previous Reclamation | $1,250,000 |
| Mine Closure | $16,890,000 |
| **Total** | $20,686,000 |

### 13.4.2.5 MIW Material That Has Not "Gone Acid"

#### *13.4.2.5.1 Remediation Scheme*

The exact location and quantity of MIW material on site is not exactly known. Therefore, all material will have to be moved to a new location. Mining equipment and infrastructure is still in place because the mine has just stopped operations. The MIW potential has been defined in the ore and the operator wishes to address the reclamation potential at this juncture. All work is done by mine personnel using equipment already at the site. MIW material is identified using wipe tests on the material and sight observation by a geologist. Any questionable material will be moved to the isolation area. Material moving costs are $1.50 per cubic yard. An ore control geologist is kept at a cost of $49,000 per year. A reclamation superintendent, the previous general manager, is also retained at a salary of $105,000 per year. Sundry costs are $200 per day. Work proceeds 250 days per year and only eight hours per day (during daylight).

Closure design utilizes the open pit for a back fill location. The first step is to deal with the water in the pit. A drainage system is designed for the pit bottom to allow additional pit water pump down, if design parameters prove incorrect. Heap material has started to "go acid". Isolation design allows for capping of the material in-place. All previous re-vegetation work must be removed and redone.

All waste material cannot be back-filled into the pit. Non-acid producing material will be moved to a new surface disposal area to be covered and re-vegetated. The time period for the new closure procedure is two years. During the reclamation work no water treatment will be necessary. Engineering and design for an approved treatment plan requires six months and costs $200,000.

#### *13.4.2.5.2 Heap Reclamation Costs*

Heap closure includes capping. Capping is done by removing all topsoil from the heaps. The side slopes of the heaps are graded to 5 to 1 where possible. Excess material is removed for screening and pH modification. The re-graded surface is then compacted and smooth graded. The heaps are covered with a rough surface HDPE liner underlain by a 10 oz. geotextile. The liner is then covered by the fines (-1/2") screened from the heap material. The +1/2" material is then placed on top of the fine material as a root barrier. The top soil is replaced on the root barrier.

| | |
|---|---|
| Remove topsoil | $25,000 |
| Heap material removal 100,000 yards | $150,000 |
| Grading | $30,000 |
| Screening | $30,000 |
| HDPE liner | $292,000 |
| Geotextile | $32,000 |
| Replacing screened material ($0.75/yd$^3$) | $75,000 |
| Re-vegetation ($1,800 per acre) x 63 | $113,000 |
| **Subtotal** | $747,000 |
| Contingency (25%) | $187,000 |
| **Total** | $934,000 |

#### *13.4.2.5.3 Mine Waste Remediation*

| | |
|---|---|
| Geologic Quality Assurance | $198,000 |
| Site Supervision | $105,000 |
| 1,562,500 cu yd moved | $2,344,000 |
| Compaction | $100,000 |
| *Capping of Pit:* | |
| Liner 40 mil PVC | $1,020,000 |
| Root barrier | $1,800,000 |
| Fine cover | $484,000 |
| Topsoil replacement/pH modification | $200,000 |
| Re-vegetation ($1,800/acre) x 25 | $45,000 |
| *Non-acid producing waste dump - area 8 acres:* | |
| Surface preparation | $350,000 |
| Re-vegetation ($4,300/acre includes grading) | $35,000 |
| EPCM | $200,000 |
| **Subtotal** | $6,881,000 |
| Contingency (25%) | $1,720,000 |
| **Total** | $8,601,000 |

#### *13.4.2.5.4 Total Reclamation Cost Estimate for Post-closure Remediation*

| | |
|---|---|
| Heap Closure | $934,000 |
| Mine Closure | $8,601,000 |
| **Total** | $9,535,000 |

### 13.4.2.6 MIW Control During Mining

Sulfur analysis of all samples taken during exploration, development, and operation, plus data collected from the computer mine models, coupled with mine face geologic screening can provide the information needed by the mine operators to segregate all potential MIW waste. The potential MIW waste will then be dispatched to a special handling structure built within the waste dump. The structure would be located in clay lenses that have a minimum of three feet of clay on all sides of the in-place MIW material. A sulfur ore control geologist would have to be retained at a cost of $49,000 per year during the mine life. The sulfur analysis cost would be approximately $1.50 per sample. Over the life of the project the extra sulfur analysis would be $1,250,000. Clay occlusion of the waste would cost $500,000. At the end of the project, closure would require cyanide detoxification, grading and re-vegetation. The estimated cost is $1,250,000. The total reclamation cost would be:

| | |
|---|---|
| Geological manpower | $343,000 |
| Sulfur analysis | $1,250,000 |
| Clay isolation | $500,000 |
| Surface Reclamation | $1,250,000 |
| **Total** | $3,343,000 |

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# Chapter 14

# USES OF MINES AS LANDFILLS AND REPOSITORIES

edited by A. J. Krause

## 14.1 INTRODUCTION

**by P. G. Corser, J. J. Kendall, A. J. Krause, and M. H. Stotts**

Disposal of waste materials has been a necessary bi-product of society for centuries. In the past, it was generally believed that leachates derived from wastes were attenuated and purified by soil and, hence, long-term groundwater contamination was not considered an issue. Moreover, it was common practice for each community to have unregulated solid waste landfills (dumps) which were often situated within municipal limits and adjacent to existing communities.

With increasing concern for the environment beginning in the 1950s, landfills came under intense scrutiny and a significant awareness developed that recognized that landfills can result in groundwater contamination, methane gas development and potential offsite migration, and common nuisances including blowing litter, increased avian concentrations and unacceptable odors. Today, there is a common theme regarding landfills that has been coined the NIMBY syndrome or "not in my back yard". As a result, the siting of new solid waste management facilities has become increasingly difficult. Sites that are often technically suitable (i.e. above the groundwater table and removed from direct impacts to human receptors) become mired in a regulatory morass due to negative public sentiment.

A logical alternative to the NIMBY syndrome is the use of abandoned surface mines for landfill disposal. Abandoned surface mines offer the following general advantages:

- A large excavation is pre-existing, thereby reducing the requirement to exhume and stockpile new material or develop an above grade landfill facility that has limited airspace capacity.
- Most mines are located in areas above the water table, therefore, impacts to the groundwater may be reduced.
- Waste rock piles commonly exist which are suitable for daily cover material.
- Fine grained materials associated with tailings disposal (slimes) are often available that can function as impermeable containment systems, including both liners and covers.
- Large mine sites are often connected by interstate and intrastate rail links which facilitate rapid and cost-effective transportation of waste materials.
- Most mine sites are situated outside of immediate residential boundaries thereby avoiding the NIMBY syndrome and common land use planning issues.
- Significant permitting impacts have been addressed during the initial permitting of the mining operation involving surface water management, wetlands mitigation, critical habitat management, and other cultural and socioeconomic impacts.
- Considerable hydrogeologic information often exists from mine engineering and exploration geology studies.
- Potential profits associated with waste disposal exists which may offset typical reclamation and closure costs.

However, adverse environmental conditions may exist, such as large open pits, that are not readily amendable to standard reclamation techniques.

The above advantages are significant factors impacting the permitability and costs of developing and operating landfill facilities. In addition, backfilling open pits with waste products may address reclamation concerns.

The advantages are offset by other issues associated with open pit mines that result in unique challenges to typical landfilling and repository practices. These issues include:

- Placement of impermeable lining systems (natural or synthetic) on steep, often vertical, inter-bench highwall slopes.
- Placement of leachate collection systems on similar

highwall slopes.
- Collection and management of surface water runoff.
- Waste placement and stability issues.
- Economics of transporting waste to remote areas.
- Weak foundation materials (i.e. old spoils, fault material, footwall clay).
- Large volumes of groundwater may infiltrate open pits over time creating the potential for excess leachate volumes.
- Transient hydrologic conditions that have been impacted by mining activities

These advantages and disadvantages of utilizing abandoned surface mines as landfills and repositories are addressed in concept in this chapter. Subsequent sections of the chapter deal with the standard landfill types and provides examples of their application to abandoned mines. In addition, a discussion is provided that addresses site selection requirements including regulatory siting criteria. General design issues and construction considerations are also provided.

Chapter 14 is useful in evaluating the benefits of re-operating abandoned surface mines as landfills or repositories. If site conditions are considered favorable, a comprehensive site investigation is warranted. In addition, regulatory and permitting issues should be addressed as well as overall project economics.

## 14.2 DESIGN OF WASTE REPOSITORIES IN MINING FACILITIES

There are numerous texts and published articles available in the literature that can serve as useful references for the detailed analyses that are required for the design of state-of-the-practice landfills. A list of some of the most often cited books and publications is presented in the list of references. This chapter is intended to provide an overview of the landfill design practices that are currently being used to meet most federal and state guidelines. In addition, comments are provided on the application of these practices to current or abandoned mining operations.

## 14.3 LANDFILL DESIGN

### 14.3.1 LANDFILL CLASSIFICATION

Under current regulatory criteria, landfills are commonly divided into different classification systems depending on the types of wastes accepted and the method of operation. Although a number of landfill classification systems have been proposed over the years, the classification system adopted by the State of California in 1984 is perhaps the most common and widely accepted. In the California system, three classifications are used which are summarized in Table 1.

**Table 1** Typical Landfill Classification System

| Classification | Type of Waste |
|---|---|
| I | Hazardous Waste |
| II | Designated Waste |
| III | Municipal Solid Waste (MSW) |

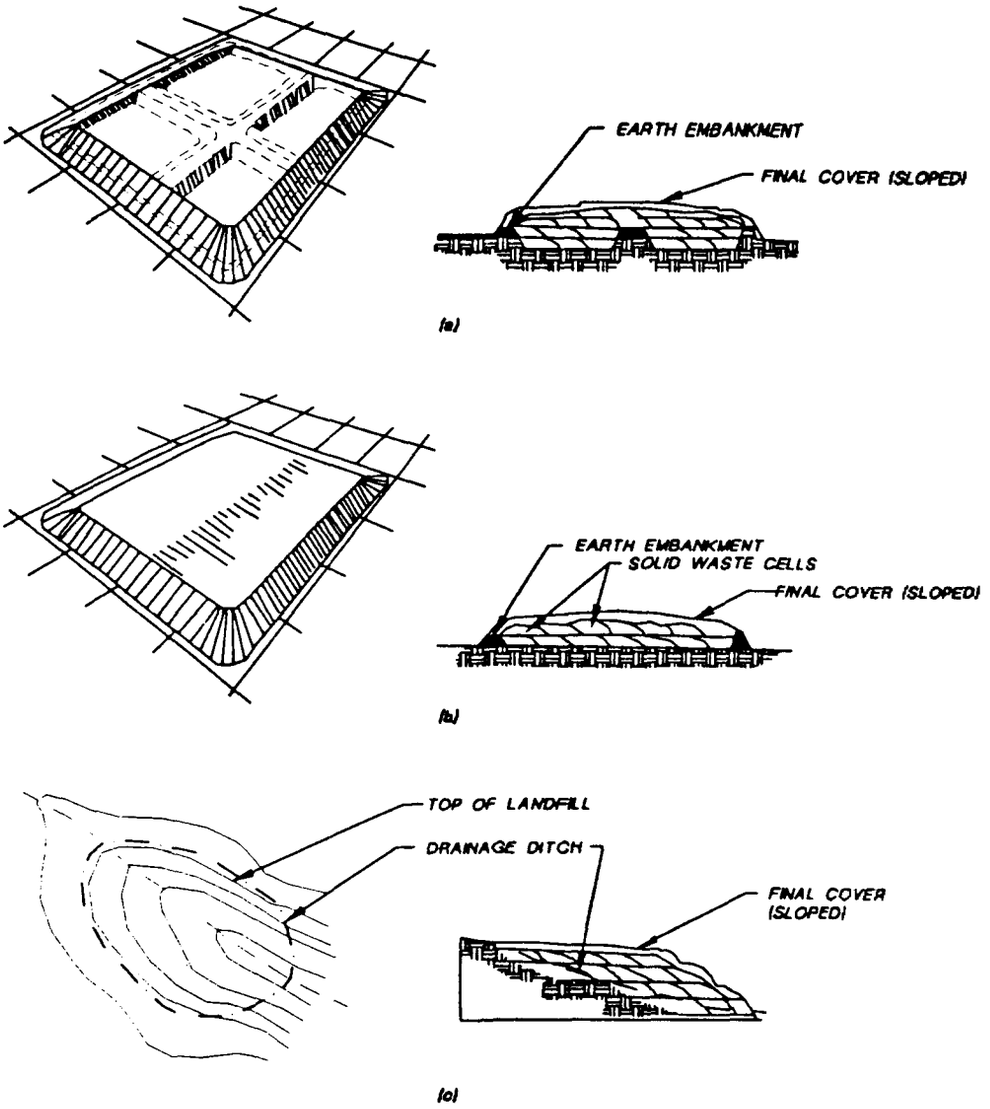
In general, the lower the landfill classification, the higher the level of regulation and more containment systems that will be required. Due to the increased regulation and siting and selection criteria required for Class I type facilities, it is expected that most waste disposal facilities planned for current or abandoned mining sites would probably be Class II or III landfills.

#### 14.3.1.1 Types of Landfills

The principal types of landfills can be classified as conventional landfills for municipal solid waste (MSW), landfills for shredded solid waste, and monofills for designated or special waste.

*Landfills for Commingled MSW* - The majority of the landfills throughout the United States are designated for commingled MSW. In many of these Class III landfills, limited amounts of nonhazardous industrial wastes and sludges are accepted if they are dewatered. In most cases, native soil is used as the intermediate and final cover material. However, in locations where suitable soil cover soil is not available, select waste materials such as petroleum contaminated soils or compost from MSW are used as intermediate cover. Reusable high strength tarps, shredded paper, foams, chipped trees, shredded yard waste and many other materials have also been used as intermediate covers to prevent blowing waste until final cover material or new waste was placed over an area. Use of these "alternative daily covers" (ADCs) can be a positive economic factor as less airspace is consumed than when soil is used, the expense of excavating and transporting soil is avoided and extraction of gas and leachate is enhanced. In addition, use of ADC often generates good public relations.

*Landfills for Shredded Solid Wastes* - An alternative method for landfilling involves shredding of the solid wastes before placement in a landfill. Shredded (or milled) waste can be placed at up to 35 percent greater




(a) EXCAVATED CELL/TRENCH
(b) AREA
(c) CANYON

**Figure 1** Landfill Methods.

density than unshredded waste, and can be placed without daily cover in some states. Blowing litter, odors, insects, and rodents have not been significant problems.

Disadvantages of the method include the need for a shredding facility and the need to operate a conventional landfill section for wastes that cannot be easily shredded. The shredded waste method has potential application in areas where landfill capacity is very expensive, where suitable cover material is not readily available, and where precipitation is very low. Compost that can be used as intermediate cover material can be produced from shredded waste.

*Landfills for Individual Waste Constituents* - Landfills for individual waste constituents are known as monofills. Combustion ash, asbestos, construction debris, and other similar wastes, often identified as designated wastes, are typically isolated in monofills away from other MSW materials.

Abandoned mine sites will, in general, not have severe limitations on available land or a shortage of soil or rock to be used as daily and intermediate cover. Therefore, the added cost of a shredded waste landfill is probably not justified. Monofills, on the other hand, may be very attractive for abandoned mining sites. The uniformity of the material and the specialized control requirements on the waste stream may be compatible with operations of a current or abandoned mining operation. For instance, a coal mine with a mine mouth power plant may be ideal for development of monofill for disposal of the ash from the power plant. Construction debris landfills may also be another very appropriate use for mining sites. Given the appropriate setting and control mechanisms, construction debris could be incorporated directly into a mine backfilling operation.

### 14.3.1.2 Landfilling Methods

The principal methods used for landfilling of MSW are 1) excavated cell/trench, 2) area, and 3) canyon. The principal features of these types of landfills are shown on Figure 1 and are described below. Landfill design details are presented later in the chapter.

*Excavated Cell/Trench Method* - The Excavated Cell/Trench Method of landfilling (see Figure 1a) is ideally suited to areas where an adequate depth of cover material is available at the site and where the water table is not near the surface. Typically, solid wastes are placed in cells or trenches excavated in the soil (see Figure 1a). The soil excavated from the site is used for daily and final cover. The excavated cells or trenches are usually lined with synthetic membrane liners or low-permeability clay or a combination of the two to limit the movement of both landfill gases and leachate. Excavated cells are typically square, up to 1,000 feet in width and length, with side slopes of 1.4H:1V to 2H:1V. Trenches vary from 200 to 1,000 feet in length, 3 to 10 feet in depth, and 15 to 50 feet in width.

*Area Method* - The Area Method is used when the terrain is unsuitable for the excavation of cells or trenches in which to place the solid wastes (see Figure 1b). High groundwater conditions, which occur in many parts of the country, necessitate the use of area-type landfills. Site preparation includes the installation of a liner and leachate control system. Cover material must be hauled in by truck or earthmoving equipment from adjacent land and from borrow-pit areas. In locations with limited availability of material that can be used as cover, compost produced from yard wastes and MSW has been used successfully as intermediate cover material. Other techniques that have been used include the use of moveable temporary cover materials such as soil and geomembranes. Soil and geomembranes, placed temporarily over a completed cell, can be removed before the next lift is begun.

*Canyon/Depression Method* - Canyons, ravines, dry borrow pits, and quarries have also been used for landfills (see Figure 1c). The techniques to place and compact solid wastes in Canyon/Depression Landfills vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of leachate and gas control facilities to be used, and access to the site.

Control of surface drainage often is a critical factor in the development of canyon/depression sites. Typically, filling for each lift starts at the head of the canyon (see Figure 1c) and ends at the mouth, so as to prevent the accumulation of water behind the landfill. Canyon/depression sites are filled in multiple lifts, and the method of operation is similar to the area method described previously. If a canyon floor is reasonably flat, the initial landfilling may be carried out using the excavated cell/trench method discussed previously.

A key to the successful use of the canyon/depression method is the availability of adequate material to cover the individual lifts as each is completed and to provide a final cover over the entire landfill when the final height is reached. Cover material is excavated from the canyon walls or floor before the liner system is installed. Borrow pits and abandoned quarries may not contain sufficient soil for intermediate cover, therefore, the cover material may have to be imported. Compost produced from yard waste and MSW can be used for the intermediate cover layers.

Abandoned open pit mines incorporate many of the same concepts as the landfilling methods presented in this chapter. Depending on the configuration of the open pit, both the excavated Cell/Trench Method and

**Table 2** Locational Restrictions for Municipal Solid Waste Landfills

| Restriction | Description | Applicability |
|---|---|---|
| Airport Safety | Facilities located within 1) 10,000 feet of any airport runway end used by turbojet aircraft, or 2) 5,000 feet of any airport runway end used only by piston-type aircraft must demonstrate that the facility does not pose a bird hazard to aircraft.<br><br>Owners/operators of proposed new landfills or lateral expansions within a 5 mile radius of any airport runway end used by turbojet or piston-type aircraft must notify the airport and the Federal Aviation Administration (FAA) | Existing units, new units and lateral expansions |
| Floodplains | Facilities located in 100 year floodplains must not restrict 100 year flood flow, reduce the temporary water storage capacity of the floodplain, or result in solid waste washout that poses a hazard to human health or the environment. | Existing units, new units and lateral expansions |
| Wetlands | Facilities may not be located in wetlands unless they successfully make several demonstrations to the Director of an approved state. | New units and lateral expansions |
| Faults | Facilities are banned within 200 feet of faults that have experienced displacement since the Holocene Epoch. Facilities in approved states may receive variance from this restriction. | New units and lateral expansions |
| Seismic Impact Zones | In approved states, facilities may be located in a seismic impact zone if they are designed to resist the maximum horizontal acceleration in lithified material for the site. | New units and lateral expansions |
| Unstable Areas | Landfills located in unstable areas must demonstrate that engineering measures have been incorporated into the unit's design to ensure that the integrity of the structural components (e.g. liners, leachate collection systems, final cover systems, run-on/run-off systems) will not be disrupted. | Existing units, new units and lateral expansions |

[1] Seismic impact zones are areas where there is more than a 10 percent probability that the maximum expected horizontal acceleration in hard rock will exceed 0.10g in 250 years.

Canyon/Depression Method may be incorporated. In both cases, surface water management and control is critical to effective landfilling operations.

### 14.3.2 SITE SELECTION

One of the most difficult tasks faced by most communities in implementing an integrated solid waste management plan is the siting of new landfills. The siting processes involve evaluation of engineering criteria and an assessment of public acceptance for a waste disposal facility. Mining sites that are being considered for waste disposal facilities may not be viewed as major impacts by the public. Since the land has been previously disturbed, the local community may view the facility as a long term economic base and source of jobs as the mining operations phase out. However, the same engineering siting criteria applied to a new facility must be evaluated for an existing mine site to determine if the site is technically feasible for development.

Factors that must be considered in evaluating potential sites for the long-term disposal of solid waste are similarly evaluated for mine siting and include:

- Haul distance
- Location zoning restrictions
- Site access
- Site specific criteria
  - Site conditions and topography
  - Climatic conditions
  - Surface water hydrology
  - Geologic and hydrologic conditions

Local environmental conditions
Final landuse restrictions

Each of these factors would be evaluated in a site characterization study. Therefore many of these factors have already been evaluated and the existing information can be used for site evaluation of the waste disposal facility.

The overall costs for siting and permitting a new landfill will vary depending on the local conditions, and are usually substantial. In California, for example, the up-front development costs for a large new MSW landfill can vary between 10 to 20 million dollars. The usage of an existing or abandoned mining site, that may have significant site characterization data and the necessary environmental and operational permits, can offset some of these initial costs. The primary factors used for evaluation are discussed below:

#### 14.3.2.1 Haul Distance

The distance that waste must be hauled prior to disposal is one of the most important variables in the economic evaluation of a particular site. Although minimum haul distances are desirable, other factors, such as environmental constraints, political concerns, and overall public acceptance of a site, can be more important than hauling costs. For example in Washington, waste from Seattle is currently being hauled, via trains, over 200 miles to a waste disposal facility in Oregon.

Haul distances for mining sites relative to population centers may vary. While mines are generally remote and situated in non-populated areas, they commonly are situated on or near major transportation networks (i.e. interstate highway systems, rail links) which may provide cost-effective haulage rates. In situations where an abandoned mine may be located within a metropolitan area, for example the Leona Quarry within the city limits of Oakland, California, the haulage costs are likely to be highly competitive with other landfilling alternatives.

#### 14.3.2.2 Location Restrictions

New federal criteria for MSW landfills contained in Part 258 of Subtitle D of the Resource Conservation Recovery Act (RCRA) contain specific requirements for the location of landfills. In addition, many states have adopted additional location restrictions. The federal location restrictions that must be met for new and existing facilities include:

Distance to airports
Floodplain restrictions
Wetland restrictions
Fault restrictions
Seismic impact zones
Unstable areas

The specific criteria that must be met and/or the mitigating design features that must be incorporated into the design are summarized in Table 2.

Not all mining sites are expected to meet the location restriction required for new landfills. However, the information required for evaluation of the criteria will probably be available from previous studies for mining operations. Review of existing information should allow a quick assessment of the feasibility of siting a new landfill at an abandoned open-pit mining site.

#### 14.3.2.3 Site Access

It is assumed that a landfill will be developed at an existing or abandoned mining site, and the access to the site will have been defined as part of the mining operations. However, site access may require improvement prior to landfill development. Ingress and egress from the landfill must allow efficient operation of haul trucks and/or passenger vehicles depending on whether the facility has public access. In addition, if the facility entrance is close to public viewpoints, some type of screening may be required.

#### 14.3.2.4 Site Specific Criteria

If a site meets the location restriction and appears to be economically feasible with respect to available waste stream and haul distance, more site specific studies must be performed for engineering design and permitting studies. These studies will be focused on further defining the geologic and hydrologic conditions at the site as they relate to environmental monitoring and to the engineering design parameters.

Studies to characterize the site for landfill development will generally include:

- Installation of groundwater monitoring wells up-gradient and down-gradient of the proposed facility.
- Background groundwater monitoring data on the site prior to the initiation of landfilling.
- Detailed characterization of the geologic and hydrologic conditions at the site, including the permeability characteristic of the near surface soils, depth to the nearest aquifer, seasonal fluctuations in the depth to the regional groundwater table, location and extent of any perched groundwater beneath the site, hydrologic characteristics of the aquifer, foundation conditions for the landfill, and suitability of the foundation soils for daily and intermediate cover.
- Surveys of the site for threatened or endangered species, archaeological sites, or wetlands that may be impacted by the development.

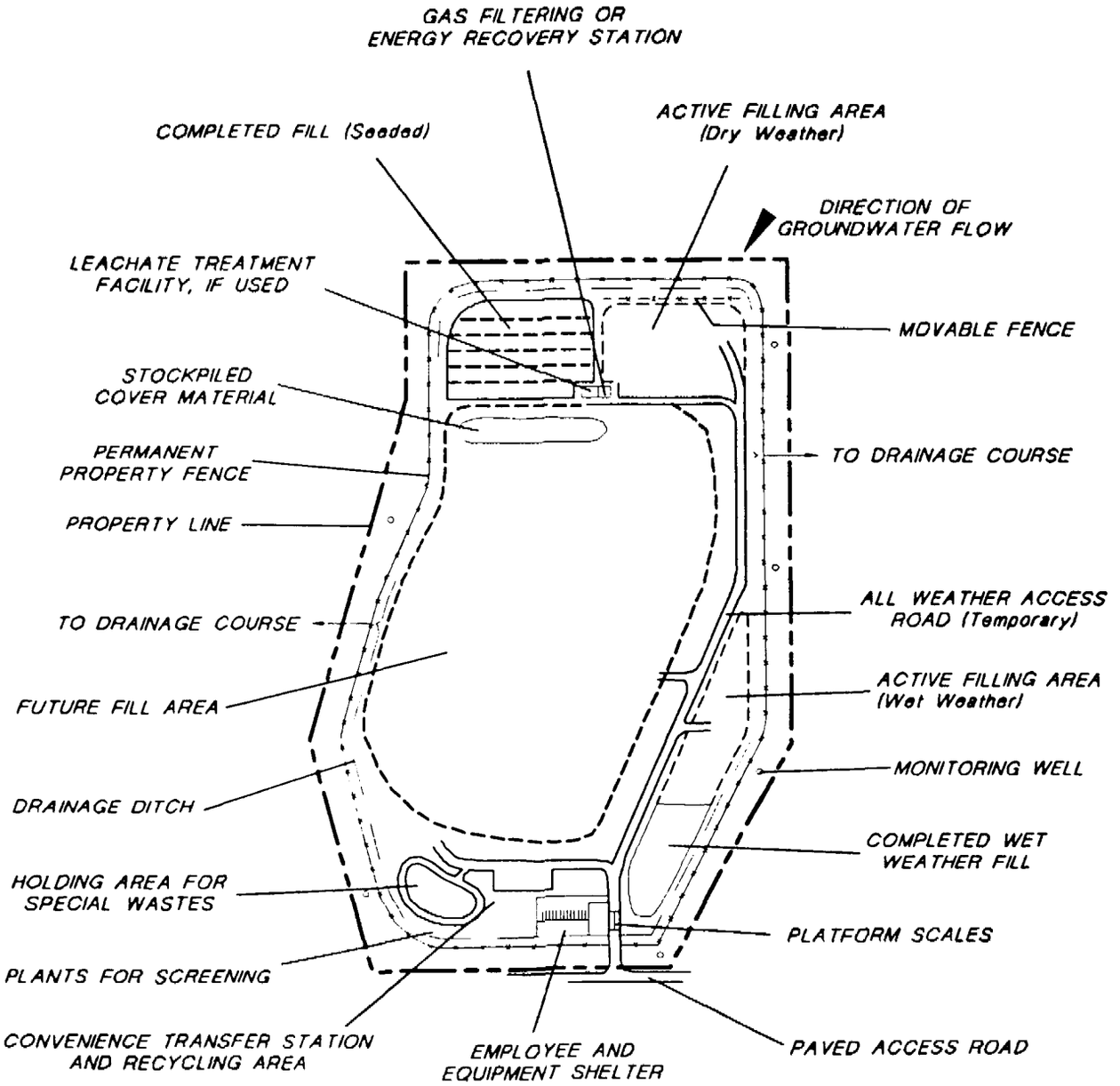



**Figure 2** Typical Layout of Landfill Site.

- Cover, liner and leachate collection system borrow source studies.

Some of the information required for the studies may have been collected as part of the mining development. However, it is expected that at least some site specific field investigations will be required to design and permit a new landfill.

#### 14.3.2.5 Final Landuse Restrictions

Most landfills will have restrictions placed on post-closure landuse, regarding long term settlement potential and landfill gas generation. However, with appropriate design measures, landfills can be utilized as park facilities, golf courses, or open range land. These types of final landuse are not substantially different from those envisioned for mining sites. Therefore, this criteria is not expected to impact the final evaluation of a mining site as a waste disposal facility.

### 14.3.3 FACILITY LAYOUT

A complete landfill facility will require not only a landfill cell, but also all of the associated support facilities. These include equipment shelters, scales, office space, transfer stations (if used), storage and/or disposal sites for special wastes, waste processing areas (composting), stockpile areas, borrow areas, drainage facilities, gas management facilities, leachate treatment, storage or transfer facilities, and monitoring systems. A typical layout for a complete landfill is shown on Figure 2. Each facility will be different in terms of the facilities required and the specific layout to meet site specific conditions. However, the layout shown on Figure 2 can be used as a guide.

Many of the facilities shown on Figure 2 may already exist or could easily be adapted from an existing mining operation. However, the most important segment of the facility layout will be the location of the landfill in relation to the active or historic mining operations. As will be discussed in subsequent sections, the location of historic mining operation or spoil piles can severely impact performance of the landfill containment systems if not properly engineered.

### 14.3.4 LANDFILL DESIGN COMPONENTS

The design of a complete landfill requires the expertise of a variety of professionals, from engineers and scientists to public relations and community marketing experts.

#### 14.3.4.1 General Design Factors

A listing of the important factors to consider in the design of landfills is summarized in Table 3.

In addition, Figure 3 provides a checklist of items to be considered in the design of a new landfill. Not all of the items listed will be addressed in every design, but should be considered by the design team to determine the specific relevance to a particular facility.

#### 14.3.4.2 Factors to be Considered

The design of landfills in mining areas is similar to the design of new landfills. However, there are several unique aspects of mining sites that must be recognized in the design process to ensure that the facility performs as designed. Some of the unique aspects to be considered in the design are listed below:

Landfilling method
Foundation conditions
Changes in hydrological regime
Settlement potential
Stability considerations
Type and condition of the country rock

*Landfilling Method* - The various methods of landfilling are discussed in *Section 14.3.1.2*. It is expected that landfills constructed within abandoned mining operations could be developed under a variety of scenarios. For example, the landfill could be developed in abandoned pits that are relatively deep with steep sidewalls or the facilities could be developed over old spoil piles or in previously reclaimed mine areas. For such sites, an "Area" filling method or a "Canyon" fill would be used.

New landfills on undisturbed ground will normally be developed to allow individual cells to be constructed in sequence to minimize leachate generation, facilitate surface water drainage, and minimize capital expenditures. However, development of landfills within mining sites may not allow as much flexibility to sequence individual cells and control surface water diversions. Specific studies may be required to determine the best landfilling sequence. Some additional earthworks may be required during the life of the landfill to facilitate proper development and operations.

*Foundation Conditions* - Typically, landfills are founded on competent soil or bedrock to ensure the integrity of the liner and leachate collection systems after loading. However, some mining sites planned for landfills may have relatively poor foundation conditions that will require special engineering designs. Poor foundation conditions may consist of old spoils, fault materials, or footwall clays at the base of the pit, or high groundwater conditions.

Landfills located over old mine spoils may result in substantial settlement of the liner and leachate collection system. Therefore, specialized designs are required to

**Table 3** Factors to be Considered in the Design of Landfills

| Factors | Remarks |
|---|---|
| Access | Paved all weather roads will be required for passenger cars and heavy haul trucks. Unpaved roads are suitable for access around the landfill and to the working face. |
| Land Area | The land area required for the development of a landfill will depend on the expected rate of waste placement. However, given the high development costs and the expense of long term monitoring at a site even after closure, it is generally expected that new facilities should be designed for 10 to 50 years of capacity. Areas for buffer zones between the active facilities and the property boundaries should also be included. |
| Landfilling Method | Landfilling method will vary with terrain and available cover. Most common methods are excavated cell/trench, area and canyon. Further discussion of these methods is presented in Section 3.1.1. |
| Completed Landfill Characteristics | Final slopes of landfill should be planned to accommodate final landuse and cover design. The slopes should be designed to provide for adequate surface water drainage (slopes of 3 to 6 percent) after settlement of the waste. |
| Surface Drainage | Install surface water drainage ditches to divert surface water runoff away from the active operations, maintain 3 to 6 percent grade on final cover to prevent ponding, develop plan to divert stormwater from lined but unused portions of landfill, and collect and store surface water runoff from active face. |
| Intermediate Cover Material | Maximize use of onsite soil materials, other materials such as compost produced from yard waste and MSW can also be used to maximize the landfill capacity, typical cover to waste ratios vary from 10 to 20 percent. |
| Final Cover | Generally will include a multilayer design with a permeability less than the permeability of the liner system components. |
| Landfill Liner | Can be composed of a variety of components from natural low permeability soil units below a landfill to multilayer components consisting of clays and geosynthetics. Cross slope for terrace type leachate collection systems, 2 to 5 percent; maximum flow distance over terrace - 100 feet; slope of drainage channels - approximately 2 percent; size of perforated pipe 4-inch diameter. |
| Cell Design and Construction | Each day's waste should form one cell; cover at end of day with 6-inches of earth or other suitable material; typical cell width, 10 to 30 feet, typical lift height including intermediate soil cover, 10 to 14 feet, slope of working face 2H:1V or 3H:1V. |
| Groundwater Protection | Divert any underground springs or seeps. Limit excavation to some suitable distance above the groundwater table to allow of fluctuation in groundwater level. |
| Landfill Gas Management | Develop landfill gas management plan including extraction wells, manifold collection system, condensate collection facilities, vacuum blower facilities, and flaring facilities and/or energy production facilities for landfills that are expected to generate large quantities of methane. |
| Leachate Collection | Determine maximum leachate flow rates and size leachate collection pipe and/or storage facilities for maximum expected flow. Design underlying leachate collection pipes to withstand overburden stress for maximum height of landfill. |
| Leachate Treatment | Based on expected quantities of leachate and location of facility to treatment facilities select appropriate treatment process. |
| Environmental Monitoring | Install groundwater, surface water and gas monitoring stations up-gradient and down- gradient of landfill. |
| Equipment Requirements | Number and type of equipment will vary with the type of landfill and operations plan. |

| | |
|---|---|
| Fire Protection | Water source should be available on site to respond to fires in the active landfill. Alternatively, outside sources could be used provided that suitable on site storage capacity is available. |
| Public Relations | An active public relations campaign should be waged that informs the public of all environmental monitoring programs being implemented and steps being taken to address community concerns about operation and monitoring of the facility. |

accommodate the settlement. These may include:

- Pre-loading
- Deep dynamic compaction
- Selective over-excavation and recompaction
- Geosynthetic reinforcement of foundation materials
- Thickened liner sections to tolerate settlement
- Selective placement of collection system piping to minimize settlement impacts

*Changes in Hydrologic Regime* - If the regional groundwater table is relatively close to the level of mining, there may be impacts to the local groundwater regime as a result of mining activities. These changes may include the groundwater level, as well as the groundwater quality. Therefore, it may be difficult to characterize the groundwater for background determination before the start of landfill operations or to predict the groundwater levels or quality after stabilization. Specific modeling studies may be required to evaluate expected conditions. Discussions must be held with regulatory agencies to establish benchmark conditions that will indicate impacts by landfilling operations.

*Settlement Potential* - Differential settlement is a common occurrence in landfilling due to the consolidation effect of the waste material. Settlement hubs should be installed in the final cover to monitor settlement rates. Areas that experience consolidation and differential settlement may require regrading to promote positive surface water runoff.

*Stability Considerations* - Stability considerations have become an important problem with the use of liner and leachate collection systems. Generally, low permeability clay liners are inherently low strength materials. In addition, recent laboratory testing and field monitoring experience has indicated that the geosynthetic components of liners and leachate collection systems have very low shear strength properties. This condition, in combination with the potential for low strength foundation materials, makes the stability of landfills a critical design task.

The stability of landfills must be evaluated under both static and dynamic loading conditions. Due to the containment requirements for landfill liners, allowable displacements under dynamic loading for liner systems are substantially less then for comparable embankments at a mine site. Therefore, normally accepted slope heights, slope angles and filling schemes may not be applicable for lined landfills.

## 14.3.5 CONSTRUCTION CONSIDERATIONS

### 14.3.5.1 Construction Quality Assurance (CQA)

The ultimate success of a landfill is dependent on the protection of the groundwater and surface water resources at the site. Designs for liner and leachate collection systems have improved in recent years to protect leachate and landfill generated gas from escaping the landfill. However, the success of the designs is dependent on the quality of the construction process. Therefore, most new landfill liner and leachate collection systems for landfills are being constructed under rigorous Construction Quality Assurance (CQA) programs to document that the facility is designed in accordance with the design drawings and specifications.

The CQA programs are either implemented by the designer or an independent third party. The components of a CQA plan will include the following components:

- Definition of authority for various personnel and organizations involved in construction
- Minimum qualifications for CQA personnel
- Observations and tests that will be implemented to confirm that the construction or installation meets or exceeds all design criteria, plans and specifications
- Sampling strategies that should be used for field and laboratory testing
- Types and format for documentation and certification to be collected during construction

### 14.3.5.2 Seasonal Construction Considerations

Due to the sensitive aspects of both the soil and geosynthetic components of a liner system, the construction of new cells or the expansion of existing cells should be planned to be constructed during the driest part of the season. Construction during the wet season can add considerable time to the construction schedule

| Leachate Collection Systems | |
|---|---|
| Leachate quantity<br>Collector pipe bedding to prevent clogging<br>Pipe materials to withstand heat and pressure<br>Means to inspect and clean out<br>Cross connections to provide alternative flow paths<br>Positive drainage | Leachate storage reservoirs<br>Pumping facilities<br>Continuous monitoring<br>Modular integrity<br>Leachate recirculation during peak flow of the treatment |
| **Leachate Containment** | |
| Material Selection<br>Specifications<br>Protection from puncture<br>Construction techniques | Leak detection<br>Subgrade preparation<br>Landfill capping<br>Controlled release |
| **Methane Gas Control** | |
| Concentration of gasses<br>Withdrawal system<br>Odor Control | Recovery as resource<br>Protection of on-site vegetation<br>Monitoring |
| **Perimeter Zone** | |
| Access control - Fencing<br>Access control - signs<br>Screening berms<br>Screening vegetation<br>Screening fences | Windblown paper controls<br>Esthetics<br>Safety<br>Cover or topsoil stockpiling<br>Handle off-site vegetation |
| **Entrance Zone** | |
| Reasonable grades (7-10%)<br>Eliminate interference with access route<br>Need for merging lanes<br>Adequate site distance<br>Adequate turning radius | Adequate width<br>Paved with a permanent surface<br>Devices to keep mud from access road<br>Esthetics<br>Prevent straight-line view into site |
| **Visual Zone** | |
| Designed to provide good image<br>Vehicle pull-off for viewing site | Traffic controls<br>Consider concurrent use |
| **Interior Zone** | |
| Provide building for administration, weighings, equipment,<br>Maintenance, storage, and parking<br>Provide employee facilities<br>Examine layout of facilities for efficiency<br>Use pull-off areas to avoid congestion on access roads<br>Provide bulk containers<br>Fire controls<br>Adequate separation to property boundaries<br>Provide minimal gas venting<br>Set up monitoring program - gas and leachate<br>Movable litter fences | Primary windblown paper controls<br>Cell construction in relation to wind direction<br>On-site surface water runoff<br>Erosion controls<br>Specification for access roads<br>Handling of cover materials<br>Equipment selection<br>Initial site improvement<br>Topsoil and cover stockpiles<br>Hours of operation<br>Utilities; water, electric, and telephone |
| **Plan of Operation** | |
| Goals to be met<br>Handling of special wastes - dead animals, industrial, liquids, hazardous<br>Placement of cover<br>Maintenance of facilities, equipment, roads<br>Operation during variable weather conditions; winter, wet, warm weather, brisk winds<br>Fires<br>Salvage | Record keeping<br>Operating hours<br>Traffic routing<br>Staffing needs<br>Vendor control<br>Dust control<br>Daily cleanup<br>Ban on salvaging |

**Figure 3** Landfill Design Checklist.

and result in added costs. Liner installations are also temperature sensitive. Caution should be used in the placement of geotextiles during extremely high and low temperatures, which may effect material elasticity, brittleness and impact strength.

#### 14.3.5.3 Contractor Selection

Most project specifications for the installation of geosynthetic materials require that the installation contractor have minimum experience qualifications in terms of previous installations and welders with a minimum of one million square feet of welding experience. It is recommended that similar pre-qualification criteria be established with the earthworks contractor. The installation of compacted clay liners is a specialized task that not all earthworks contractors are qualified to perform. Placement and compaction of landfill clay liners is not the same as placement of any structural fill. The placement specification, and grading and surface preparation requirements are generally in excess of normal fills. Some of the differences are noted below.

- Very tight placement specifications in terms of water content and dry density are common.
- Specialized processing is often required to ensure the material is homogenous and does not contain oversized material or excessive clods.
- Quality control and quality assurance requirements are much stricter than for other earthworks projects.

The contractual arrangement between the owner, earthworks contractor, and geosynthetic contractor can be set up in different ways depending on the owner. Generally, the earthworks contractor and the geosynthetic contractor require very close coordination to operate efficiently. Therefore, having the geosynthetic contractor as a subcontractor to the earthworks contractor will facilitate their coordination for onsite work. However, this type of relationship does not allow the owner direct control over the geosynthetic contractor and cannot directly enforce quality control procedures. Depending on the project and the needs of the owner, one relationship or another may be best for a given project. In many cases the CQA monitor will be directly contracted by the owner to ensure a high degree of independence.

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# Chapter 15

# ECONOMIC IMPACT OF CURRENT ENVIRONMENTAL REGULATIONS ON MINING

edited by J. A. Murray

The mining industry faces three major types of economic impacts as a result of current environmental regulation. First are the reallocations of resource demands caused by environmental regulations on other industries (e.g., low sulfur coal demands caused by regulations on coal-fired power plants). Second are the direct costs of installing, operating and maintaining abatement equipment. Third are the indirect costs of permit acquisition, permit acquisition delays, monitoring, reporting and file storing. These indirect costs are far more detrimental to the mining industry than the other costs. The first and second economic impacts will be discussed in Section 15.2, using large-scale economic modeling results. The third economic impact will be developed in more detail in Section 15.3.2 to show that, without schedule delays, current U.S. environmental regulation may reduce a project's profit by 11 percentage points, and of those, only 3 percentage points may result in mitigating adverse environmental effects. The balance of the loss in profitability is expended on baseline studies, application preparation, monitoring, report generation and other administrative and legal tasks.

As will be discussed in Section 15.3.3, profitability declines further if delays in the permit acquisition process are considered. Assume there are two identical projects with identical environmental mitigations incorporated into each project; the project outside the United States can be twice as profitable as a project that is subject to the administrative aspects of the U.S. environmental procedures.

## 15.1 INTRODUCTION

Since the early 1970s environmental regulations[1] have exerted tremendous economic pressures on both the United States and offshore mining industries. During this same period, political instability in the oil-rich Middle East and the mineral-rich former communist bloc, with attendant increases in fuel efficiencies, decreases in military material and supply requirements, and the restructuring of the trading patterns, have superimposed an additional, different set of economic pressures causing changes in the world mining industry. Further, increases in United States and foreign populations plus increases in per capita consumption have resulted in rising demands for mined materials. In spite of the scope of the overall changes in economic conditions, the environmental regulations have significant and discernable economic impacts on the mining industry.

The types of impacts will vary. Environmental regulations can have large-scale effects on the economics of entire regions. For example, mining activities have been phased out of one geographic area and been replaced by mining in another area. A case in point, the Clean Air Act, which significantly reduced power plant allowable $SO_2$ emissions, shifted demand and, consequently, mining from the high sulfur coals in eastern states to the low sulfur coals in western states. The overall economic effect on coal mining was more tons of lower-ranked coal shipped and at a higher price. However, the apparent beneficial economic impact on the overall coal mining industry is not without the loss of individual mining jobs and support businesses in eastern states, which partially offset the gain in western states. A purpose of this example is to illustrate also that an environmental regulation directed at one industry (e.g., electric power generation) can have an economic impact on another industry (e.g., coal mining) or another geographic region.

Another example of large-scale economic impact is

[1] Unless otherwise noted, references to "environmental regulations" or "mining industry" in this chapter will mean "United States federal, state or local environmental regulations" or "United States mining industry," respectively. Likewise, references to "offshore mining industry" will be so designated. Finally, "world mining industry" is the combined mining industry and offshore mining industry.

where established commodity demands are reallocated. The Clean Air Act mandated reductions in vehicular emissions, which resulted in smaller and lighter automobiles, causing shifts from iron and steel consumption to aluminum consumption. While the environmental regulation caused a shift in the demand for different types of materials mined, it was business decisions, or lack thereof, by individual automobile manufacturers in various countries that caused a global shift in *where* these resources were mined and smelted. This example is mentioned to illustrate a distinction between an impact of an environmental regulation and other concurrent factors.

Typical economic statistics reports make a distinction among various types of mining (i.e., those with Standard Industrial Code (SIC) designations for mineral mining, metallic ore mining and coal mining, hereafter collectively designated as "the mining industries"). Another distinction is made in the economic statistics between the mining industries and related SIC designations such as the primary metals industry or the stone, clay and glass products industry. The primary metals industry has been ranked as the industry either most heavily impacted by environmental regulations or second only to the petroleum refining industry, depending on which grouping of economic impact indices are being used. Having made these distinctions, it is important to note that the scope of this Handbook is limited to the mining industries. These direct economic effects of the environmental regulations on the mining industries are discussed in Section 15.2.

In addition to large-scale or general economic effects on the mining industries caused by the environmental regulations, each new project, operating mine or closed property is also affected by environmental regulations (including related land use controls and water rights legislation) established at the federal, state and local levels. Site-specific environmental considerations will determine a mine's feasibility, profitability, longevity, and contribution to the community. Even an optimistic (short) environmental permit acquisition process in combination with the environmental monitoring requirements can decrease a new project's profitability by 11 percentage points. These effects are discussed in Section 15.3.2.

The impact of the environmental regulations on a mine's economic feasibility is determined more by schedule delays and other related uncertainties rather than by direct expenditures for pollution control. As shown in Section 15.3.3, the delays allowed by the procedural requirements of the environmental regulations are causing the most severe adverse economic impact on the mining industries. As a result, many domestic mine operators are pursuing mining opportunities outside the United States. Also, mines in other countries are installing environmental safeguards similar to those required by United States standards, but they are doing so without regulatory delays. The mining industry of these countries is expanding.

This Chapter's discussion of the economic impact of the current environmental regulations does not cover the economic impact of other regulations such as the Mining Law of 1872, MSHA, health benefits, trade policies, or other nonenvironmental regulations. The economic impact of these regulations are in addition to and must be superimposed on top of the economic impacts caused by environmental regulations. Such a superimposition is beyond the scope of this Handbook.

Details of the costs of compliance with specific current environmental regulations are covered in the topic-specific chapters elsewhere in this Handbook. Those chapters cover permit acquisition programs, baseline studies, or compliance costs for specific major commodities and mining techniques.

## 15.2 MACROECONOMIC IMPACT OF CURRENT ENVIRONMENTAL REGULATIONS

Environmental regulations have quantifiable impacts on the economics of the mining industries as well as the overall economy. These general economic effects are currently the subject of debate among academic, industrial, labor, legislative, regulatory and environmental groups. Similar debates have been going on for centuries and were even mentioned in Agricola's mining treatise from the 1500s. Often, the past or current debates take place in terms that will pit issues that can be quantified (usually in monetary terms) against issues that cannot be so quantified. Resolution of the tangible vs. intangible debates are the stuff that requires tough statesmen to make reasoned, far-reaching policy decisions. In the United States many such decisions are based upon short-term, politically expedient factors. The balance of this Chapter will cover tangible, monetary effects of the environmental regulation.

### 15.2.1 ECONOMIC IMPACT ON THE TOTAL ECONOMY

The original intent of the environmental legislation was to protect human health with the promulgation of primary standards. Secondary standards were then set to protect property, plants and animals. The secondary standards contained explicit and implicit references to economic parity among the compliance costs, total economic impact and the value resulting from the protection. For example, secondary ambient air quality standards for particulate control were, in part, justified by soiling indices for clothing and outside building surfaces; compliance costs were justified by commensurate

reductions in laundry detergent consumption and house paint requirements. Accordingly, most federal pollution control legislation requires some degree of economic evaluation of resulting regulations. However, most of these evaluations are limited in scope to one specific media (air, water, solid waste) pollution abatement, which may trade air pollution for water pollution. For example, one specific industrial category may be evaluated, while neglecting the effect that a change in one industry will have on another industry.

By initially establishing environmental goals based on ambient measurements, environmental legislation created economic pressures that soon influenced the site selection. Some new nonmining industry projects were directed to less polluted areas which, by virtue of existing clean air and water, could assimilate more pollution prior to exceeding an ambient standard. In these areas, the capital and operating costs of the pollution control equipment would be less, providing a cost incentive to locate in or relocate to such areas. Of course, the mining industry is not a highly mobile industry. A mine can be located only where nature has deposited a resource. In spite of the unique siting requirements of the mining industry, it became affected by the resulting legislation aimed at remedying the general relocation problems.

The first remedy the federal legislation selected was modeled after basic concepts originating in labor legislation. The major element of the concept was to offer a nationwide set of laws and requirements to create a level playing field, wherein the aspects or issues granted legislative protection would not influence the location of production facilities. In this manner, there was to be no economic incentive available to one geographic region over another. (Of course, individual states could enact more stringent laws.) The labor movement used this type of legislation to develop nationwide bargaining units and contracts. There was a school of thought that the labor costs would rise uniformly throughout the United States. The competitive consequences within an industrial sector due to changes in labor cost would be severely dampened, and no single company would lose a competitive edge. Thus, as long as international competition was held away at the borders, labor costs would not affect the viability of a subject industry.

From the labor model, the concept of new source performance standards was developed, wherein each industrial facility category had to achieve fixed emission and effluent standards. It was reasoned within the environmental legislative and regulatory processes that the cost of pollution control would then not disrupt the competitive nature of a facility, regardless of the background pollution levels, as long as the ambient standards were being attained. For the mining industries, these new source regulations have been in place since the early 1980s. These emission and effluent standards are also now being applied to some new offshore projects. This acceptance by the world mining industry is led by the various western government-sponsored world lending agencies and free-trade agreements. Thus, as this trend continues, the economic disparity related to pollution control between the United States and offshore mining industries will decrease.

In an attempt to further level the playing field within the United States, the regulatory community developed the concept of nationwide application of uniform techniques for pollution control. These have become known as "best available control technology" (BACT); "best available technology" (BAT); "reasonably available control technology" (RACT); "maximum achievable control technology" (MACT); and approximately a dozen more acronyms for synonyms. Again, the differential economic impacts are intended to preclude cost advantage from facility to facility or region to region when applied uniformly on the nationwide basis to specific industries. However, these approaches result primarily in added pollution control equipment and related costs in excess of that required to meet the ambient concentration standards, which are established to meet an environmental objective.

In other words, the MACT and other similar acronyms are requirements to purchase and install pollution control equipment because it is available, not necessarily because it is needed to mitigate a defined environmental or ambient concentration concern. As a result, the associated pollution control expenditures are more difficult to justify in countries without the wealth of the United States because there are no apparent corresponding environmental benefits.

In the legislative and regulatory processes, attempts have been made to minimize or level the economic impacts, but there is little information available to correlate the impacts on the United States economy resulting from the environmental regulations. At least at the federal legislative level, there is a common expression: "Ready, Fire, Aim." Some legislators and staff believe any action is better than no action and that any law always can be corrected later by additional ("Ready, Fire, Aim") legislation or by the judicial system. Success is then measured by reactions of lobbyists and public opinion polls. There is a need for better methods for evaluating the economic impact of the environmental regulations. Some important, though limited, attempts have been made to develop such information.

Fitting the activities driven by environmental regulation into an overall model of the national economy remains a monumental task. First, modeling of the U.S. economy is itself a monumental task. Second, the gathering of the environmentally related expenditures is difficult because there is uncertainty whether data obtained from diverse sources will accurately reflect its

proposed use in a model. And third, any such modeling has a temporal component that is continuously affected by the changing environmental picture as well as national and world events (e.g., oil embargo, war, drought). The answer to this, of course, is simplifying the assumptions, which in turn can greatly influence the results. In light of the above, selecting a proper model becomes an important feature of an economic evaluation. Furthermore, only through consistent use of such a model can results be compared. That is, jumping from model to model can be viewed as "shopping" for desired results.

Also, more extensive modeling is needed to better understand the use and/or misuse of commonly used indicators of economic impact. An often misused indicator is the percent of the Gross National Product (GNP), or more recently Gross Domestic Product (GDP), that is spent on pollution abatement or pollution control devices. Some groups use this percent as a measure of growth in the economy because of the increased economic value of goods and services circulating in the economy as a result of expenditures for pollution control and other environmental activities. Other groups will use this same percent of GNP or GDP as a measure of shrinkage in the economy because these environmental expenditures siphon the needed funds for facilities, exploration or research that are the underpinnings of a productive and growing mining economy.

In response to the above requirements and complexities, an extensive modeling technique and data base has been developed by Dale W. Jorgenson and Peter J. Wilcoxen of Harvard University. Their work has been reported in a series of technical papers covering the economic effects of existing environmental regulations and projections of the economic impacts anticipated to result from potential new environmental regulations. The Jorgenson and Wilcoxen economic model used 34 commodities and services sectors of the economy plus government enterprises, personal consumption, savings, imports, exports, product substitution and productivity growth.

The results of the Jorgenson and Wilcoxen studies indicated that from 1972 to 1983 the U.S. GNP, which was then only growing at an annual rate of approximately 2%, would have grown faster by an annual rate of 0.2% (i.e., at an annual rate of 2.2%) in the absence of the environmental regulations. The U.S. economy during this time was also adversely affected by two major OPEC oil embargoes, which according to Jorgenson and Wilcoxen, were compensated for in conclusions derived from their economic modeling procedures. For the same time period, others using less comprehensive models were predicting a much lower rate of the economic slow-down due to compliance with environmental legislation.

The Jorgenson and Wilcoxen modeling efforts predicted a similar lowering of the rate of economic growth for the next 60 years as a result of the Clean Air Act Amendments (CAAA) of 1990. This reduction in economic growth is superimposed on the reductions caused by previous environmental regulations.

Another purpose of relating the CAAA results of this modeling effort is to provide insight as to the effects on the national economy that result from spending on pollution control. For example, it has been estimated that the CAAA alone will require new pollution control equipment and operating expenditures of approximately 2% of the GDP annually. However, this level of expenditure does not result in an overall growth in the U.S. economy; rather, the U.S. economy would grow faster without such an expenditure. On the other hand, the economic growth will not be decreased by the full amount of the expenditures. The model of the CAAA economic impact predicts a slight, short-term increase in the real GDP through 1997 averaging approximately 0.05% of the GDP as a result of the heavy capital expenditures required for compliance. By 1997, the gain in the real GDP due to the CAAA expenditures will have been erased, and by the year 2005 (CAAA mandated compliance date), the real GDP will have been reduced by 0.4%. The economic impacts of the CAAA will stabilize by the year 2020 with the real GDP being permanently lowered by more than 0.5%.

The modeling efforts similar to the above have not been conducted for other types of environmental regulations which were implemented after the 1983 study and which relate to:

- RCRA, CERCLA and SARA (i.e., Superfund)
- Endangered species, biodiversity and wetlands (i.e., antispeciesism)
- Wild and scenic rivers, wildlife areas (i.e., reduced multipurpose uses for public lands)
- SMCRA - (i.e., mine closure and reclamation)

Also, the modeling of the economic effects during the 1970s to early 1980s may have been underreported by a quirk in the IRS regulation, which does not allow the cost of pollution prevention to be considered in the reporting of pollution control costs. For example, IRS codes would consider water spray on an open stockpile as a method of pollution abatement (i.e., dust suppression). However, if a cover (e.g., a dome) were to be installed over the stockpile to "prevent" the dust emissions, it would not be allowed to be considered "pollution abatement" for purposes of accelerated depreciation for taxes or purposes of funding by government issued bonds if those bonds were to pay tax-free income to the bond holder. Thus, the dome expenditure could go unreported and not be included as a gross economic statistic typically available for large-scale models. This IRS ruling had great influence on both the related primary

**Table 1** Impact of Current U.S. Environmental Regulations Through 1983 on Selected Mining Industry Groupings and Related Industries

| Industry | Share of Pollution Abatement as% of Total Industry Costs (%) | Share of Industry as Percent of Total U.S. Abatement Costs (%) | Share of Abatement Devices as% of Industry Investment (%) |
|---|---|---|---|
| Metal mining | <0.5 | <1 | <1 |
| Coal mining | <0.5 | <1 | <1 |
| Nonmetallic mining | <0.5 | <1 | <1 |
| Clay, stone & glass products | 1.0 | 4 | 12 |
| Primary metals | 2.5 | 13 | 20 |
| Paper and allied products | 1.7 | 7 | 22 |
| Petroleum | 1.3 | 15 | 12 |
| Chemical and allied products | 1.6 | 11 | 23 |

metals industry and the clay, stone and glass industry as a disincentive to invest in process changes to prevent pollution. Instead, the ruling was an incentive to spend for add-on, end-of-pipe pollution abatement expenditures. Even though such process-change expenditures were made by some of the more visionary business managers in the desire to comply with the federal, state and local environmental regulations, the reporting quirks make it difficult to obtain such expenditures for inclusion in any economic model; hence, even the most comprehensive economic modeling is likely to underestimate the adverse effect of the environmental legislation on the United States economy.

The modeling of Jorgenson and Wilcoxen also indicates that the economy will experience the effects of the mandated abatement legislation for 15 to 60 years after the enactment. This time period extends well beyond the period encompassing the legislative action, the regulatory promulgation, judicial appeals and regulatory compliance deadlines. In other words, the period of economic impact goes well beyond the period of purchase and installation of the abatement equipment.

### 15.2.2 IMPACT ON MINING INDUSTRIES

In general, "the mining industries" (i.e., the combined industrial segments defined by economists as coal mining, metals mining and nonmetallic mining) have not experienced as large a cost as many other segments of the economy. In keeping with the scope of this Handbook, the closely allied industrial segments (i.e., the primary metals industry and the clay, stone and glass products industry) have been excluded from the discussions of the economic impact of environmental regulations. However, there is an overall advantage to be gained by including these industry segments for the purpose of this discussion. The first aspect is that the mining industries may be lumped together with these closely allied industries during discussions of the cost of environmental regulations. This may mask certain perceptions of the economic impact experienced by individual mining industry segments. The second aspect is that the abatement costs, although important, are not the best indicator of the economic impact on various segments of the mining industry.

Compared with the mining industries, the primary metals industry and the clay, stone and glass products industry are subjected to much greater costs as a result of current environmental regulations. The primary metals industry has experienced some of the highest costs resulting from compliance with the environmental regulations. Only a few other industries will occasionally exceed the cost impact experienced by the primary metals industry. Several abatement cost indicators are presented in Table 1. In addition to the three major segments comprising the mining industries, the primary metals industry and the clay, stone and glass products industry are given for reference. Also, to provide additional reference for the significant costs to the primary metals industry segment, the abatement costs for three additional

**Table 2** Effect of Abatement Costs Resulting from Selected Environmental Regulations on Selected U.S. Mining Industry Groupings and Related Industries

| Industry | Percentage change in price of product | | | Percentage change in quantity of product shipped | | |
|---|---|---|---|---|---|---|
| | Modeled through 1983[1] (%) | Modeled CAAA of 1990[1] (%) | Anticipated current U.S. regulations[2] (%) | Modeled through 1983[1] (%) | Modeled CAAA of 1990 (%) | Anticipated Current U.S. Regulations[2] (%) |
| Metal mining | +2 | +0.75 | +5 | -2.5 | -2 | -15 |
| Coal mining | +7.5 | +6.5 | +10 | -8 | -7 | -15 |
| Nonmetallic mining | +2 | +1 | +5 | -0.75 | -0.5 | -5 |
| Clay, stone & glass products | +2 | +2 | +5 | -1/10 | -1 | -5 |
| Primary metals | +2.5 | +3 | +5 | -2.5 | -5 | -25 |

[1]After Jorgenson and Wilcoxen.

[2]Impact of all current U.S. environmental regulations including those listed from Jorgenson and Wilcoxen but excluding changes in land-use regulations and 1872 Mining Act.

industry segments (i.e., paper, chemical and petroleum) are provided in Table 1.

Because the abatement costs for the mining industry segments appear relatively minor, as shown in Table 1, the economic impact of the environmental regulations on the mining industry must be found in other indicators. Table 2 provides the impact on price and production for the two sets of environmental regulations selected by Jorgenson and Wilcoxen for their economic modeling efforts. The coal mining industry is the most heavily impacted of the mining industries. Environmental regulations impact on the coal mining industry was mostly due to the shift from high sulfur to low sulfur coal and to fuel policy shifts related to greenhouse gases. In the absence of these two effects, the changes shown in Table 2 under the pricing and quantity shipped columns for the coal mining industry related to abatement and mitigation expenditures at the mine site would decrease to about the same levels as those shown in the respective columns for the metal mining.

An additional interpretation drawn from Table 2 confirms that mining activities are moving outside the United States. For example, the regulations of the 1970s (as reflected in the "Through 1983" column) and the CAAA of 1990 have less of an impact on the nonmetallic mining industry compared to the metal mining industry, which is shown in terms of the change in quantity shipped due to the environmental regulations. (It should be noted that there can be a total increase in shipments due to total growth in population and per capita consumption; environmental regulations depress that total growth by the percentages shown in Table 2.) Many of the mining operations that comprise the nonmetallic mining industry and also the clay, stone and glass products industry serve local markets and are very sensitive to transportation costs (e.g., the cost of shipping lime can be large part of the delivered price whereas the delivered price of gold is independent of transportation cost). As a result, this category is not particularly vulnerable to distant competitors. This is an explanation as to why these two industries are anticipated to have the least change in the quantity shipped due to environmental regulations.

Many of the nonmetallic mining industry and the clay, stone and glass products industry operations are conducted by smaller, not heavily financed companies. Therefore, they are least capable of relocating assets or changing their product mix to adjust to the changes in

the market caused by environmental regulations. The smaller companies also have greater difficulty coping with financing and maintaining market share during the periods of capital and/or permitting expenditures required by the environmental regulations. Furthermore, the smaller and local companies are less likely to have the personnel resources to implement the capital, reporting, monitoring, permitting and community relations programs required by the regulations. This demand on personnel is compounded by similarly increasing demands made by other agencies (e.g., MSHA) and land-use planning jurisdictions. These factors have contributed to many of these companies going out of business and to the changes in ownership of many operations wherein small operators are purchased by larger, more diverse corporations. These results of environmental regulations are difficult to reflect in large-scale economic models.

On the other hand, the modeled impact of the CAAA of 1990 indicated a small price increase in the mining industries products. Also, as shown in Table 2, there will be a decline in the quantity of product shipped due to environmental regulation. For example, metal mining industry prices will rise approximately 3/4%, but the product shipments will decline by approximately 2%. The result is a net loss in revenues. A similar trend is seen in the model results for the primary metals industry. The decline in quantity shipped is indicative of the metals productions going overseas (i.e., increased imports).

The impact on the metals mining industry is not as great as the slowing of the shipments in the primary metals industry. Typical reasons for the metals mining industry to do better than the primary metals industry include the following. Many nonferrous smelters in the United States have been closed, and nonferrous concentrates that once fed those smelters are now exported. Departure of the aluminum smelters will decrease primary metal shipments without affecting the metallic mining industry because all bauxite is now mined outside the United States

As noted earlier in 15.2.1, the Jorgenson and Wilcoxen model data presented in Table 2 includes effects from only the noted regulations but does not include the combined effects of all current environmental regulations. However, the economic impact of all environmental regulations, if modeled, would show further increases in the price of the product and decreases in the quantities shipped. Lacking such model results, the impact due to all of the current environmental regulations has been extrapolated from the available model data. Those anticipated values reflecting the economic impact of all current regulations have been included in Table 2. Because of increases in both United States population and per capita consumptions, there is no indication that the overall consumption of mined products will be decreasing. A conclusion is that additional required mine products will be made up by increased imports. The resulting adverse effects on the balance of trade are reflected in the diminished rate of growth of the overall economy noted in Section 15.2.1.

### 15.2.3 ECONOMIC BENEFITS OF REGULATION

Since the decade of the 1980s, there has been a swing away from the intent of the original environmental legislation and regulation which sought to maintain a balance between cost and environmental benefits. For example, during the 1970s the secondary Ambient Air Quality Standards were established with an attempt to balance the benefits to property and flora and fauna against the costs to the human economy. However during the 1980s, the Endangered Species Act and Wetlands preservation requirements were undertaken without consideration to the impact on the human economy. The 1990s bring efforts to control potential problems associated with greenhouse gases and ozone layer depleting emissions. The worldwide costs of implementing the proposed control strategies are of such enormity that much of the environmental legislation has been put under scrutiny to determine the costs and benefits of the various components. There is an apparent recognition by a growing number of politicians that unlimited resources cannot be devoted to environmental control. Therefore, priorities must be established.

As mentioned in the previous section, there are economic models that start to explain the cost impacts of environmental regulations. The complementary benefits models have yet to be developed. One of the difficulties in creating a benefits model is how to quantify the seemingly intangible. For example, how is the value of a wild and scenic river to be measured or quantified?

Interestingly, as early as 1960, Miller and Starr in their textbook, *Executive Decisions and Operations Research*, highlight "The Buckingham Method" to handle problems of this sort. Tietenberg and other serious scholars are developing methods to provide such quantitative information for the dollar value cost that can be associated with improved visibility, wild and scenic rivers, potential cancer cures from rain forest insects, and other seemingly intangible issues. These analytical methods are somewhat embryonic; however, the efforts appear to be leading toward a science and, more importantly, databases. When more fully developed, these methods will be able to contribute routinely to future risk assessments and the economic impact of the environmental benefits for use by the legislative and regulatory community within the early, mid-decades of the 21st Century. Such cost and time may be well spent in the overall review of the regulatory promulgation processes if the philosophical questions can be framed in quantifiable or, at least, semi-quantifiable parameters

**Table 3** Example of Typical Relation Among Various Components of Project Costs

| | Mechanical/abatement project | | Civil/reclamation project | |
|---|---|---|---|---|
| | Illustrative costs ($) | Percent of direct construction costs (%) | Illustrative costs ($) | Percent of direct construction costs (%) |
| **Cost Component** | | | | |
| Treatment device (equipment, related freight) | 800 | 35 | 0 | 0 |
| Minor equipment (pumps, tanks, motors, starters) | 400 | 17 | 100 | 5 |
| Bulk materials (pipes, wire, conduit, concrete, steel, fertilizer, seed) | 500 | 22 | 500 | 22 |
| Construction labor | 500 | 22 | 1,300 | 57 |
| Field distributable costs (security, tools, equipment rental) | 100 | 4 | 400 | 16 |
| **Direct Construction Cost** (including contingency) | 2,300 | 100 | 2,300 | 100 |
| Engineering, construction management, field and shop quality control, procurement, safety | 300 | 13 | 200 | 8 |
| Owner's site costs (insurance, project management, permits[1], startup | 300 | 13 | 200 | 8 |
| **Indirect Construction Cost** | 600 | 26 | 400 | 16 |
| **Total Construction Cost** | 2,900 | 126 | 2,700 | 116 |
| **Owner's Project Costs** (finance charges, property costs, taxes, legal) | 500 | 22 | 500 | 22 |
| **Total: Project Cost** | 3,400 | 148 | 3,200 | 138 |

[1]Including building permits but excluding major environmental permit efforts.

prior to litigation. In summary, there are societal benefits resulting from many of the current environmental regulations, but the metrics of the benefits are only now being developed.

## 15.3 IMPACT ON PROJECT FEASIBILITY

### 15.3.1 COST BASIS

When presenting cost data, the time references must be taken into account. The value of an expenditure made today is different from the value of an identical expenditure made at some future date. This effect is the net present value (NPV) and is a reflection of the rates of return requirements of the project and investment community.

The relative difference between present and future values will further increase or diminish depending on how the unit cost of an expenditure item changes with time. This major time-dependent effect is escalation, which is a reflection of changing productivity and costs

of living. Unless otherwise noted, costs will be in terms of first quarter 1993 dollars.

Yet another aspect of using cost data is to determine what is included in the "cost." Table 3 is an example of a project cost.

The absolute values are not important because they were only selected for purposes of illustration, but the relative ratio among the various cost components is important. The relative ratios are generally consistent within ±5 absolute percentage points for many projects.

As noted in Table 3, the mix of cost component percentages differs depending on the type of project. In general a project may be considered either a mechanical project (e.g., acid mine drainage treatment plant) or a civil project (e.g., ditching, recontouring, revegetation). In either type of project, some or all of the direct construction cost components are known and are less variable from project to project than are the indirect costs. Therefore, the preliminary estimates of a project cost are often factored from the direct construction cost or a single component of the direct construction cost.

Finally, Table 3 provides a useful checklist of the full range of cost items that are required for a total project. It is well to note that no contingency costs are shown. Instead, the contingency costs have been distributed throughout the separate line item in the direct and indirect construction costs. It is also a common practice to add contingency as separate line items to the subtotals or total lines instead of the distributed manner shown. Contingency will range from over 30% in the early conceptual phases of a project to less than 5 percent when engineering is complete. Because the contingency is included in the direct construction cost and because the indirect costs are factors of the direct cost, the normal contingency in the indirect costs is usually included in the respective percentages of the direct costs.

### 15.3.2 PROJECT COMPLIANCE COSTS

Project compliance requirements are discussed in various other chapters throughout this Handbook. Some of the chapters deal with mining of a specific commodity and the associated compliance costs. Other chapters deal with the general baseline data and permit acquisition programs and associated costs. This section will discuss typical environmental compliance costs and the impact on a project's feasibility. However, the reader is cautioned that, depending on site-specific circumstances, the variations in typical costs may be one order of magnitude.

*Pre-exploration* due diligence is used to avoid purchasing, among other environmentally unattractive features, a superfund site, wetland, etc. One-time cost: $5,000 + 0.25% of the direct construction cost. (As mentioned in the previous section, many projects can be factored from the direct construction costs).

*Exploration* permit and compliance costs cover the reclamation for drill pads, bulk sample excavation and access roads. Annual cost: $1,000 + 0.03% of the direct construction cost of the capital project. Of course, until the exploration program is underway, it can be difficult to know what the direct construction costs will be, but most companies will have some indication of the size and duration of the mining project for which they are looking. If the exploration is in a jurisdiction that requires an environmental impact evaluation prior to the commencement of exploration, there would be a one-time cost of $35,000 plus the above annual cost.

The *development phase* has two separate environmental costs. The *permit acquisition* for small projects that require the local agencies to adopt a negative declaration (i.e., no significant adverse environmental consequences) is usually handled by a local planning agency in a manner similar to conventional building permits. One-time cost: $1,500 + 1% of the direct construction costs. On the other hand, a large project or a project requiring extensive mitigation will require environmental impact reports, and the project may be in remote areas for which no baseline data exist. One-time cost: $400,000 + 4% of the direct construction cost, and annual costs beyond the first year of $100,000 + 1% of the direct construction cost. For many lead agencies, the minimum mandated time for data acquisition, report preparation, and public review processes is two years. Typically, additional time will be required by the agencies. Note that world-class mining operations outside the U.S. can obtain environmental assessments acceptable to international financing institutions and permit approvals for one-time costs of $100,000 + 0.5% of the direct construction costs, and the typical time frame is approximately one year.

Also during the *development phase*, there are the *capital cost expenditures* for the environmental mitigation to control runoff, treat acid mine drainage, suppress dust, etc. These mitigation and pollution control costs are in addition to those required in typical, prudent mine designs. For example, surface water diversion to protect a mine from flooding, but also used to minimize the quantity of water treated according to NPDES requirements, would not be included as a mitigation cost. However, a similar ditch required to prevent sheet-flow runoff and provide a detention pond for settling solids would be included as a mitigation cost. The pollution control capital expenditures will average 3% with a typical range from 1% to 6%, of the direct construction cost. Note that the mitigation costs for the "processing" of ore by leaching or tailings disposal are not included against the mining operation because these are required for the process to operate. In offshore jurisdictions requiring participation from world financial institutions, a project will also experience mitigation

capital costs in the same 1% to 6% range.

It is interesting to further note that the environmental permitting process for mines in the United States can cost more than the capital cost of the mitigation measures. Of course, this is not true in the primary metals industry, for example, where the mitigation cost will be 30% to 60% of the direct construction costs.

The *operational phase* requires monitoring, reporting, record preservation, and community relations. These activities will cost approximately 3% of the operating budget and are quite labor intensive for the top management of the mine. A plant manager may spend up to 25% of the time working on environmentally related matters. Also, the plant manager has been designated in much of the environmental law as being the responsible party in the criminal and civil court systems. In addition, operating and maintenance costs during the operational phase will be approximately 0.1% of the mine operating budget. As with the capital costs, the administrative costs exceed the cost of improving environmental conditions during the operational phase.

In the *closure/post closure phase* structures are removed, and ground surfaces are contoured and revegetated. Underground mines may be plugged, and other measures for the control of acid mine drainage are implemented. This phase may be equivalent to 4% of the direct construction costs, when expressed in similar year dollars. However, the NPV calculations will discount the impact of the closure/post closure expenditures which are many years in the future.

In summary, an optimistic permit acquisition program plus mitigation costs just outlined will increase the project total capital costs by approximately 5% plus 3%, respectively (i.e., 8%). The additional monitoring and reporting costs in the operational phase will reduce the net revenue by approximately 3%. The net effect is that an offshore mining project will be approximately 11% points more profitable than a mining project following the current environmental regulations. Also, of that 11 percentage point swing in profit, only 3% (capital cost of mitigation) actually improves the environmental conditions.

### 15.3.3 IMPACT OF SCHEDULE DELAYS

Most mining projects' schedules are dominated by the land-use/environmental permit acquisition procedures. A major grassroots mining project must obtain several dozen separate environmental permits and/or approvals from various agencies at the local, state and federal government levels. The requirements for these permits are given in other chapters of this Handbook depending on the type of permit or the commodity from the mine.

Mining projects are inherently risky ventures. For example, conventional risks affecting the feasibility of a mining venture include:

- Extent and grade of the ore reserves, only known through statistical extrapolation from a limited number of boreholes and bulk samples.
- Project capital and mine development cost estimates and related finance charges.
- Mining costs, also known only through statistical extrapolation from a limited number of boreholes and bulk samples.
- Operating cost uncertainties in fuel and power rates, labor rates, mine water quantity and treatment costs, equipment wear and spare parts consumption.
- Natural disasters (primarily flooding) during construction, operational and abandonment phases.
- Processing uncertainties and recovery rates.
- Marketing uncertainties of demand, pricing structures and competitors' business strategies.
- Changing federal, state and local government programs affecting taxes, employee health benefits, off-site waste disposal costs, labor laws, fuel policies, strategic material stockpiling, and international trade treaties.
- Availability of motivated, skilled operating personnel.

In addition to the above standard mining industry risks, the risks involved in the acquisition of environmental permits required by and in accordance with the administrative procedures of the environmental regulations adversely affect the economic feasibility of new mining projects. Some of the environmental risks are "delay only" risks associated with many of the federal and state environmental permit review programs. In these programs, the agency approval processes are essentially nondiscretionary because a permit is to be denied only if all regulatory conditions are not met. (Note that the double negative of "denied" and "not met" are typical of most regulatory language, and it is used here for that reason). Most often in these types of regulations, the agency staff has discretion on how fast the permit applications are processed. The loopholes wherein permits are not approved due to staff inaction have been partially corrected by the processing deadlines contained in the legislation; however, the staff continues to exercise a wide latitude in determining when a permit application is "complete." Only after a permit application is determined to be complete does the nondiscretionary clock start. All schedule delays translate to an adverse impact on a project's cash flow and, hence, profitability. Additional expenditures by project sponsors for nonmandated or even extraneous "mitigation" measures have been known to accelerate processing the permit applications. Such "green mail" payments are business decisions weighing payment costs against schedule delay costs and possible acrimonious litigation.

Primarily at a local government level, various agencies may have discretionary powers when reviewing

a project. Often this occurs when appointed planning commissioners or elected county supervisors review land use permits. Mining is sometimes a "conditional use" of the local zoning ordinances. As such, the granting of conditional use or special use permits to allow a mining operation becomes an arbitrary decision by appointed or elected government officials. Because the mining venture may have to expend significant property acquisition, exploration, engineering and baseline data acquisition funds prior to making a presentation at a conditional use hearing, this often represents a difficult-to-justify risk of investors' funds. *Chapter 19* of this Handbook discusses legislative and regulatory trends wherein the BLM multiple-use planners and others are working to achieve similar discretionary power over federal lands.

For the most part, neither the capital nor operating costs for pollution control or mitigation will increase during the environmental permit review processes because the required pollution control costs are already included in a project before it is submitted for review. Therefore, the major impacts of the schedule uncertainties are three-fold. First, the permitting delays directly reduce the profitability of a project because of increased time between the capital expenditures and receipt of the operating revenues.

Second, the required profitability hurdle by the prudent investment community is higher whenever there is an additional uncertainty or risk associated with a project. The schedule risks imposed as a result of environmental agencies' permitting procedures are superimposed on all other traditional risks inherent in a mining project. Therefore, an increased profit is required to cover the additional risk.

Third, the up-front permit preparation costs, combined with the schedule risks, require greater financial resources than were previously required prior to the complex permitting programs. This is forcing many small enterprises out of business. In general, the loss of small enterprises will reduce the number of exploration programs. Also, the small enterprises may have limited access to capital and are forced to either abandon a property or sell to larger companies, which have the capacity to afford the up-front cash flow.

In the complex environmental permitting programs, the spread between the up-front expenses and the future revenue stream is further increased by additional up-front costs. Engineering must be accelerated to provide more details for inclusion to the environmental permit applications. In general, a feasibility study for a "go - no go" financial decision can be prepared with the metallurgical testing 50% complete, and the mine and concentrator engineering at 5% to 10% complete. However, for the permit process, the metallurgical (and other products) testing needs to be approximately 90% complete, often with additional testing exclusively for environmental purposes. The engineering will have risen to ±20% complete, but the additional engineering completeness usually does not help refine the data needed for the capital cost estimate. Much of the engineering is to demonstrate that agency's and/or public's proposed alternatives are not feasible. In the late 1970s through the mid-1980s, it was sufficient to have criteria requiring that the design meet the codes; for example, that diversion ditches would pass a 500-year precipitation event. The current regulatory process now requires the detailed specification and drawing of the ditches. When these details are prepared in the early stages of a project, they most often require major revision when the normal engineering design process resumes. Thus, the engineering efforts for the permit input is often an added expense. Profitability may decrease as a result of the permitting delays. Two different types of financing approaches are included

Table 4 provides an example of how much mine project profitability may decrease as a result of the permitting delays. Two different types of financing approaches are included.

**Table 4** Decreased Mining Project Profitability Due to Delays in Permit Acquisition Schedule

| | **Profitability discount factor*** | |
|---|---|---|
| **Duration of permit acquistion program** (Years) | Company with institutional financing | Nonrecourse institutional financing |
| 2 | 1.0 | 1.0 |
| 3 | 0.95 | 0.81 |
| 4 | 0.90 | 0.66 |
| 5 | 0.80 | 0.54 |
| 6 | 0.76 | 0.43 |
| 7 | 0.71 | 0.35 |
| 8 | 0.66 | 0.27 |
| 9 | 0.66 | 0.20 |
| 10 | 0.62 | 0.15 |

*Base case = 2 years

The column entitled "Company with Institutional Financing" is typical of the conventional financing for a large company with sufficient assets for loan collateral.

The "Nonrecourse Institutional Financing" column is typical for the small enterprises wherein the investors are at risk for all expenditures until the loan is granted by the institution. The financial institution is then at risk for the project, which is the collateral for a nonrecourse loan. The small enterprise investors usually must wait for their share of net revenue until after the financial institution loans are paid. The profitability of a project may decline dramatically due to schedule risks alone. The converse is that investors will anticipate some degree of delay and adjust their profit requirements upward accordingly. This will decrease the number of potential mining operations available for development inside the jurisdiction of United States permit regulations.

With "Company with Institutional Financing," the financial resources are available, at some risk, to complete the engineering and start ordering long lead-time equipment prior to the issuance of the permits. This allows the project to be completed faster, shortening the time from investment to revenue. On the other hand, with the limited investment capital typical of the nonrecourse financing, there are no funds available to pay for the engineering or to start advance purchasing until the loans are approved, which usually will not occur until all of the permits are issued. This tends to further lengthen the time from investment to revenue, i.e., decrease profitability. Because there are many types of financing schemes, the above effects of a fast-track project execution are not included in Table 4.

The following is an example of how Table 4 may be used. Assume that a company has a policy of not participating in projects with less than 15% anticipated profit and is considering properties inside and outside the United States. Further assume these are two identical properties and the mine prospect in the United States will meet the 15% profit hurdle even if the permit process takes a total of six years. The project outside the United States would show a profit of:

| | |
|---|---|
| | 15% because the mines are identical |
| plus | 11% due to the additional permit acquisition and operational monitoring/reporting costs |
| less | 3% common mitigation costs included in the above 11% |
| | 23% |

divided by

| | |
|---|---|
| | 0.80 profitability discount factor from Table 4 |
| or | 28% would be the profit in pursuing an offshore mining prospect |

Removing the risks, costs and uncertainties of the permitting process would help to keep an option available to pursue new mineral deposits in the United States Reducing these administrative costs would not adversely affect the environment.

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# Chapter 16

# FINANCIAL ASSURANCES FOR CORRECTIVE ACTIONS, CLOSURE AND POST CLOSURE

edited by R. W. Phelps

## 16.1 INTRODUCTION

**by R. B. Vrooman**

All mining operations generate waste material as well as waste water. This waste material, which in rare cases may exceed several billion tons, is generically referred as "mining waste." It consists of matter that cannot be economically processed and substances that have already been processed. These materials include overburden and interburden, or waste rock, and mill tailings each of which contain varying amounts of hazardous constituents. Many of these materials would in fact fall within the federal definition of hazardous waste were it not for the Bevill Amendment to the Resource Conservation and Recovery Act (RCRA).

Nearly all mining waste presents a potential threat to the environment, and in fact constitutes the prime environmental consequence of mining. Absent proper safeguards, this environmental threat is often ongoing during operations, and it often continues long after mine closure. Federal legislation has been proposed that will serve to regulate these materials much like other hazardous waste. Drawing on the parallel with RCRA, it is anticipated that mining companies will soon be required to provide financial assurance that any planned or unplanned remediation activities at a particular mining operation will be implemented no matter what, and in the meantime many states have already required financial assurance from mining operators. In other words, mining companies will be asked to provide financial assurance that once their mining operations stop or are otherwise interrupted, funds will be available to complete any necessary remediation activities.

There are several means available to provide financial assurance that remediation activities will be completed upon the cessation of mining activities. These means include trust funds, surety bonds, letters of credit, corporate guarantees, and insurance. Suffice it to say, not every one of these means will be available to every mining company. Moreover, these means are not mutually exclusive. Some mining companies will want to combine more than one of these means to meet financial assurance requirements.

The mechanics of setting up a trust fund or of procuring a surety bond are beyond the scope of this chapter, as are the mechanics of obtaining a letter of credit, purchasing insurance or providing a corporate guarantee. Clearly, the individuals involved in these actions will vary depending on the means selected. However, in every instance, a detailed estimate of what it will cost to perform all required remediation activities will have to be produced. This estimate will in effect form the basis for determining which means of providing financial assurance are actually available to a given mining company. This estimate must therefore be as accurate as possible.

In preparing remedial cost estimates, mining companies should determine the cost of remediation at a time when the extent and manner of a mine's operation would make closing the mine and performing remediation activities the most expensive. Estimates should also reflect the cost of hiring a third party to perform the remediation activities. In so doing, mining companies will have anticipated the worst-case scenario. The temptation to underestimate remediation costs must be avoided. There is otherwise a good chance that permitting delays will result if the underestimation is discovered. On the other hand, protracted litigation may ensue if the underestimation goes undetected and remediation costs exceed the underestimated amount. The potential for civil and criminal sanctions should also not be overlooked.

In many instances, remediation estimates will be so large as to threaten the very economic viability of ongoing mining operations or proposed mining operations. Mining companies will be reluctant to set aside such large sums of money to assure the performance of remedial activities, which may not be

completed for decades. Fearing the worst-case scenario discussed above, the regulatory community will nonetheless demand full protection. When this occurs, mining companies may want to consider funding trust funds on an annual basis over the active life of their mines. Indeed, unless a mining company is wealthy enough to provide a corporate guarantee as a form of financial assurance, large remedial estimates will make obtaining surety bonds, letters of credit and insurance so cost prohibitive as to leave this as the only means available to most mining companies to provide financial assurance.

Nevertheless, the environmental practices of today's mining companies are the subject of close public scrutiny. By providing adequate financial assurance that funds will be available to perform remediation activities when a mine closes, a mining company helps put the public's collective mind at ease. The absence of this financial assurance in no way provides the public with sufficient comfort that remediation plans are anything more than plans. A mining company that provides financial assurance in effect lets the public know that it will stand by its remediation commitments and that the environment will be protected.

### 16.1.1 FINANCIAL ASSURANCES AND THE MINE LIFE CYCLE
**by J. J. Marcus**

The life cycle of a mine usually includes the following phases or milestones:

- Discovery/exploration
- Development (sometimes called engineering/construction)
- Operations
- Closure
- Post closure

Increasingly, financial assurances tend to be required during the exploration phase of a project, especially if major disturbances are anticipated. However, since costs involved are several orders of magnitude below those required for final closure they will be not be treated in detail. Nevertheless, a prudent company performing exploration should include a suitable line item in its budget to cover reclamation should the campaign produce negative results.

Customarily, after a positive exploration effort, a comprehensive (sometimes called "bankable") feasibility study is developed, at which time various estimates are prepared and the project return on investment is calculated. Customarily, estimates are then provided for:

- Permit preparation and presentation
- Detailed engineering
- Purchase of equipment, materials, and supplies
- Construction of facilities (mine, processor, and infrastructure) of the mine
- Development of mine
- Startup costs
- Working capital
- *Accident contingency
- *Closure
- *Post closure
- Overall project contingency

To ensure that new mining operations have sufficient funds available for corrective responses during production and also to take care of final shutdown, financial assurances are increasingly being demanded up front by the appropriate regulatory agencies. On the state level, assurances are now being required for those items indicated by the asterisk (*). Similar guarantees are also being gradually sought for mining companies already in operation. The main body of this chapter deals with those financial instruments available to the mining companies to satisfy the regulatory agencies' current and anticipated requirements, how they can be used, and important aspects pertinent to their use.

## 16.2 FEDERAL GOVERNMENT PERSPECTIVES
**by R. E. Deery**

The purpose of this section is to discuss the role allocated to financial assurances (or bonding) during the federal management of mineral resources, as well as to a lesser extent on private and state lands. This section contains a review of bonding from the federal policy perspective and an explanation of how the function changes with the agency's mission. An historical perspective is included, followed by a section dealing with the public's understanding of the issues and its desires. The current unsettled state of bond availability will be examined, and the emerging role of the EPA appraised. Finally, the future will be considered in special relation to the Bureau of Land Management (BLM).

### 16.2.1 POLICY ISSUES

The principal policy issue is the functional definition of the guarantee, which is primarily determined by its specific purpose. Is the industry fostered and encouraged, or merely tolerated and regulated? Once that question is answered, the policy role of the financial guarantee can worked out. There are generally two choices: "insurance" policy or filter. Is the bond intended to ensure performance with a set of management objectives, such as reclamation, closure and maintenance, or is it to serve

as a filter that serves to exclude the financially under-qualified from an economic activity? For many governmental agencies that regulate professions or licensed activities such as hairdressers, plumbers or home improvement contractors, a bond is simply a filter that keeps the under-financed, and presumably unqualified, practitioner out of the marketplace. Likewise, excluding the incompetent, unmanageable or unrepentant practitioner will also influence the policy regarding bonds. The choice of role will likely be reflected in the nature and the size of the bond.

The mission of the regulating agency will also affect how it chooses to respond to the policy questions. A purely regulatory agency will likely choose to be more inflexible when controlling an industrial activity. On the other hand, a government resource manager, that is an agency with a commodity to be sold in the market place, will likely try to be more flexible when also regulating an industrial activity. This question of duality of missions in terms of resource development and environmental care has been increasingly described as an "irreconcilable position" (see *Sect. 2.4.1.*). In any case, both pure regulators and resource developers and environmental managers will be further influenced by the culture of the agency, which may be generally stated as the extent to which the agency understands, and on occasion, intrudes into operations.

There are major issues confronting not only the land and minerals managers, but the regulators as well, when they have been forced to deal with the question of financial guarantees. The first issue that immediately arises is the general lack of reasonable availability for some of the traditional financial instruments. Of special concern is the corporate surety, which for years provided the largest number of guarantees for the mining industry. The second major issue is the balancing of short-term versus long-term liabilities for the new concepts of closure and post closure. This is of particular concern for both the land and minerals managers and the regulators in this "Superfund" era. Federal land managers are increasingly being held accountable for activities that are decades and in some cases even more than a century old. Regulators now face the task of devising control systems that keep existing operations from repeating the past scenario of occasional environmental failure, while at the same time keeping those same operations from closing down in the face of new requirements.

### 16.2.2 THE PUBLIC'S DESIRES

The "concerned" public has increasingly come to view the environment as something to be protected even when some jobs are at stake. This phenomenon has become sufficiently important that politicians across the political spectrum now strive to be known as being environmentally proactive. However, most of the concerned public lacks a clear understanding of the physical and financial processes of extracting the minerals, their net worth to society, and the actual environmental impact of mining. The concerned public is generally supportive of the notion that a financial guarantee should serve as an "insurance policy" should something go wrong. The concerned public may possibly also relate to the use of financial guarantees as a filter-and-screen to limit entry to the market place. Undoubtedly, zero-risk financial-assurance requirements ensure that many higher-risk, small- and medium-sized mining companies will find it difficult to continue operations. Nevertheless, support for full cost bonds remains a strong issue among many environmental activists and even among non-environmentalists who did not wish to be ultimately responsible for an asset risk without sharing the asset profit.

### 16.2.3 HISTORICAL PERSPECTIVE OF FINANCIAL ASSURANCES

A historical perspective provides a basis of understanding for the present confused state-of-affairs over financial assurance requirements. Bonds were a part of the federal lead leasing system developed in 1824 by U.S. Army Lieutenant Martin Thomas for the deposits being mined close to the joining of the Fever and Mississippi Rivers, near Galena, Illinois. The purpose of the bonds was to ensure collection of rents from both the miners and the smelter operators. Individual prospectors could obtain a permit without posting a bond, while large mining operators had to post a $5,000 bond for a five-year lease. Smelter operators had to post a $10,000 bond to obtain a license. Successful at first, the system increasingly became riddled with fraud and corruption driven in part by a deeply held philosophical opposition by the miners and processors to any federal ownership of the land, much less the mineral deposits.

By the late 1830s, one of the smelter operators owed rents on 2 million lbs of lead. The bond became the object of litigation that ultimately reached the Supreme Court in the case United States v. Gratiot. In arguing that the bond should not be forfeit, the lawyer for Gratiot, Senator Benton of Missouri, contended that the Constitution only gave Congress the power to sell the public domain, not to create a federal leasing system. The Court sided with the government, and clearly established the power of the Congress over the public domain under Article IV of the Constitution. The decision came too late, however, to save the leasing system, which by then had virtually collapsed and was ended with the Act of July 11, 1846. As a consequence, the United States was left with no mineral development laws for the next 20 years. In that time a major land acquisition from Mexico and several placer rushes along with the increased development of lode mining

completely recast the character of the U.S. mining industry and its laws.

The product of 15 years of debate and the modification of two previous interim acts, the General Mining Law of May 10, 1872, was and continues to be silent on the subject of surface resources, including payment of damages or the posting bonds. This is not to say the United States did not care about the surface resources and on occasion actively pursued deliberate trespass or wastage of surface assets, particularly timber resources. In part, this disinterest was due to the public lands disposal policy in the Act. The title transfer provisions of the law, which allowed the mining claimant to obtain fee title to the surface, made concerns about the surface assets seemingly unimportant, since it was generally assumed that most mining claims would be patented. Why then should there be any bother about something that was going to be given away. This attitude was further reinforced by the lack of rents and royalties so thoroughly discredited by the collapse of the earlier Mississippi Valley lead-leasing programs.

The first clearly expressed concerns over bonding were largely restricted to those occasions where the surface and mineral estates were in separate ownership. This was initially taken into account by the Act of Feb. 27, 1913, which permitted the State of Idaho to select certain lands known to be valuable for phosphate and oil. The Act allowed the state to receive title to the surface estate but reserved the phosphate and oil rights to the federal government. The Act permitted entry and development of the mineral resources, but with a new twist from earlier mineral development laws. Before entry on to the lands any person not acting on behalf of the United States was required to furnish, subject to the approval of the Secretary of the Interior, a bond or marketable asset as security for the payment of all damages to the crops and improvements by reason of prospecting. A similar requirement for a mining operation allowed for actual payment of damages or the giving of a good and sufficient bond.

This shift to a public policy requiring protection against damages to crops and improvements when the subsurface and surface title estates were separately owned became generally applicable three years later. The legal vehicle was the Stock Raising Homestead Act of 1916. This Act, allowed homestead entry on lands suitable only for grazing, creating the large areas of private surface underlain by reserved federal minerals found along the high plains and elsewhere in the West. The Act regulated entries for coal and all other mineral deposits (including oil and gas which was then subject to the Oil Placer Act of 1897). It required the mineral entryman engaged in prospecting to compensate the surface owner for damages to crops resulting from prospecting and also required the mineral entryman performing development and mining to make payment of damages or to provide a good and sufficient bond approved by the Secretary of the Interior. Curiously, the next major change in the United States' mining and mineral laws, the Mineral Leasing Act of 1920, was silent on the subject of bonds. Instead, this Act arranged for leasing rather than staking of non-hardrock (non-intrusive) or sedimentary type deposits such as coal, salt, trona, etc. Bonds were not required for leasing or operations by the act, but over the years, administrative requirements for bonds were introduced by the Secretary of the Interior.

The next step in the progression of events began in 1967, with the Department of the Interior's (DOI) report on surface coal mining and the environment. Congress responded to the growing public debate about strip mining by ordering, in Section 205c of Public Law 89-4, the *Appalachian Regional Development Act of 1965*, the Secretary of the Interior to make a survey and a study of the issue of strip/surface mining operations and their effects in the United States. The conclusion and recommendation of that study was published by the Secretary in 1967 as "Surface Mining and Our Environment." It identified the need to repair past damage and to prevent future unnecessary injury from strip and surface mining and recommended a program for each category. To prevent future "unnecessary" damage the report recommended a federal program to establish standards and reclamation requirements for surface coal mines regardless of ownership; based on state primacy with a provision for federal preemption should a state fail to properly implement a program. The proposed federal policy called for measures to control the environmentally harmful effects of operations including: water pollution controls, elimination of public safety hazards, control of soil erosion, conservation of resources, and preservation and restoration of natural beauty. The report recommended a permit procedure that included: operator adoption of a reclamation plan; penalties for failure to obtain a permit or refusal to meet standards; the use of performance bonds; the creation of an enforcement staff; submittal of periodic operator reports; a prohibition on mining in urban areas; and the use of flexible rules to account for local conditions. The 1967 DOI report created a model that was used to prepare most of the subsequent efforts in the area of reclamation, and notably influencing the efforts to write the draft legislation that became *the Surface Mining Control and Reclamation Act of 1977* (SMCRA).

Section 509 of SMCRA required performance assurances that had to cover the full cost of reclamation. It allowed for the use of surety bonds, collateral bonds, self-bonding and combinations of these instruments. It permitted upward and downward adjustment of bond requirements as future reclamation costs fluctuated. It also allowed for incremental or partial bond release for an undergoing reclamation in three phases: the major increment could be released after backfilling, regrading

and the re-establishment of drainage; an additional reduction in the bond amount after revegetation; and the remaining amount after all reclamation requirements have been satisfied.

Pursuant to SMCRA requirements, the National Academy of Science was directed to study the applicability of the provisions of SMCRA to non-coal minerals commodities. Known as the COSMAR study and published in 1980, the report failed entirely to consider the subject of financial guarantees but did conclude that a SMCRA-like law for hardrock minerals was unnecessary and very likely costly. State mining reclamation programs generally developed under the influence of SMCRA. Most of the Rocky Mountain states designed coal management programs under SMCRA in the late 1970s that became effective in the early 1980s. Many of the states then quickly turned their attention to the non- coal sectors of the mining industry and not surprisingly used the SMCRA coal bonding concept as the basis for bonds for the other minerals.

### 16.2.4 CURRENT SITUATION

For most of the public land and the minerals that underlie them, the passage of the Federal Land Management and Policy Act of 1976 (FLPMA) is the watershed divide between mere federal oversight and actual federal intervention in operations. Prior to the passage of FLPMA, various reports and pre-cursor bills addressed bonding, but in hardly any detail. The 1971, proposals for modifying the mining laws, from both the industry and the administration, included language on financial assurance requirements. Likewise, the Senate versions of FLPMA included descriptive rhetoric on performance bonds, a provision that was left out of the final bill. With the passage, clear congressional instructions to manage operations emerged.

In 1974, two years in advance of the passage of FLPMA, using separate authorities, the U.S. Forest Service (FS) promulgated surface management rules for hardrock operations conducted under the Mining Law on lands within the national forest system. The regulations allowed the authorized officer to require bonds as a condition of approval for an operation. In 1980, after a four-year effort, the BLM also issued surface management regulations for operations conducted on public lands. A somewhat naive view of the role of bonds was expressed in the preamble to the final rules. The BLM noted that default on a surety bond would likely serve to eliminate an operator from further participation in the industry. Unfortunately, this filter was neatly short-circuited by two other actions, one regulatory and one policy. First, the use of collateral in the form of cash or negotiable U.S. securities was allowed by final rule, eliminating any hope that the surety industry would police the industry. Second, the role of bonds was at the outset, merely incidental to getting cooperation of all sectors of the industry. On public lands, the BLM generally deferred to the state mining reclamation programs for standards as well as for bonding. Unlike the Forest Service, the BLM at the time chose not to require bonds from operators until a record of noncompliance had been established by an operator.

In the early 1980s, regulatory interest shifted away from the Rocky Mountain states, with their well developed programs, to the Great Basin states, which had a long tradition of little state control. The BLM was pressed to be more assertive in seeking bonding. The pressure for change originated both from within and from without the agency, notably the U.S. GAO, responding to congressional concerns. BLM's policy changed late in 1989, with a requirement for mandatory bonding concurrent with approval of all mine operation plans, and a further proposed rule change to require all mining activities greater than casual use to post a bond. Interestingly, an earlier version of the new policy with respect to plans of operations requiring full cost bonding was withdrawn because of intense congressional pressure.

By the mid-1980s financial assurances requirements for the oil-and-gas industry became the cutting edge for all BLM policy. This resulted from complaints by small and independent oil and gas operators over their increased difficulty in obtaining traditional surety bonds. Concurrently, the BLM proposed rule changes in 1985 to effect a consolidation of bond types from 12 to 4; it also increased bond amounts, which had only been adjusted once in 56 years.

There was substantial support for the consolidation but equally substantial opposition to the increase in the bond amounts. All progress on the rule was abandoned. The degree of resistance was sufficiently unsettling that the BLM created a task force composed of senior BLM and Minerals Management Service field-managers to study the issue. In 1986, the task force made several recommendations beginning with the idea, that wherever possible, BLM should "piggy back" its bonds on state bonds. The BLM should also allow "third party" bonds from someone who is neither a leasee or lease operator, but merely a patron. Furthermore, the BLM should expand the availability of available financial instruments by accepting personal bonding including letters of credit and certificates of deposit. Finally, BLM changes in the administrative procedures associated with bond reduction and release were advocated.

In addition to the task force, the BLM contracted a study by Haigler, Bailly & Co. to examine the trends and conditions pertaining to the use surety bonds in the oil and gas industry. One of the conclusions of the study was that the decline in oil-and-gas prices seemed to forcing some operators precipitously out of the industry. The result was an increase in failure to properly plug abandoned wells and perform surface reclamation. The

study confirmed the decrease in the availability of surety bonds and indicated the trend was likely to continue. The study went on to conclude that bonding is an effective tool for the federal land manager to ensure that reclamation was carried out. Further, surety bonds were more productive vehicles than personal bonds due in great part to the role played by the sureties in managing their exposure at the pre-qualifying stage, during the life of the bond, and after a claim had been made against the bond by the land manager. The study also noted that some of the bond amounts were not high enough, but no action to increase them was yet justified. The study noted that any increase in bonds would not likely affect the overall status of the industry as it was under pressure from low prices. As to the manner in which federal land managers chose to increase bond amounts, the study concluded that an across the board increase for all leases would have a significant impact on production while an incremental increase limited to new operations would have a much lesser impact. The study seconded the use of letters of credit and certificates of deposit as a method of expanding bond availability and further suggested the establishment of a contingency fund.

In 1988, many of the proposed changes came to pass under the Federal Onshore Oil and Gas Leasing Reform Act of 1987. As mandated by the Act, the BLM implemented final rules which declined to increase bond amounts, added personal bonds, and discussed piggy backing with state agencies at some length. The rule concluded that piggy backing could be accomplished, but that a separate memorandum of understanding with each state agency was required. With a perversity reserved only for government reinvention activities, legal advisors with the Department then opined that such agreements would not be permissible under the 1920 Act. Following this outcome, the BLM administratively allowed for phased bond release when remaining reclamation solely consisted of revegetation, and then also consolidated the types of bonds.

In response to increasing complaints from coal operators, congressional interest also prompted a GAO study in 1988. That study likewise found that surety bonds had become increasingly difficult to get in the four states that the report examined. Fewer companies were still active in the business of writing surety bonds for reclamation. Small and mid-sized operators when required to replace bonds had replaced the generally nonexistent surety bonds with collateral- based financial instruments, which often required 100% of the bond's face value. The result was a general lack of liquidity on the part of these companies, reducing their ability to continue in the business of mining coal. Larger operators with greater financial reserves were reported to have lines of credit usually available, although these too were drying up (see *Sect. 16.9*).

Thus, in response to the "surety bond crunch" of the 1980s, both of the major federal land managers, the FS and BLM began to allow financial assurance instruments other than the traditional corporate surety bond. The instruments allowed by the FS included; cash or checks, irrevocable letters-of-credit, assignments of savings accounts, and assignments of certificates of deposit. Furthermore, the BLM followed the lead of the U.S. Office of Surface Mining by showing that it intended to be more willing to accept risk in it's choice of acceptable collateral instruments. Given the general inability of the smaller operators subjected to the proposed regulations, BLM has accepted the necessity of assuming an increased degree of risk.

Throughout the 1980s and into the 1990s, financial guarantees have become a troublesome workload for both the mining industry practitioner and the government policy and decision-makers, and regulators. Simply put, both groups find themselves squeezed between a financial marketplace and a public unwilling to accept any degree of risk. The financial response has been one of reducing exposure through a variety of methods, most of which ultimately mean more costs to the industry. The unwilling public has increasingly demanded that no potential cost go uncovered, increasing the amounts and coverage of guarantees and adding more costs to the mining industry.

In 1988 the U.S. Office of Surface Mining Reclamation and Enforcement (OSMRE) published final rules on amendments to the SMCRA permanent program for administration of financial guarantees. In approving the use of third party self guarantors, OSMRE noted that nine sureties and two banks recently failed affecting the bonds of some 400 mining companies. OSMRE noted that a financially sound corporate guarantor may be in as good an economic position as some surety companies to guarantee completion of reclamation. OSMRE noted, in its previous rules, that it assumed sureties contained minimal risk and they would almost always provide funds need for reclamation in the event of forfeiture. OSMRE concluded with an observation that there was a great need to monitor and track guarantor's financial security.

Among the other signs of declining availability for the industry in the late 1980s was the publication of an apology for, or an explanation of, the surety's side of the story, which appeared in the October 1989 issue of *Mining Engineering*. Sureties tend to review five elements in their due diligence. Three of these involve the short-term and long-term financial health of the principal, another the company's relations with the regulators, and the last, the basic economics of the mineral deposit. The uncertainties that were responsible for decreased bond availability involve the long-term, changing reclamation standards, which become a continually moving target; long lead times for operations to commence; and long periods of liability. Other

uncertainties included the inability to do the reclamation rather than simply pay the regulator, relationships between state and federal regulators, poor release practices and finally the notion that the surety seems to be at the mercy of everybody else.

During the 101st Congress, oversight hearings on mining related issues before subcommittees of the Senate Energy and Natural resources Committee and the House Interior and Insular Affairs Committee looked into the bonding crunch. The hearing held in the House was more substantial than that held by the Senate, at least in terms of the issue of the lack of available surety bonds and the causes of the issue. The House hearings took statements from GAO personnel, federal administrators, industry representatives, and representatives from the surety industry. The surety representatives and the industry representatives were of a single mind with respect to the effects of SMCRA on bonding in the coal industry. The FS estimated that 50% of the existing coal operators in the national forests would be forced out of business if they had to obtain surety bonds. Surety bond availability was almost nil, particularly for small operators, collateral demands were extremely high, reclamation standards remained a moving target, cost estimates appeared excessive, and there were delays in bond release. All participants agreed that shorter liability periods for revegetation were appropriate, as was the use of phased and incremental bonding, and the use of bond pools and sinking funds. Bond release mechanisms needed considerable improvement. In addition, the surety industry noted that SMCRA contained some very nearly fatal flaws. One is the inability of the surety to cancel the bond as it applies to as yet undisturbed ground, all the while being asked to provide credit for an activity with long-term liability that commences when an operator's cash flow stops. Other problems include the large sums created by the full cost bonding calculations with long periods of liability and an inadequate bond release system.

One year later, the hearings were held before the Senate. Only one surety professional provided a statement for the record. However, the message was similar, and it was focused on the hard-rock mining industry instead of the coal industry. Bond availability was generally minimal and for small- and medium-sized operators; bonds were increasingly difficult to get at an affordable price. Only the few large operators with a good track record and who were capable of meeting the long-term financial obligations could count on getting bonds at reasonable costs. This state of affairs was not likely to continue for several reasons, among them the looming presence of the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Response Compensation and Liability Act (CERCLA). Once again similar needs were stated for an increase in surety bond availability; use of phased and incremental bonding, better defined reclamation standards, shorter liability periods for revegetation, cancellation allowance of a bond on as yet undisturbed land within the permit boundaries, and relief from the joint and several liability provisions of RCRA and CERCLA.

### 16.2.5 EPA CONSIDERATIONS

The significant new element in the issue and the party responsible for the introduction of the term closure is the Environmental Protection Agency (EPA). The EPA has, since the mid-1980s, been developing a federal program to regulate mine waste disposal. The authorities for this program are Subtitles C and D of the Resource Conservation and Recovery Act, as amended, (RCRA, 42 USC 6901, *et seq*). The program began in earnest with a report to the Congress on mine wastes followed by a determination as to the proper program to be used to regulate the industry. In 1985, the EPA Administrator determined that a modified solid-waste program was appropriate rather than a hazardous-waste program. The formulation of a program to regulate mine waste received its direction from the management of municipal solid waste. This led to a proposal that mine waste should be handled in a fashion that was similar to that used to treat land-filled garbage. The first staff level discussion document was known as Strawman I, soon followed by Strawman II. These staff level documents were used to elicit public comments on the ultimate form and shape of the program. There is no doubt that the new RCRA program, when issued, will require financial guarantees sufficient to ensure closure and long-term monitoring of a site.

The issue of underlying ownership of operations (and responsibilities) has been a major point of discussion among federal agencies. The EPA has likened the situation to that of the Department of Energy at Rocky Flats. EPA legal staff now considers a major precedent has been set for all federal land by citing the DOE's surrender (at Rocky Flat) of sovereign immunity by way of RCRA. Under this state of affairs, the underlying federal land managers would then be treated no differently than any large corporate-landowner who leases a mineral property to a third party. The federal land managers would be fully subject to federal penalties, and the police powers of any state with primacy, for any lapses on the part of the operator. This scenario would effect a major change in the relationships between the BLM, FS, and the states.

The issue of EPA's regulatory program intruding into management of ongoing mining operations has likewise prompted heated discussions. The EPA, in Strawman II, indicated that "regulated materials," those with a potential to cause environmental effects (harm), would be controlled along with mine wastes. EPA has claimed that a strong degree of support for this position already exists

among the states. In brief, EPA now sees the need to regulate sub-ore and ore piles, heap and dump leach piles and the accompanying operations, and control or manage mine water during and after operations. Obviously, this perceived need, if realized, will bring EPA squarely into the management of all active mineral operations. The EPA, or their state surrogates, would then be intimately involved in the details of mine plan development as well as approval of operations, reclamation and closure.

Closure is a RCRA term, meaning complete shutdown of an operation that goes beyond surface reclamation. It includes dealing with the prevention of pollutants to either surface or groundwater as well as airborne releases. Extended periods of monitoring and liability for remedial action approach 30 years in both Strawman I & II. In a significant departure from standard reclamation statutes, the liability for monitoring and remedial action rests with the landowner and the facility operator. Since both RCRA and CERCLA surrender sovereign immunity, the manner in which the liability will be guaranteed in the post-closure phase will be particularly important to the federal land manager. A potential for exceedingly large guarantees being required by the federal land manager is very real. Likewise, there is the possibility that future activities will simply be denied as having a potential cost too great for the public to bear should some aspect of the closed site go wrong. Federal land managers have continued to work with EPA staff on the development of the program, for now all that can be said is that closure and subsequent monitoring will be the new paradigm at some point in the near future.

### 16.2.6 OUTLOOK FROM BLM'S POSITION

There has been a response to the increased need to manage activities to reduce liability under RCRA and CERCLA. Federal land managers are being increasingly attentive to the sequence of events that leads from a grassroots exploration project to a producing mine and finally to a closed property. This scrutiny is both a blessing and a curse. It is a blessing because the federal land manager must become more familiar with exploration and mining and thus more sensitive to the industry practitioner's concerns. It is also a curse, in that the industry will not operate without the close monitoring and intervention of the regulator in the course of operations.

The BLM mining-law administration program has received increased funding through the adoption of user fees for recording mining claims. This shifted appropriated funds within the agency to now allow BLM to review and manage all operations in greater detail. This has several practical effects; the review of proposed operations has intensified—so reclamation plans will now be required to have greater detail. To support the more complex reclamation plans, the BLM developed a reclamation policy and accompanied it with a reclamation handbook to provide uniformity of practice. They are identified as BLM Manual Section 3042 and Manual Handbook H-3042- 1.

To accompany the intensified review, BLM adopted a policy of mandatory bonding that includes the use of maximum bond amounts (caps) for exploration operations and those portions of mining operations that do not use leachates. Those portions of operations that use cyanide or other leachates are bonded at levels which equal 100% of the cost of neutralization and reclamation. To accompany the policy, BLM has opted to make maximum use of phased authorizations, concurrent reclamation, incremental bonds, and release by operational phase. To support the pending increase in management of financial guarantees BLM is developing a detailed handbook for bond administration. The handbook will detail the who, when, and where of administering the bonds. A significant point to note is that any estimate of reclamation costs will be determined on the basis of BLM contracting out the effort.

The proposed state-federal roles in the new BLM program have been a continuation of the pre-existing positions and functions. In the final surface management regulations, the states were invited to enlist in joint state-federal administration programs. The granting of "primacy" to the states, as is done in many of the federal clean-water and -air programs, was not allowed by the final rule, even though the proposed rule considered it. There is no one form for the joint programs to take, but generally BLM defers to the states in all matters including bonding. With respect to state bonds, by policy the BLM will accept a state bond in lieu of a federal bond if it is within 75% of BLM's calculated cost estimate for the reclamation or the bond ceilings.

All of the states with programs require either a notice or a permit to conduct operations. Most recognize exploration as a separate activity from mining and treat it differently from actual mining operations. Bonding of exploration efforts is generally required, although terms tend to reasonably reflect the difference between exploration and mining. Most of the states have a small miner's exemption for exploration activities. All of the states with programs require permits for mining activities and several have special permits for small sized operations. All of the permits have bonding requirements.

## 16.3 ESTIMATING THE ASSURANCE REQUIREMENT

**by J. J. Marcus**

It is extremely difficult to estimate a corrective action on a projected mine. Presumably, all weak links have been

identified and safeguarded in advance; however, reality indicates that Murphy's Law will apply somehow or somewhere. Major calamities in the past have included caving, collapsing, and flooding of mines; breaking of tailings dams; rupture of water pipelines; flooding of heap leach piles; and invasion of drinking water aquifers. Lesser problems include all the above plus fires, chemical spills, and additional accidents of various kinds. For many conventional risks such as fire and even chemical spill, accident insurance will usually suffice. If the appropriate regulatory agency insists on additional standby funds the amount is usually subject to negotiation and may either be commingled with the conventional working capital, or else placed into an escrow account. Working capital is usually equal to the gross value of several months of normal production.

While it may be necessary to estimate closure and post-closure costs prior to operation, this is very difficult to do because: 1) actual on site conditions differ markedly from those anticipated, 2) periodic upgrades in technology during operations will be incorporated into the production (and maintenance) flowsheets, 3) changes of basic industry economics occur which may dictate changes in operating conditions and philosophy, and 4) regulatory requirements will probably change over time. As a case in point, the post closure period customarily varies for coal mines from 5 to 10 years, for mines in other mineral commodities up to 30 years, and in the case of California—"forever." Undoubtedly over time, the post-closure period will be more narrowly defined. Because of changing conditions regulatory agencies tend to request updated closure and post closure plans and new cost estimates either after major operating changes or conditions take place or periodically such as every three or five years. Regulatory agencies almost always require increases in financial assurance requirements to take into account changing circumstances including inflation.

Closure activities are also sometimes referred to as reclamation, especially when applied to surface coals mines. These activities usually include:

- Decommissioning facilities and/or infrastructure and final beautification
- Decontamination of materials (wastes)
- Removal of hazardous materials
- Land reclamation:

  Replacement of material mined
  Reshaping (recontouring) of the land
  Revegetation;

- Surface water reclamation:

  Special measures such as capping and adit plugging
  Conventional source control and containment of polluted waters
  Treatment of polluted waters
  Source and end use control of unpolluted waters
  Stream revitalization(s)

- Groundwater reclamation
- Dust suppression
- Site safety plan implementation (including safeguarding the "attractive nuisances")
- Site reuse plan implementation

Post closure activities may include:

- Ongoing treatment of polluted waters
- Inspection and repair of safety and warning devices
- Physical inspection of critical site areas
- Sampling and assaying
- Record keeping
- All remediation as required

*(Abstracted from Marcus, J.J., "Financial Assurances For Mine Closure; A Discussion Of The Issues," Engineering and Mining Journal, August 1990.)*

Estimates for closure and post-closure are generally based on the costs for a responsible regulatory agency to manage the effort using third party contractors to complete the work. This often includes an overhead cost for management by the regulatory agency, and all costs for the third party contractors. The latter are based on yearly rates and for manpower, including their burdens, overheads, out-of-pocket expenses, and profit. In some cases, standardized rates such as those prepared by Ford, Bacon & Davis, Inc., are utilized, which are generally conservative and overestimate closure costs. Occasionally, a regulatory agency will allow utilization of costs provided by the operating company for employment of their own equipment or submittal of a cost estimate from third party contractors working for the company to establish an hourly or per acre rate to determine closure costs.

## 16.4 TYPES OF FINANCIAL ASSURANCE INSTRUMENTS

**by R. W. Phelps**

Financial assurances can be provided in the form of cash, CDs, stocks, or corporate bonds. Few companies can afford to tie up collateral or assets for the long periods required by financial assurances. Consequently, other methods are overwhelmingly used. Four general types of instruments are commonly available for providing financial assurances. They include:

- Surety bonds
- Standby Letters of Credit
- Insurance
- Self-guarantees

### 16.4.1 SURETY BONDS

Surety bonds tend to be the most heavily used financial instrument employed by mining companies. They have been in use for at least two decades. *They do not constitute an insurance policy*. Rather, surety bonds provide an extension of credit. This is conventionally extended by an underwriter to a regulatory authority guaranteeing that a third party (mining company) will fulfill the stipulated environmental requirements. Thus surety bonds are a vehicle whereby a government entity, through its regulations, is provided a financial assurance that mining reclamation will be completed in a suitable and agreed upon manner.

The surety bonds are issued for specific tasks such as removal of facilities, regrading and reshaping of roads, dumps, pits, and other disturbed sites, replacement of growth medium, seeding, fertilizing, mulching, etc., where needed, and other stabilization measures. There is generally a revegetation-success criterion as part of the regulations or part of the permit which maintains that, only when vegetation meets a certain density, productivity, etc., will the bond be released. The mining industry is also starting to see surety bonds applied to such activities as ground water monitoring around tailings or heap leach facilities, closure of heap leach facilities or other facilities which contain toxic substances, etc. There are also many ways of initiating and releasing bonds through phased implementation and phased release.

The basis of the bond is the permit issued to the mining company that spells out the total cost to reclaim a site after mining or exploration activities are complete. A premium is paid by the mining company to the underwriting institution. This is a guarantee that if reclamation is not completed to the standards of the permit and the applicable regulations, that funds are made available to the agency to complete the effort. Often the underwriter will require a Letter of Credit to back up the bond, which makes it more expensive. A demand letter is also generally attached which requires the mining company to repay the bonding company in case the surety is drawn by the regulatory agency.

### 16.4.2 STANDBY LETTERS OF CREDIT

A standby letter-of-credit (letter of credit) is similar to a surety bond in that a lending institution guarantees that money is available to complete reclamation. This provides coverage if the company should not complete reclamation as required and/or does not have the financial resources to complete it. A letter of credit is issued by a bank and is usually for a larger sum of money than originally estimated for closure. A fee must be paid to the lending institution to cover the transaction (even if draw-down does not occur). Should the letter of credit be drawn down then it is immediately converted into a conventional term loan by the lender. This of course requires that the company be carefully investigated prior to the issuance of the letter of credit to ensure its ability to pay back the total value of the letter of credit if draw down occurs. The mining company must be found to be in good standing based on an assessment of both financial and environmental risk. Customarily, a demand letter is attached to the letter of credit that stipulates that the mining company owes the lender the amount of the surety if it is drawn by the regulatory agency.

Letters of credit are usually issued for a period of one year, although for recurring commercial purposes "revolvers" for up to three years may be issued. Consequently, before the end of the year the mining company must either obtain another letter-of-credit, provide the regulatory agency with a suitable alternative, or the letter of credit is drawn down by the regulatory agency. In other words, the letter of credit is a short-term solution for a long-term problem.

### 16.4.3 INSURANCE

Although technically available, insurance is infrequently employed for financial assurances except of course for "conventional" corrective actions. Insurance is based on risk with a known statistical background, for example actuarial tables on longevity of life, occurrence of a specific type of accident, etc., compiled over long periods of time. For closure, there is no risk as it must occur, the only uncertainties are the date of the requirement and the final amount required. If a policy is written, the regulatory agency is made the beneficiary of the funds should the environmental requirements not be completed or should the company prematurely go out of business. A Nov. 22, 1993, ruling by the California Supreme Court forced insurers to pay the costs of defending lawsuits against corporate policyholders accused of environmental damage. This precedent will only make insurance companies even more leery of insuring against environmental risk.

### 16.4.4 SELF-GUARANTEES

Corporate guarantees (also known as self-bonding or self-insuring) are the financial instrument of choice for mining companies, due to the lack of cost and paper work involved. In general, a corporate guarantee is based on an evaluation of the assets and liabilities of the company and its ability to pay the cost of all eventual environmental operating and shutdown requirements, as specified in the permit issued by the regulatory agency. Corporate guarantees require a long history of financial stability, a predetermined rating by either Standard & Poors or Moodys, and at least an annual financial statement prepared by an accredited accounting firm. The

question of suitability of assets versus liabilities is quite often determined by various financial ratios such as the "current ratio" or the "shareholder's equity." The regulatory agencies have great leeway in deciding upon the level of acceptable financial rating and type and minimum value of ratio employed. For a discussion of financial ratios and financial assurance risk see Marcus, J.J., "Financial Ratios For Mine Analysis," *Engineering and Mining Journal*, Sept. 1990.

### 16.4.5 ESCROW ACCOUNTS

A mechanism presently exists pursuant to which an annually funded trust fund can be created. It is codified within the regulations promulgated under RCRA. In fact, were it not for the Bevill Amendment noted earlier, it would in many instances be applicable to mining operations today. Simply stated, parties that want to set up such a trust are required to retain a trustee whose trust operations are regulated and examined by a federal or state agency such as a bank, savings and loan, trust company, brokerage firm or insurance company. Then, utilizing the remediation estimate discussed above and the formulas and other criteria set forth in these regulations, annual trust payments and other requirements can be determined.

Escrow accounts, also known as trust funds, may be required by a regulatory agency. They are especially associated with self-guaranteeing, but may also include the pledging of cash or different forms of quick assets or marketable securities. Setup and maintenance costs are moderate as long as they meet the reclamation requirements of their permit. Essentially, the trust fund is set up with the regulatory authority as a beneficiary until reclamation is approved and released by that agency. Interest on the account can either flow back to the mining company, or can be allowed to accrue towards further reclamation liability for ongoing activities. An unattractive aspect is that those funds are tied up until release by the regulatory authority. Mining companies that are considering setting up an annually funded trust will want to consider these regulations carefully, as it is anticipated that the regulations, or regulations similar to them, will soon become applicable to mining companies.

## 16.5 COVERAGE MECHANISMS

**by J. Bokich**

There are three principal financial assurance coverage methods: life of project, statewide and/or blanket guarantee, and phased bonding.

### 16.5.1 LIFE OF PROJECT

A life of project financial assurance coverage mechanism is based on an up-front, lump-sum amount to encompass all expected exploration and mining operations planned at the time of the instrument's issuance. This allows maximum flexibility for expansion without the need for ongoing reevaluation of the instrument's cash value to increase coverage at a later date. This is generally undesirable from a company standpoint because, during the early stages of the operation, the total financial assurance requirements may not be necessary. This can result in up front over-bonding, and the payment of increased premiums (an opportunity cost). The over-bonding may be due to the use of a contingency fund and/or the fact that the mine area disturbed usually increases over time. Additionally, should a company become insolvent and the instrument be attached by the regulatory agency, the agency will likely try to obtain more of the funds than are *actually* needed to complete the required reclamation effort.

### 16.5.2 STATEWIDE AND/OR BLANKET GUARANTEE

A statewide or blanket bond is a vehicle generally utilized for exploration, where a company posts a lump sum amount to apply to all of its operations, generally confined to one state. As projects are submitted for permit approval, the reclamation costs that are applicable to that ongoing permitting will be attached from the statewide bond to a specific permit. For example, a company may post a $50,000 reclamation statewide bond. During that year it may obtain permits for five exploration projects with a total of $10,000 per project reclamation bond requirement. As each permit is approved, $10,000 out of the statewide bond is earmarked towards a specific project. With those funds already being in place, it accelerates the permitting process and allows the operator to initiate his exploration activities. This can also be applied to mining operations but is less frequently done, as it is seldom that mining activities are permitted at such a rapid pace or rate during a given period of time.

### 16.5.3 PHASED BONDING

This type of mechanism is becoming more common. It matches mining expansions with proportional increases in financial guarantees. For example, a mine might be bonded to disturb 300 acres and a decision is made to expand and to cover another 100 acres in the upcoming year. Without this mechanism, the company must increase the face value of the instrument to cover the 100 acres prior to initiation of those new activities. Thus phased bonding has the dual advantage of allowing the company to maximize its coverage while minimizing its liability exposure and cost of premiums.

## 16.6 FINANCIAL GUARANTEE DISTRIBUTION MECHANISMS

**by J. Bokich**

Distribution of funds set aside for reclamation can be realized in two different ways: on a lump sum basis or through a phased release.

### 16.6.1 PROJECT BOND RELEASE

This mechanism provides for all funds to be held until final reclamation is completed and approved by the regulatory agency. Upon final acceptance the entire sum is then released at one time. This is the least favorable mechanism because company assets are held escrow or premiums paid over the longest period of time—another opportunity cost situation.

### 16.6.2 PHASED RELEASE

There are three methods of phased bond release geared to: 1) specifically defined work phases (different activities in the reclamation process), 2) specifically defined areas that are reclaimed, and 3) a combination of Methods 1 and 2. The combination method is the most attractive as it allows for the earliest release of bond liability.

For example, with Method 1 at surface coal mines, it is recognized that the major cost of reclamation is the dirt work required for backfilling, reshaping, and regrading. Most agencies currently allow from 65% to 90% of the amount for reclamation to be released when the dirt work has been completed to the satisfaction of the permit requirements and the agency. This cost generally includes replacement of growth medium where it is required. The next phase is the actual seeding and other activities required by the permit such as mulching, fertilizing, rip-rapping, etc. for revegetation and stabilization of an area. Generally, another 5% to 25% of the bond amount is release upon completion of the seeding and other stabilization methods required for revegetation. The last increment of 5% to 15% of a cash set-aside is generally held upon completion, or meeting the revegetation success criteria. This final cash installment is held in the event that revegetation does not succeed as required by the permit and additional seeding must be done, and is generally not significant in that little work will be required re-seeding or for re-stabilization.

Under the Method 2 scenario, again the case of a surface coal mine is employed as an example. A waste rock dump within a multi-dump mine is to be fully reclaimed. Steps involved are those mentioned above including dirt handling through seeding. The cash allocated to that specific area can be released either in a lump sum or in parallel to the different phases of work. This again is a good vehicle for the company to utilize as it frees up assets or premium requirements at an earlier date instead of waiting until the entire environmental reclamation project is complete.

## 16.7 RELEASE CRITERIA

**by J. Bokich**

Probably the most important aspect of setting up financial assurances, and probably the least well defined, is the bond release criteria. For many surface mines the criteria that allows for the release of a bond is based on a revegetation standard. All release criteria, however, are synchronized with the prescribed post- mining land use. The post-mining land use is decided either by the appropriate regulatory agency or in the case of public lands by the private land owner. Many of the western mining lands are remote and were primarily utilized for grazing and wildlife preservation prior to the mining activities, and consequently, this is the most common designated post-mining land use.

On private lands in many states, the regulations provide that the land owner has the ultimate determination of post-mining land use. If the owner wants to change the post-mining use from other than the original pre-mining use (such as the grazing of livestock or wildlife to a post-mining use as a golf course) that is the owner's prerogative. There may be some opportunity for challenge to changes of post-mining land use on private lands through public comment during the permitting process; however, as long as those uses do not impede on the rights or utilization of adjoining lands, then the land owners wishes should prevail. In addition, private lands will still have to meet requirements of the Clean Air Act, Clean Water Act, and other applicable federal laws that recognize no property boundaries.

Another important concept for bond release criteria, and the development of a post-mining land use on public land, is molding those to fit resource management regional goals. Most public lands managed by a federal agency have been included under resource management plans for a specific area such as a FS or BLM District or Resource Area. Wherever possible, the mining company should work with the land management agency to ensure that the post- mining land use designated in the permit, and the revegetation goals, meet the prescribed regional resource management goals as closely as possible. It will be possible in many areas to enhance conditions for wildlife or other values through proper planning and implementation of reclamation. If the post-mining land use and the mine-closure plan meet the goals of the resource management plan, then they should be factored into the release of the sequestered funds, and once those goals are met, then the cash should be released to the mining company.

A common measurement tool for release of funds at a surface mine is actual revegetation success as a measurement of the vegetative establishment over a certain period of time after seeding. Time periods such as two, three, or ten years after seeding are used and vegetative measurements such as productivity, density, etc. are measured. If they meet the pre-established criteria, the escrowed funds are completely released. Land stability is another important factor that has not been as widely utilized but can be important. In some areas revegetation may not be the final goal and some measurement of slope stability and erosion may be utilized for the final release criteria.

## 16.8 CREDIT RISK EVALUATION AND OBLIGATIONS

**by R. Early**

Following the theory of being unsecured (i.e., not backed by collateral), sureties or lenders will base extensions of credit, for financial assurances only after careful review of: the applicant's financial strength and history, their expertise in the field, and a full definition of the obligation. The applicant will typically be asked to provide several years of audited financial statements prepared by an independent accounting firm. The surety underwriter or lender analyzes the audited statements looking for positive trends, liquidity, profitability, and financial stamina. The composition of the balance sheet is reviewed to determine cash balances to meet daily debt requirements, working capital to finance short operating costs, leverage and the required debt service and net worth to evaluate the entire value of the applicant. The applicant's income statement is checked to monitor profitability from operations as well as after-tax consequences. The cash flow statement reports operating, financial, and investing activities. The notes associated with the financial statements also disclose information about the applicant's financial health. Trend analysis will establish financial direction of the applicant, either positive or negative. Trend analysis will also provide an avenue for forecasting future results based on the recent past. Sureties or lenders calculate various financial ratios to assist their underwriting efforts and compile peer group comparisons to evaluate the applicant's relative performance.

Resumes and in-depth questionnaires are commonly sought to establish the level of experience that management and other key personnel exercise over the applicant's operations. The quality and regulatory compliance of the active site is reviewed to ensure that any legal ramifications will be met. Any awards for achievement in reclamation or mining attest to the operator's ability and are included in the evaluation.

The sureties also review the environmental obligation. Difficulties for the physical closure and post closure are examined in relation to their possible onerous consequences as well as the bond form to ensure that it follows the contract or any legislative statutes. These obligations are normally noncancelable by the surety. The surety's or lender's liability remain outstanding until the bond is released and returned. The liability spans the lifetime of the mining operation as well as a period for full closure, or subsequent maintenance. Given that surety bonds are performance obligations the sureties fear the judicial authorities may interpret the bonds as a liability policy covering any resultant effects rather than the intended purpose of guarantying satisfaction of the contract or applicable statute.

Initially sureties or lenders were reluctant to move into this arena due to their lack of information on the bond form and its underlying requirements, the intended purpose of the state legislation requiring the bond and from the court's interpretations. As these concerns are being addressed, the sureties and lenders are very cautiously developing guidelines to underwrite the risk. They are specifying credit rates and devising methods to undertake the obligation. Presently, they may write the bonds or loans uncollateralized or require a percentage up to the full bond amount. Collateralization may be tied to a particular portion of the risk. It may take the form of cash, letters of credit, or escrows from production tonnage, tipping fees, or revenues. While release of the surety amount may be distant, reductions and replaceable instruments will be more palatable to the sureties and lenders as they continue to understand the risk and evaluate how to manage and control the underwriting of such obligations.

## 16.9 COMMERCIAL BANKING ASPECTS

**by J. E. Florczak**

The growing amount of environmental regulation has created a demand by mining companies for financial assurances of various forms from commercial banks. In this connection bank products fall into two general categories, primarily distinguished by whether or not the commercial bank or the mining company borrower assumes the credit risk. Major discussion is limited to the use of pledged certificates of deposit (and comparable instruments), and the use of standby letters of credit.

### 16.9.1 CERTIFICATES OF DEPOSIT

A relatively simple form of financial assurance from a commercial bank is the pledge of cash in various forms. This method relegates the commercial bank to the role of

a custodian or escrow agent on behalf of the regulatory agency requiring the financial assurance. Because the bank takes little or no credit risk, this form of financial assurance can usually be easily arranged. The cash can be used to purchase a certificate of deposit (CD), which can be pledged to the relevant government regulatory authority. Another technique is to nominate the bank as an escrow agent, with the funds managed in an investment account, and the beneficiary of the escrow being the regulatory agency. The advantage of this arrangement is the relative ease of documentation. After all, it is simply the mining company's cash being deposited in safekeeping for the benefit of the government authority. Commercial banks charge nominal fees for such arrangements. The disadvantage is that the mining company must tie up surplus cash in relatively low yielding assets.

### 16.9.2 STANDBY LETTERS OF CREDIT

The use of standby letters of credit (L/C), where the bank assumes the credit risk of the mining company, has been a more common practice than pledging cash. A standby L/C is simply an irrevocable promise to pay a beneficiary upon written notice that a specified event has occurred. In particular, the event could be the failure by the mining company to perform the required clean up or closure. Commercial banks take the credit risk of the mining company to issue standby L/Cs. As a result, the bank's decision is reached exactly as if a loan request was being evaluated. Additionally, just as a loan has a fixed maturity date, a standby L/C is usually issued for a fixed term. Often, the expiration of a standby L/C is one year after its issuance. In virtually all cases, the beneficiary has the right to obtain payment under the standby L/C if it is not renewed, or an acceptable alternative financial instrument is not provided, 30 or 60 days before expiration.

For many years, commercial banks issued standby L/Cs to assure the reclamation of surface- and underground-coal mines. These standby L/Cs were typically issued on behalf of companies that were existing customers of a bank and who were acceptable credit risks. Limited recourse project financing sponsored by existing customers or well known and highly rated companies could also obtain reclamation standby L/Cs. In certain instances if a company or project sponsor did not meet a banks' credit criteria, the banks would issue standby L/Cs if they were fully collateralized by cash, short-term U. S. Treasury Bills, or other acceptable liquid investments. Banks performed little or no environmental due diligence to issue these standby L/Cs because environmental regulations had little direct impact on the bank. These instruments were very useful in the surface coal-mining industry in which there was a fast turnaround between stripping and reclaiming. Full mine closure represents an altogether different situation with an intermediate- to long-term turnaround period.

### 16.9.3 EFFECT OF 1992 REGULATIONS

The promulgation of the 1992 Environmental Regulations and the decision of the much commented upon "Fleet Factors" Case sharply curtailed commercial banks' willingness to take on any environmental risks. The Fleet Factors case, in particular, heated up the dispute over a lender's liability under CERCLA. Specifically, in 1990, the Eleventh Circuit Court's decision in "United States versus Fleet Factors Corp.," suggested that a secured creditor could incur environmental liability if its involvement with the financial management "...is sufficiently broad to support the inference that it could affect hazardous waste disposal decisions if it so chose." Fleet Factors had attempted to collect on a defaulted loan from a borrower who had stored hydrocarbons in oil drums on its property. Fleet eventually was forced to hire an outside contractor to move the drums. Although recent court cases have softened the effect of the Fleet Factors decision, nevertheless, banks are extremely reluctant to become involved in any credit extension if there is any chance of being named a "potentially responsible party" (the notorious PRP label), especially since banks tend to have "the deepest pockets."

The Fleet Factors effect on bank lending practices has been dramatic. Before making a loan, or issuing a standby L/C banks now require an environmental assessment of any property taken as security. In some cases, a bank may decide not to take a security interest in certain parcels in order to avoid any environmental risk. Banks may require an environmental cleanup before a loan is granted. Loan agreements now contain detailed representations, warranties, and covenants dealing with environmental matters. Banks are only comfortable if, during the life of the loan, they may: police compliance with environmental laws, require cleanup, conduct inspections, monitor the operations, restructure the loan, exercise forbearance, give final advice, exercise legal rights, perform a site environmental cleanup consistent with the approval of the authorities and the regulations, and foreclose and sell a property. However, banks are now particularly careful not to participate in the management of a property that in any way exposes themselves to environmental cleanup responsibility.

### 16.9.4 TRENDS IN THE BANKING INDUSTRY

Taking into account the new environmental risk that

banks could be facing it should be no surprise to the mining company chief financial officer (CFO) to know that standby L/Cs for financial assurance have become a scarce resource. They tend to be limited to those very few strong customers of a bank, and even then, only as an accommodation. Still they are available to certain companies and particularly for well structured projects. Banks control their risk by issuing the standby L/C for a term that is well within the life of a mining project. The expectation is that the standby L/C will be terminated by the project sponsor, or cash collateralized, well before the end of a mine's life.

During the past decade the commercial banking industry has begun to rapidly consolidate. There are approximately 14,000 banks in the United States, and most of them fail to earn adequate rates of return on their employed capital. Large mergers like Bank of America and Security Pacific, and Chemical Bank and Manufacturers Hanover will continue to change the banking landscape. Moreover, many banks will narrow the scope of their business in order to focus on a few products or services in which they have a competitive advantage. This includes scaling back international operations. The result will be a reduction in the number of banks willing to work with mining (and also petroleum) companies and a reduction in the availability of services to the mining industry, such as standby L/Cs for environmental purposes.

Furthermore, the collapse in real estate values, and the destruction of much of the savings-and-loan industry has caused bank regulators to increase their scrutiny extending to the lending practices of commercial banks. The effect has been difficult to measure, but there has been a very obvious increased reluctance by banks to consider riskier transactions. Environmental risks are certainly much more difficult for a bank to justify under the present climate and degree of supervision.

Capital guidelines put forth by the Bank of International Settlements (BIS) have been adopted by all U. S. banks as required by federal regulations. Each loan product, including standby L/Cs are assigned a capital "weighting" factor. Standby L/Cs that assure observable "performance" rather than guarantee a financial obligation (assurance) require only 50% of the capital of a fully funded loan or financial standby L/C. Prior to the BIS guidelines, standby L/Cs were not shown on a bank's balance sheet, and did not attract any capital. Still a bank is theoretically able to earn twice as much on a performance L/C than a similarly priced loan or financial standby L/C. However, the practice has been to not reflect a lower pricing on performance L/Cs, unless there is strong competition for the particular customer's business. In general, the price for all standby L/Cs has increased, just as the price for all commercial loans have increased owing to tougher capital guidelines.

In summary, standby L/Cs as financial assurances for mining companies are available from commercial banks, but the supply will be limited and the price higher than that in the past. Banks are extremely reluctant to enter into any financial transaction that might result in their becoming PRPs. Recent court cases seemed to have somewhat diminished that risk, but the outlook is still uncertain. The number of banks dealing with mining companies is shrinking as a result of industry consolidation, tougher regulatory oversight, and increased capital costs stemming from BIS guidelines. Good credit-worthy customers will be able to obtain standby L/Cs, but it will be an accommodation in an overall relationship. In many cases cash collateral may be required, environmental assessments may be required, and more complex representations, warranties, and covenants will be negotiated by the borrower and the bank.

## 16.10 PUBLIC ACCOUNTING ASPECTS

**by R. Weyand**

Generally accepted accounting-principles (GAAP) require that future obligations of any entity (company) be reflected as liabilities in the company's periodic financial statements. GAAP also require that the expenses incurred in the course of revenue producing operations be recorded in the same accounting period as the related revenue is recorded. The intention of the accounting rules is to give financial statement recognition to the company's responsibilities to comply with environmental regulations and/or institute corrective actions, as well as to provide for closure and post-closure costs of mining facilities.

Reclamation, environmental and closure costs are generally grouped into three categories: 1) costs required to be paid immediately, 2) costs required to be paid in the future based on past and current mining activity, and 3) costs to be paid in the future based on projected future mining activity.

Costs required to be paid immediately usually are in the nature of corrective actions—actions requested by regulatory agencies or in response to accidental occurrences. Such costs should be immediately recorded as expenses as soon as they are identified and such costs can be estimated or better yet be fully determined.

Costs required to be paid in the future, based on past or current mining activity, relates to mines presently operating or previously closed where reclamation and other closure activities will be required. GAAP required such costs be currently estimated and recorded as expense over the life of the mining operation. At such time as the mining operation is terminated, the estimated reclamation and closure costs should be completely recorded.

Costs required to be paid in the future based on future mining activity are similar to those for current mining activity. While it is prudent to develop estimates of such costs as part of the economic evaluation process, GAAP only require such costs to be recorded when mining activities are underway and production has commenced.

### 16.10.1 RECORDING OF COSTS

Accounting recognition of reclamation, environmental and closure costs is based on detailed estimates prepared by engineers and environmental experts as to total costs to be incurred to perform all necessary reclamation and closure activities and an understanding as to the mining activities that relate to each detailed estimate. The accounting process essentially attempts to apply a systematic method to correlating expenses to be incurred with the revenues generated from the related activity. With respect to mine sites, the estimated costs are usually allocated over a measure of production—either tons mined (both ore and waste) or units of end product. In either case, each accounting period is allocated costs based on the relationship of the current period's production to overall production expected over the life of the mining operation. With respect to milling or other processing operations, reclamation and closure liabilities are often recorded using a straight-line method based on the estimated useful life of the facility.

## 16.11 METHODS FOR REDUCTION OF FINANCIAL (BONDING) OBLIGATIONS:

**by J. Bokich**

As indicated, financial assurance mechanisms and processes are sometimes expensive, confusing, and difficult to administer and obtain prompt release. There is no recipe to ensure reduction of long-term financial obligation through the permitting process. It is obviously very important for operating personnel to spend significant time on minimizing impacts and limiting disturbance to mining areas to the greatest extent possible. This environmental planning will reduce the overall liability and reclamation burden on an operation, and furthermore yield good relations with the regulatory agencies and interested environmentalists. Proper planning should take into account the backfilling of pits in a sequential manner, the shaping of dumps or placing dumps in lifts, and all other functions that can lead to less reclamation costs and lower financial assurance obligations.

Much care is required to ensure the correct structure of a permit application. It is particularly important to carefully analyze and select every word that goes into an application. The mine operator must have a complete understanding of all implications of the commitments being made. Care needs to be taken to ensure that the application addresses applicable regulations, and that overly restrictive requirements that are not required are not committed to. Finally, areas of possible ambiguity should be either eliminated or completely defined.

Another mechanism for producing long-term liability is to conduct concurrent reclamation during operation of the mine. As soon as roads are no longer needed, waste dumps are completed, pits completed, etc. those areas should be reclaimed. This will lessen the overall bonding requirement, reduce premium costs or withholding of assets and again is well received by the regulatory agencies and the public. And lastly, a specific plan must be made for determining bond release. It is up to the company to determine when an area has met bond release criteria, and to pursue the release of the bond with the appropriate agencies.

Generally, financial assurance requirements and the mechanisms for application and release are relatively new in the hard-rock mining industry in the West. They have been evolving in the coal industry since 1977. Hard-rock miners should learn from the coal experience, which points out that the most critical items in the whole formula are the release criteria. This aspect is the most argued over and misunderstood piece of the puzzle, and currently has no clear-cut resolution. Because of the very serious nature of the financial resources that are tied up providing assurances, it is imperative that companies take a proactive approach toward the development of new ideas and mechanisms for bonding through their permit applications, and through the development of reasonable regulations with the local land management agencies or state agencies that enforce reclamation programs for mining operations.

## 16.12 CONCLUSION

Financial assurances for corrective actions, closure, and post closure will attain even greater importance through the intermediate term for both new and operating mines. Theoretically, several financial instruments are available to the mining company to provide the necessary assurances but in actuality their choices are becoming more limited and increasingly expensive. (This situation has been compared to dealing with one's own shadow—when you need a loan it runs away {it is hard to get}, when you don't need the loan it closely follows). This situation undoubtedly will generate cries for relief, which may include a greater emphasis on self-guaranteeing. The difficulty with self-guaranteeing is that ultimately the federal government and the U.S. citizenry provide the backup should the mining company go into default.

Possible alternative mechanisms could include:

- State controlled/operated insurance pool
- Operator controlled insurance pool (collective)
- Special tax to set up a fund
- Special provisions for private-sector financial guarantors (for example super liening)
- Tax-exempt environmental-control bonds

The dual role of some government agencies in terms of development and environmental care is being more actively examined. Whether it will continue is difficult to determine. However, it is obvious that certain agencies have in the past viewed the development aspect as being more important than the environmental aspect.

An area of major concern is that the small- and mid-sized mining companies, which tend to be under financed, will have great difficulty arranging for financial assurances. Thus the small- and mid-sized mining companies will have to become increasingly dependent upon associations, such as joint ventures, with larger, better-funded mining companies.

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Chapter 17

# INTERNATIONAL ENVIRONMENTAL CONTROL OF MINING

edited by D. Malhotra

## 17.1 INTRODUCTION

The vast majority of countries in which mining plays or has played an important economic role have in place environmental regulations of one form or another. The degree of enforcement varies greatly. Severe environmental problems related to mining have resulted in socio-political upheaval in several areas. Nevertheless, the citizens of all nations are demanding more activity from their government officials. The people want stricter environmental laws that are enforced.

The nations of the world may be classified into three major categories: the industrialized lands, the developing lands, and the communist and ex-communist states. All categories are acutely aware of the need for environmental control of mining, and are involved to widely varying degrees in environmental care and remediation. Pollution problems are similar for mining operations worldwide. However, the level of pollution and abatement practice varies greatly.

To generalize, in the industrialized lands the current condition of mining is in a state of rapid decline due to the depletion of reserves. Nevertheless, mining may still play a major role in the economy, especially in Canada and Australia. In any case, past or current mining is a matter of concern and a high level of environmental activity abounds (see Section 17.3.1 for activities in Europe).

The mining industry in the developing countries is commonly given a high priority because of its crucial importance to the economy (as a case in point, see Section 17.3.2 for the situation in the Philippines). The mineral base is needed for industrialization. The mining sector provides direct employment opportunities to the rural population where most mines are developed, and indirect opportunities in the cities for different types of support. Finally, exports of mined products favorably impact the "balance of payments." Of course, this positive impact of mine development and operation is countered by the fact that mining generates "considerable disruption of the physical environment, such as pollution of rivers, deposit of overburden and tailings, destruction of the natural landscape, air pollution by dust and gases, and the disruption of the marine environment by offshore mining (United Nations, 1992a)."

The communist and ex-communist countries, especially in Europe, have a well developed industrial base. Mineral resource development was given a high degree of priority in the development process. However, this progress was achieved at the expense of neglect of the environment. Although there are environmental laws on paper, very little or no enforcement of them was practiced by the communist countries. The environmental problems (e.g., acid mine drainage, pollution of rivers, smelter gases, etc.) are tremendous at existing operations in those countries. The problems may be worse than those in the developing countries. Therefore, in this chapter, these countries are grouped with developing countries as far as environmental regulations/enforcement is concerned even though they have an industrialized base similar to that of the developed countries.

## 17.2 GLOBAL ENVIRONMENTAL AGENDA

In the Western world, public attention to environmental issues first came to the forefront in the late 1960s and early 1970s. After a decade of conflict and controversy surrounding several major development projects, the United States government passed the National Environmental Policy Act in 1969, incorporating into law the concept of environmental and social impact assessment as a tool of inter-sectoral integration.

During this era, developing nations essentially viewed environmental degradation as a problem of industrialized nations. The United Nations took the lead in organizing an International Conference on Human Environment in Stockholm in 1972. Several world leaders attended and addressed the conference. Though

mining issues were not specifically addressed at this meeting, it was the beginning of the awareness of the need to address environmental issues related to growth and development in industrial sectors globally. The United Nations, through its World Commission on Environment and Development, issued a report advancing "the notion of a 'global commons' and issued a strong challenge to all countries to embrace the concept of long-term sustainability in their national development strategies (United Nations, 1992a)." The commission defined "*sustainable development" as a level of economic activity "that meets the need of the present without compromising the ability of future generations to meet their own needs.*"

Though the definition of sustainable development is still vague, a more precise definition will emerge over time. However, it is important to note that several important principles have emerged from the imprecise definition:

- The present and future fundamental needs of people must be met.
- Economic prosperity, environmental health, and social stability are inter-related and inter-dependent at all levels (i.e., from local to global).
- Environmental quality must be maintained or restored.
- Resources, both renewable and nonrenewable, must be used prudently in order to preserve them for future generations.

At first glance, it may seem absurd to link the concept of sustainability to mineral resources because the latter are non-renewable and hence non-sustainable, except in the context of recycling. However, significant implications for the mineral sector become apparent upon closer examination of the basic principles of sustainable development: 1) maintenance and restoration of environmental quality; 2) maintenance of social and community stability; and 3) preservation of resources for future generations. These three factors will likely provide the basic framework (i.e., social and political) for future mining activity. For example, land and water are primary resources used to produce several commodities: food, minerals, energy, recreation, etc. An integrated resource management approach will have to be taken to decide first what mix of goods/commodities the society should produce from the area and then allocate available resources to different products. Hence, these vital resources may not get distribution proportionately as the mining industry may desire.

Among the recent proliferation of conferences addressing the issues of environment, the international round-table conference *Mining and the Environment* held in Berlin in 1991 has particular significance to industry for several reasons: it addressed the question of long-term sustainable development for the mining industry, and it was organized by institutions with influence on the availability of funds.

The meeting was organized by the Development Policy Forum of the German Foundation for International Development (DSE) and the United Nations Department of Technical Cooperation for Development (UN/DTCD). The meeting recognized the need for international guidelines and addressed issues related to "the role of mineral resources in achieving sustainable development. The main purpose of the meeting was to formulate international principles, guidelines, and national regulatory standards regarding mining, with particular emphasis on developing countries in order to initiate a constructive process between the various actors involved, such as the mining industry and developing country governments." The meeting also discussed the need and mechanism for better coordination and cooperation among, and between, bilateral and multilateral development agencies in respect of mining and environmental activities in developing countries. Global problems, economic and non-economic alike, provide ample evidence of the need for more effective international development cooperation (United Nations, 1992b)." The meeting concluded with a compromise on a set of environmental guidelines for mineral development. They are outlined in Appendix I.

The United Nations organizations have continued to play a key role in placing environmental problems on the world's agenda. The United Nations Economic and Social Commission for Asia and the Pacific (ESCAP) organized a seminar on *Environmental Management for Mining and Mineral Resource Development* in Bangkok in 1991. The objectives of the seminar were "to identify training needs and evolve a plan of action in regard to environmental management in the mineral resource sector." The delegates reviewed the Berlin declaration on environmental management for sustainable development of the mining industry (given in Appendix I), discussed the present status of environmental regulation in the region and the role of private industry in resource development, and the training needs of the region. Based on extensive discussions, they arrived at a list of recommendations for the consideration of ESCAP. A review of these recommendations, given in Appendix II, indicates that what is applicable to the ESCAP region also is applicable to all other developing regions of the world. For example, assistance in development and impact assessment of environmental legislation and the establishment of national training resource centers for mining and the environment are needed in all developing countries.

UN/DTCD has organized two conferences on small-scale mining: the *Inter-Regional Seminar on Small-Scale Mining in Developing Countries* in Ankara (1988); and *Guidelines for Development of Small-/Medium-Scale*

*Mining* in Zimbabwe (1993). These meetings confirmed the existence of a high level of small-scale mining activities in developing countries (United Nations, 1993). Small-scale mining can and does make a significant contribution to national objectives in developing countries in various ways:

- It encourages the creation of indigenous entrepreneurship, which helps in the process of industrialization.
- Since small-scale mining is labor-intensive, as opposed to highly capital-intensive modern mining, it creates employment. This is very important in countries with widespread unemployment. For example, the number of people involved in small-scale mining activity in the two countries with the largest small-scale mining subsectors in the world, Brazil and India, exceeds 1.5 and 0.5 million, respectively. Some other countries with extensive activity in this sector are Bolivia, Zimbabwe, Ghana, and the Philippines.
- Small mines also provide an excellent opportunity for transforming unskilled labor into semi-skilled and skilled labor.
- Small mines can be brought into production not only in a fraction of the time required for a large operation, but also with significantly lower financial requirements. This is important in light of the fact that capital became a scarce commodity in the 1980s.

Recognizing that small-scale mining can have a significant impact on national and regional economies in the developing countries, the basic question that should be addressed is, "What needs to be done to assure orderly growth of the small-scale mining sector within the framework of sustainable development?"

The growth of the small-scale mining sector has generally resulted in unacceptable technical, environmental, and social practices. These miners find it extremely difficult to cope with environmental protection requirements. They generally are entrepreneurs and don't have formal knowledge of geology, mining, metallurgy, or environmental aspects. Preparation of environmental impact assessment statements (EIS's), good pre-production environmental management plans, and very often, highly technical equipment are required to prevent undesirable effects on the environment. Small-scale miners cannot prepare such plans or afford to have them prepared by specialists. Nor can they afford to acquire or operate sophisticated pollution-prevention equipment. Governments need to enforce basic environmental standards, assuming they have sufficient technical staff to do so, which is not the case in most developing countries; moreover, enforcement is extremely difficult in micro-scale mining districts, and enforcement of stringent environmental laws will adversely affect mine production costs for most operators.

Developing countries could ruin their small-scale mining sector by having government officials police the enforcement of environmental regulations. They have to evolve innovative approaches to managing this sector with minimum impact on the social and human environment. A good beginning in this area is underway, though a lot more needs to be done.

An international agency for small-scale mining, Small Mining International (SMI), was established as a non-profit organization at the École Polytechnique in Montreal, Canada, in 1989. This organization was dedicated to strengthening and supporting the small mining sector as an aid to rural social and economic development, particularly in developing countries. Several developing countries are creating similar organizations to promote small-scale mining; for example, in India, the National Institute of Small Mines was created in 1989 to promote the role of small-scale mining in national development and international cooperation. The principal objectives of this organization "are to encourage the small mining sector to use technical and scientific methods in its operations, and to raise consciousness regarding environmental protection." Zimbabwe Mining Development Corporation (ZMDC) encourages the formation of mining cooperatives in Zimbabwe. These cooperatives receive extensive technical and administrative assistance from the government through ZMDC. Similar organizations have also been created in other countries, such as Ghana, Bolivia, and Brazil, to assist small-scale miners in the technical, environmental, management, marketing, and financing areas.

Intergovernmental organizations, development banks, nongovernmental organizations, research institutions, experts, and private-sector enterprises appear to be forming an expanding network to implement sustainable development in the mining sector. In 1991, the International Council on Metals and Environment was formed to promote sound environmental policies and practices. The organization's members are mining companies, and the primary goal is to create environmental guidelines for developing countries. Also, the UNDP, UNEP, and the World Bank have established the Global Environmental Facility, which is expected to provide $1.3 billion (U.S.) for low-interest loans and grants to countries to ameliorate environmental problems.

In summary, there needs to be a "cradle-to-grave" approach to environmental problems in the mining sector. It is not sufficient merely to develop international standards; regional authorities need to be able to enforce them without detrimental effect on the entrepreneurial spirit or national/regional priorities. This will require a flexible, region-by-region approach. Human resource

development, technology transfer and adaptation will be the key issues in achieving sustainable development. A good beginning has been made in the developing countries, but a lot more needs to be done.

## 17.3 REGULATORY OUTLOOK

Though the degree of environmental regulation of mining varies from country to country — even among major mining producers in the industrialized countries — there appears to be a commonality in the general approach to addressing the problem. The common elements in environmental regulation are:

- Land availability for mining is restricted. Environmentally sensitive areas (e.g., due to the presence of wildlife, religious significance, etc.) are excluded from mining activity.
- An Environmental Impact Statement (EIS) process is required for governmental approval to ensure that consideration has been given to the environmental impacts of the decision.
- Permits are required for any pollution-generating aspects of mining activities.
- Reclamation of the surface area is required after cessation of mining activity.

The majority of industrialized and developing nations in which mining plays an important economic role have in place environmental regulations in one form or another. However, as the situation in the United States is constantly in flux, it is even more so outside the U.S. Environmental awareness and global development agencies' practice of tying the grant of loans to the meeting of strict international environmental standards are forcing developing countries to change their existing laws. Hence, it is impossible to provide an up-to-date, comprehensive record of world mining environmentalism in this chapter. General guidelines regarding the current status of environmental laws for mining in different countries are summarized in this section.

### 17.3.1 COMPARATIVE TRENDS
**by A. L. Dangeard**

#### 17.3.1.1 Introduction

Mining creates economic wealth out of natural goods: raw materials, land (directly, when excavating, and indirectly, when deposing overburden and treatment waste), and water. Most of it is returned to the reclaimed land or to the flow of water. If the condition of these natural elements is degraded to the point of preventing further use by others, or if it can cause harm to their health, environmental problems arise and must be dealt with. The attention to health is not new. The first comprehensive laws on occupational safety and drinking water were voted in shortly after World War II in the United States and Europe, well ahead of the later introduction of all-embracing environmental legislation in the 1970s. In mining, occupational safety traditionally was the object of special attention. The more visible environmental impacts of mining exploitation (overburden and tailings, namely, large-volume and mostly low-toxicity waste) had also been regulated by special mining legislation for some time. The less visible damages, like acid mine run-off or heavy metals in river sediments, dust particulates, sulfur emissions, etc., were approached later, in the 1980s and early 1990s, as a new wave of environmental statutes followed increased concern for sustainable development.

In the early 1980s, the mining industry in the developed countries rapidly adjusted to these new concerns for water and air quality and proper land management. Two reasons may explain this generally environmentally positive action of mining companies:

- Technologic changes in the treatment of ores were already underway, particularly in North America, as a result of the high dollar and the previous surge in energy prices. New, less polluting processes in hydrometallurgy and pyrometallurgy were developed and introduced, and many spectacular improvements in pollution control could be obtained by better operational practices.
- The costs of conforming to new legislation for water, land, and (with the exception of smelters) air pollution control were undoubtedly significant, but as a percentage of sales, lower than expected, and probably smaller than in other manufacturing industries (1% to 3%, based on a sampling of mining company reports, while values above 5% were more common for the chemical sector).

Such expenses have to be put into perspective, as profits were low during this period. In addition, the cost of environmental protection in the mining industry may be somewhat higher than the average national figures: environmental protection expenses are estimated around 1.1% of the GNP in Europe and 1.5% in the United States (with all the usual reservations about comparing figures from diverse sources).

Nevertheless, this effort was remarkable in an industry which is in the first line of cyclic impacts and which had a high level of indebtedness during the 1980s. Mining in Europe and the United States would seem to deserve a better image than it has been granted so far, particularly considering that it was generally on the leading edge of the environmental scene.

The late 1980s and early 1990s witnessed wider or reinforced environmental regulation in Europe, as well as

the United States A new holistic approach (named by some as "environmentalism") is inspiring a seemingly inexhaustible flow of legislation, complex and not always based on serious economic studies. At the same time, in the larger context in which the industry operates, mining is changing or will change at an unprecedented pace:

- In spite of the economic downturn in parts of the developed world, the demand for raw materials continues to increase and we should expect larger quantities of raw materials to be produced, traded, and introduced into manufactured products. Their uses are concentrated in a number of surroundings, justifying a new concern for the environment in many places.
- Development banks have created a new type of conditionality for the receiving countries: no outside capital without prior modernization of the environmental regulatory framework. For its part, international private investment will be deterred by unpredictability, mandating a due-diligence review of potential civil liability. This implies modern environmental statutes or the negotiation of special agreements. The first three years of the 1990s saw the adoption or revision of environmental laws in most countries engaged in privatization of their mining sector. The environmental legislation of the United States and the European Union (EU, or European Community, EC) is being generally used as a reference prior to transposition to the Third World.

Why are these two regions setting the trend in environmental regulation? There is well-developed environmental legislation in other mining countries, but none as systematic and ambitious. New general rules continue to emerge internationally in the world of mining:

- A large part of international capital is linked to the investment decisions of the international mining groups, many of which have headquarters in North America or Europe, where strong financial centers also operate. The environmental culture adopted by these groups in the 1980's is now being transferred to their expanding subsidiaries in other countries.
- While cautious of the argument of environmental dumping in matters of trade, the internationally operating mining companies are highly conscious of the international consequences of more severe environmental obligations. This is particularly relevant in Europe, where the mining base is more limited.
- Standards for environmental characterization of raw materials — in particular, for toxicity or eco-toxicity — are directly or indirectly incorporated into product standards. The considerable work in progress in Europe in the field of standardization extends from the Comité Européen de Normalisation (CEN) to ISO. These standards are becoming international and are being adopted by the newly industrialized countries seeking access to European or North American markets for their manufactured products.

From this quick overview, one may conclude that environmental legislation is no longer a specialized field, outside the main focus of economic reasoning or mining operational planning. It is now a central aspect of mining strategy. This will be shown from two angles:

- How the markets for mining may be influenced by regulation on eco-toxicity and recycling, affecting either the mining products themselves or the manufactured products incorporating mined raw materials.
- How the production of non-energy mined raw materials, from the investment decision to the actual conduct of operations, will adjust to a fully regulated environment.

#### 17.3.1.2 Trends in the Minerals Markets

When a global approach to the environment is taken, the prevention of pollution will encompass not only the production processes — at the origin of the problem, so far dealt with by the environmental legislator — but also the employment of manufactured products themselves. The consumer has to be protected from possible harmful contacts with materials incorporated into a product. Furthermore, through a product's life, its mineral components may be dispersed and may result in the accumulation of possibly dangerous substances into natural media. These risks are at the base of the most active discussions currently underway in connection with devising new legislation.

Miners are familiar with preventive measures when there are risks of toxicity for people or the environment. Special rules have been introduced for asbestos and then for lead. In the case of lead, particular prohibitions on dissipative uses (in gasoline) were decided. In addition, lead batteries are themselves regulated in order to foster recycling, with a view to preventing lead from ending up in the environment. Many more minerals are now being examined for possible risk by regulatory authorities in all parts of the world.

The expansion of environmental legislation in the field of toxicity and recycling is the most important development to be watched by mining companies at the present time; indeed, as the stakes are often difficult to quantify (health, bio-diversity, etc.) or the threshold of toxicity uncertain, it may result in quite unexpected and

sudden decisions such as total bans or new types of responsibilities for producers ("take-back" packaging schemes). Finally, recycling will obviously affect the competition between materials.

#### *17.3.1.2.1 The Issue of Dangerous Substances*

The first legislation on dangerous or toxic substances was introduced decades ago. In the United States, the Toxic Substances Control Act was passed in 1976 to complement the toxicity provisions of specialized statutes on air, water, and waste. The EU in 1967 adopted the Directive on Harmonized Provisions for Classification, Packaging, and Labelling of Dangerous Substances — 67/548, with many revisions (91/689). As new scientific or technical evidence emerged, this field became very specialized and difficult to monitor. While it is an open process in the United States and EU, the procedural battles are highly technical and more secretive. The interests of manufacturing or chemical industries, which play a leading role in discussions with the European Commission, are not necessarily the same as those of the mining industry.

Recent evolution in the United States gives a much more active role to preventive measures. Industry requirements (reporting and testing, in particular) are on the rise. In coordination with the toxicity provisions of the Clean Air Act or Water Pollution Control Act, risk management programs at federal and state levels are being developed on a more systematic basis. Their objective remains the screening out of dangerous substances before they enter commercial production or end up in soil or water after being discarded.

In Europe, if one were to judge only by the number of directives, legislation would seem more comprehensive than in the United States (directives on dangerous preparations, pre-marketing requirements, specific controls for certain products, export and import controls, draft lists of dangerous substances, etc.). But one should remember that, in order to become effective, EU directives have to be incorporated into the national laws of member countries. The enforced implementation of environmental legislation by litigation is not developed in Europe as compared to the United States. Up to now, most legislation was spurred on by the common market objective: to allow products to circulate easily, with compatible standards, even though the ultimate sanction (forbidding a product to enter a national market) still rests in the hands of national health security authorities.

With the advent of the Maastricht Treaty in November 1993, the situation has changed notably. Environment and human security became objectives of the Treaty in their own right, independent of the goal of achieving a common market. Recent EU legislation for toxic products is in the form of "regulations," which, unlike directives, apply directly in all member countries of the Union. The objective of dangerous-substance regulation is evolving from market harmonization toward a systematic policy of risk prevention and elimination. For example, the "existing substances" or "new substances" regulations of 1993 will greatly extend requirements for the industrial sector, with required production notifications, risk assessment procedures, testing, and reporting. A priority list of dangerous substances will set the work program of assessment in the coming years.

The mining industry will be called on to participate in the expanding field of environmental risk assessment because many of its products will appear on lists or classifications of various intent. The mining companies should not leave this field to the experts. It will be necessary to anticipate the possible results of these procedures. Indeed, future risk abatement measures could greatly affect the use and marketing of mining products. Mining strategy choices have to include an evaluation of the risks to people and the environment at all stages of the life of specific minerals entering into goods being manufactured. Before formulating a strategy, two questions must be answered: how to manage these risks to take into account possible hidden costs, and how to avoid or limit more extreme measures such as total prohibition?

#### *17.3.1.2.2 Trends in Recycling Legislation*

Mines are traditionally familiar with recycling: secondary materials have been part of the source of supply for metals as far back as mining has been practiced. Recycling has mostly been driven by the markets: its costs are high, and operating profitably requires good entrepreneurship. As a result, one should be cautious of the possible effects on the markets of regulating such activities. Nevertheless, recent trends have been in the direction of imposing more regulation on industries using materials to be recycled. This is part of the new holistic approach covering the whole life cycle of products so as to better protect the environment.

Regulatory authorities are seeking two different objectives at the same time which may lead to contradictions:

- One objective is to prevent waste, and in particular hazardous waste, from accumulating in the environment. This is the intent of important legislation on hazardous waste in Europe and the United States. Such legislation favors the treatment of dangerous waste as close as possible to its source, introduces controls on shipments of dangerous

waste, and may impose duties on producers in order to make incineration or harmless disposal financially viable.

- The second objective aims at achieving higher rates of recovery or recycling, with a view to a better land use (space for dumps is becoming scarce) or long-term management of mineral resources and avoiding dissipative uses. These goals would inspire, among others, measures for promoting a better functioning of the markets, easier transport, and wider international circulation of secondary materials for recycling at the most economic location. It should also encourage energy recovery and/or conservation (which has its own set of pollution problems). In Europe, new legislation on enforced recycling of packaging has created market chaos for certain secondary materials. The "take-back" packaging schemes of several European countries (France and Germany in particular) have yet to prove that they can function properly. In the meantime, the European Council Legislature has set general objectives in terms of percentage of recycling (including incineration with energy recovery) without indicating how these objectives might be achieved. Certain national laws (in France, 13-07-1992 on waste) have prohibited the dumping of any waste that could still be "recovered" (dumping only "ultimate" waste) without calculating all the costs that the public will have to bear in the future. More recent European proposals include a review of "priority waste streams" (namely, used cars, electronics, demolition waste, etc.), which is supposed to eventually conclude in more measures for encouraging waste prevention and final dumping limited to "ultimate waste."

Clearly, regulation and the function of the market can be reconciled only with the greatest attention and priorities based on some compromise between the two poles. Moreover, subsidies cannot easily vary with the ups and downs of the business cycle, which should be the case if it is desired to realize a goal of a permanent recycling percentage.

U.S. legislation concerning hazardous waste management is relatively remarkable in terms of the goal of the Resource Conservation and Recovery Act of 1976 (RCRA), which establishes a system of control over hazardous waste "from the cradle to the grave." This approach was initiated earlier than the related European Hazardous Waste Directive of 1978. Excepting the special Superfund legislation, the U.S. system of hazardous waste management seems more flexible but less effective than the intricate series of measures subsequently introduced in EC legislation. In particular, the attitude toward secondary materials is less dogmatic than comparable EC regulation, with a clear priority for appropriate supply of these secondary materials to the affected industries.

The status of EU legislation on waste recycling is influenced by the particular needs or politics of a few countries, namely, Germany, the Netherlands, and some of the Scandinavian nations. The objectives of avoiding dissipative uses and of treating dangerous substances at the source have inspired a whole body of rules: Framework Directive on Waste (75/442 and subsequent amendments — 91/156), Regulation on the Supervision and Control of Shipments of Wastes (93/259), and Directive on Landfilling of Waste (93/275). The issue of transportation has been taken up successively by the Basel Convention (March 1989), with the introduction of a system of green, orange, and red labels, and then by the OECD multi-lateral agreement on the movement of waste intended for recycling. Unfortunately, this still leaves a large degree of uncertainty on the national controls which will eventually apply to the trade.

Toxic products and waste regulations are influencing the competition for materials, in particular, between aluminum and plastics, which have different recycling or recovery characteristics. Rules for dangerous substances may also have negative impacts on the markets for metals: psychologically, heavy metals are easier to target on lists of substances than are complicated chemical compositions. When combined with regulations on toxicity, recent waste regulation in Europe will put additional constraints and costs on treatment or disposal. This should be accepted if predictable and discussed with industry. However, potentially severe marketing consequences may appear; in one recent instance, a manufacturer became aware that the ultimate waste discharge rule of the 1992 French law will imply incineration of the non-recyclable part of its product at the end of its life. As air emission from incinerators is subject to stricter limits, the company started to analyze the non-recyclables for possible traces of dangerous substances coming from various components. Since it does not want to face penalties at the incinerator, the conclusion for the company may be a change in the procurement of raw materials.

More unexpected results of this type are in store as a lattice of statutes is gradually introduced from the EC to the national legislation of the member states. It will take some time, as less than half of the environmental measures adopted by the EC Council have currently been transposed into national laws. But with the greater enforcement power afforded by the Maastricht Treaty, Union institutions will inevitably accelerate the entry of European environmental legislation at the national level.

### 17.3.1.3 Mining Investment and Production

Strategic evaluations precede decisions to invest in a new mine or acquire an existing one. At this time, an EIS has

to be presented to the regulating authorities and made available to the public. Its findings are part of the feasibility study, and subsequent changes may impact the findings of the final feasibility report. A mining enterprise is first a local affair which has to be approved as such, starting with the EIS, which is usually open to public scrutiny. Then, the permitting authorities, local and national, will set the framework for actual operations. Legislation on permitting is now well developed in the United States and Europe, and the methods of approach are often similar. There are, nevertheless, significant differences that will appear when reviewing requirements at the investment stage and in the conduct of mining operations.

#### *17.3.1.3.1 Investment in New Projects or Acquisitions*

The starting of new projects requires the preparation of an EIS. This is now standard procedure in both the United States and the EC, but the responsibility for preparing the EIS differs in each area.

In the United States, the National Environmental Policy Act of 1969 (known as NEPA) requires an Environmental Impact Report (EIR) to be prepared by a "lead" agency prior to any major federal action, in particular, before any decision to grant operating permits. In practice, the regulating authorities usually request the prospective operator (promoter) to provide the necessary data for drafting the EIR (by supplying an EIS). However, the final document is the complete responsibility of the federal agencies concerned and must include the study of all alternatives. In addition, the federal decisions are subject to review and control by the federal judiciary.

In the EU, the EIS is presented by the mine developer. Directive 85/337 on the Assessment of the Effects of Certain Public and Private Projects on the Environment is mandatory for various types of projects, but implementation for "extractive ores" is left to the discretion of the member states (Annex II of the Directive). The EIS is already part of the national mining laws in most European countries. In France, for example, there is one single procedure: the EIS for a mining project is submitted to the local regulatory authorities. This submittal opens the procedure for granting the various required permits (most of which are delivered by the local Prefect), as well as for the federal authorization to exploit minerals. For quarries, the procedure is kept entirely at the local level. In Germany, the federal mining law of 1980 was modified in 1990 to incorporate the requirement for an EIS and to extend the whole concept to eastern Germany. In the UK, two procedures apply concurrently for mine planning: one in the hands of the Mines Authority, and the other in the hands of the Local Planning Authority; both require a prior environmental assessment.

The EIS (or EIR in the United States) document opens the way for application for permits. In the United States, different permits must be obtained for air, water, and land, which are governed by separate statutes. The EC is working on a single permitting system, the logical counterpart of a comprehensive assessment approach. The Integrated Pollution Prevention and Control Draft Directive of 1993 (IPPC) is currently being discussed with industry representatives and governments. It is expected to introduce, through the avenue of EU legislation, the concept of "best available technology" (BAT) as the basis for standards on air emission, water effluent, and waste disposal. Previously developed in the United States separately for each natural environment (media), the BAT references should not have the same legally binding character in the EC.

When adopted, the IPPC directive should represent a real simplification of the procedures. (Every miner is acutely aware of the importance of limiting procedural delays, when profitability of an operation is so dependent on the rapid start-up of a new mining venture.) It should facilitate practical discussions of the balance between cost-effectiveness and environmental benefit.

Environmental civil liability should be evaluated prior to an acquisition of a mineral property or the decision to bring a new mine into operation. Developments in this field are most significant. In the United States, the issue was raised in the late 1980s for closed and abandoned sites following several serious environmental accidents. The experiences pertaining to employment of the Comprehensive Environmental Response, Compensation, and Liability Act (Superfund) in the United States has created serious misgivings in Europe and elsewhere. Such a system of strict liability, joint and several as well as retroactive, when applied to past mining operations may add unpredictable if not unbearable expenses. In Europe, the current mining operations are not sufficiently numerous to support all the charges of a long mining history. One may suggest that the mining companies should be obliged to initially concentrate their efforts on active sites. In addition, they must set aside the funds necessary for future reclamation when the mine shuts down (i.e., closure and post-closure). It is felt by many that for past operations that were closed under the rules prevailing at the time, corrective costs should normally be covered by public funds.

At present, the EU is proposing to create a new regime for civil liability (Green Paper on Liability of 1993). There are disparities between civil liability protocols in the Union member countries. Germany has a special rule for environmental responsibility in the Federal Mining Act of 1991, and already has a law on environmental liability. Holland mirrors Germany in this respect, but has stricter liability provisions. Discussions

underway between member states express widely varying views on the opportunity for Union regulation of this matter.

Finally, the example of Superfund liability in the United States, with responsibility extending to the lenders (banks) that financed mine development, has rapidly spread the practice of prior "environmental audits" to practically all of the world's owners of mining properties. Such audits imply that environmental legislation exists and appears stable. Thus, Superfund has indirectly encouraged a large extension of environmental legislation in other countries.

#### *17.3.1.3.2 Mining in a Fully Regulated Environment*

Mining operations have always been conducted under special administrative controls, for example, with respect to safety and conservation of resources. Mining companies generally prefer that new regulations on air, water, land use, and waste handling remain under existing mining statutes and administrative supervision. In fact, a separate mining jurisdiction is difficult to justify for air and water, which are natural media shared by many other uses. Indeed, the recent laws on air and water in Europe and in the United States have no exemption for mining (except for RCRA on a temporary basis). In Europe, when these general environmental laws are incorporated into mining laws, the mining companies may have to face cumulative administrative supervision as is currently the case in the United States

It is suggested that for waste handling and land usage, the current exemption should continue. For mining waste, RCRA in the United States and the Framework Directive — 75/442, replaced by 91/156 in the EC, have essentially similar mining exemptions. (More recent legislation has had no additional impact on mining. However, in the United States, the federal legislature is currently examining the possibility of changing the landmark Mining Act of 1872, which could entail tremendous changes for the mining industry, especially in terms of access, permitting, and royalty). Nevertheless, Superfund in the United States or the numerous directives on hazardous waste and proposals on landfilling in the EU would apply to all industrial sectors. However, there are many reasons that would justify a special rule for mining waste, be it only the mere volume of material concerned: in the United States, 15% of all waste (in South Africa, up to 80%). Terminology and comparison are obviously inadequate when they are put into the same category as domestic or industrial waste, the high volume of overburden, the dumps of certain gold treatment residues, which may be toxic, and other types of tailings with low toxicity. It is obvious that mining needs special waste disposal rules.

Special regulations for mining as it affects land use should also be maintained, because land use is the core of long-term management of mineral resources. In the United States, this is exemplified by the very name of the concerned federal agency, viz., the Bureau of Land Management. Wetlands, National Parks, and the use of federal lands are major issues for mining in the United States In the EU, land remains a national preserve. For example, there is no EC legislation on preventing emissions on land. New policies of land and resource management appear in recent national legislation. In the UK, the Town and Country Planning Act of 1990 and the recent amendments to the French Law on Quarries of January 1993 provide a new emphasis on the long-term management of aggregates and building materials, resources that are becoming relatively rare in many parts of Europe.

A comparative review of the extensive regulation on air and water quality in the EC and the United States is beyond the scope of this section. Determination of emissions/discharge standards and "environmental quality standards" (EQS) are complex procedures that bear the respective marks of diverse regulatory processes. For example, in the United States this has led to open political processes and subsequently the adoption of legally binding BAT. On the other hand, in the EC there has been a tendency toward law-making by experts. Some recent trends may be identified as they may affect the mining industry:

*For air quality, the United States Clean Air Act* is an example of the most comprehensive set of rules existing in the world today, and even these have been updated since 1970. Industry problems are taken into consideration, but generally, the ambient quality objectives dominate. The trend is toward reinforcing state programs, developing market instruments (tradeable permits), enhancing the monitoring of all significant emissions (the Acid Rain Program), and setting up risk-management programs for priority toxic substances. By comparison, and in spite of its problems of trans-boundary air pollution, the EC has been much slower in implementing its own Directives on Combating Air Pollution from Certain Industrial Plants — 84/360. There are some air quality standards for a handful of substances, but they are not always efficiently enforced. The energy problem dominates the air quality regimes, and it is proving difficult to adopt common economic incentives.

*For water quality, the United States Clean Water Act* was amended in 1987 to reinforce compliance with minimum nationwide discharge standards. The tendency is to raise surface water quality standards in local programs (for example, around the Great Lakes). Concerning groundwater, the developments of the Safe Drinking Water Act provided the drive for protection when an

aquifer is the sole source of drinking water. Toxic substances are targeted for reinforced prohibitions. National effluent discharge limitation is industry-specific and determined after extensive consultation. The United States EPA issues policy-guidance memoranda designed to help evaluate site-specific factors affecting metals toxicity that should be of interest to all mining companies.

*E. C. legislation on water quality standards* (Directive on the Quality of Waters Intended for Human Consumption — 80/778) and on discharges (Framework Directive on Pollution Caused by Certain Dangerous Substances Discharged in the Aquatic Environment — 76/464) were both introduced at a relatively early stage in the enviro-legislative process. The current debate on the level of standards, which certain member countries find too costly to maintain, is typical of regulation adopted under political urgency without first studying the economic balance of cost/benefits in an open debate. Indeed, the cost of abstracting and treating water will increase in Europe in the coming years. In France, the Law on Water — 3-1-92 is establishing a policy of comprehensive and balanced water management plans at two levels: the aquifer system and the river basin. Pollution taxes and fines are reinvested in the basin and managed jointly by users and either local or national regulatory authorities.

### 17.3.1.4 The European Union and in the United States

1. ***European constitutive statutes***:

*Treaty of Rome 25-3-1957*; creation of the European Commission and Council

*Act of Brussels 20-09-1976*; direct suffrage for electing the European Parliament

*Single European Act 1-07-1987*; strengthening of the institutions and of the common market

*Treaty of Maastricht 2-02-1992*; creation of the European Union (the term only applies to the Council of Ministers)

2. ***Member States***:

Greece, Germany, France, Spain, Ireland Italy, Luxembourg, Netherlands, Portugal, United Kingdom, Denmark, and Belgium (order of the Treaty for the rotating Presidency as of the first half of 1994). Note that Austria, Finland, Norway, and Sweden are candidates to join during 1994.

3. ***Legal acts***:

- Regulations are directly applicable in each member state.
- Directives are the basis of EC legislation. The results to be achieved are binding for member states, but the national authorities reserve the method of achieving them.
- Decisions are individual in nature and are administratively implemented.
- Recommendations are orientations of expressions and are not binding.

4. ***The legislative process***:

*Council of Ministers of the European Union:* the Council adopts or amends proposals of the European Commission, a decision is ratified by majority, except in the case of sensitive subjects of diplomatic, political, or social nature when unanimity is required.

*European Commission (17 Commissioners):* the Commission submits proposed legislation to the Council and implements the decisions. The legislation is drafted upon consultation with the Economic and Social Council and/or independent experts.

*European Parliament:* the Parliament is involved in the legislative process through consultation, cooperation ("assent"), and co-decision. The co-decision procedure was introduced by the Maastricht Treaty and concerns such questions as right of establishment, education, culture, public health, consumer's protection, technologic research and development, etc. The assent procedure applies to association and commercial agreements of significance.

*Court of Justice:* the court ensures interpretation and application of the Treaties of Rome and Maastricht.

### 17.3.1.5 Conclusions

In comparing EC and United States environmental laws as they impact on mining, all potential problems could not be covered. In particular, additional thought should be paid to information provided to the public (United States Right-to-Know Act, EC Seveso Directive, and IPPC draft Directive). Furthermore, mining operates in a local community, and poor local relations have often been behind a deteriorating image of mining in the past. Considerable efforts have recently been made by mining groups, and the situation is changing. Mining generally deserves a better image and is likely to play a larger role in the new orientation of world environmental policies. Like other industrial sectors, mining has had to face up

to the extreme complexities and abundance of environmental legislation in both the United States and the EC. Certain conclusions appear evident. First, mining has been among the first sectors of industry to adjust to the new body of all-embracing environmental legislation. And, mining privatization played an important role in spreading environmental regulation in many countries.

By its very nature, mining is close to a natural phenomenon. As such, it will be a necessary interlocutor for the new global approach to environmental problems. Better long-term conservation and management of natural resources implies an economic discipline on a time scale familiar to miners. The business of mining deals with scarce resources over a long-term perspective. Recent trends outlined in this section are already part of the new mining culture: management of resources on a local basis (water, building materials, etc.), prevention of dissipative uses by improved recycling, and promotion of efficiency in production processes (better recovery means less pollution), etc.

The recent mining experience in relation to environmental regulation may underline a paradox: while the environmental laws of the United States and the EU are being used as a reference by many of the developing countries, European and North American environmental laws have evolved after notable environmental misfortunes, as there were no preconceived patterns and implementation has been gradual, sometimes erratic, and often costly. Environmental legislation needs simplification and better information to and input from the public. The condition of the natural environment has certainly improved, but the stakes are not sufficiently documented. For many developing countries, where natural resources are more fragile and play a more important role in sustaining production and life systems, environmental regimes would probably need a somewhat different approach based on a better initial knowledge of the prevailing natural economic and ecological systems, better understanding of the impact of demographic and economic development, and more ambitious and rapid goals of improvement. On these issues, the mining industry appears well-versed in the situation and is thus prepared and able to play a constructive role.

### 17.3.2 REGULATORY OUTLOOK FOR THE PHILIPPINES

**by E. O. Pitschel**

Since 1986, when democracy was restored with the first democratically elected president (Corazon Aquino) in three decades, the Philippine national government has been working hard to attract foreign investors, including mining companies. During the Aquino administration, work was initiated on a comprehensive overhaul of the old Mining Code with input from various sectors, including the mining industry. This work resulted in a new Mining Act, HR 10816, that was approved by the Philippine House of Represen tatives and passed in January 1994 under the current Ramos administration. Agreement was finally reached on the new Mining Act in early 1995. It passed both the House and the Senate, and was signed into law by President Fidel V. Ramos on March 3, 1995. It is now called the Philippine Mining Act of 1995.

The House-approved version of the new Mining Act specifically spells out that natural resources, including minerals, belong to the State. It outlines the required permitting process, environmental impact assessment (EIA), the various phases of a mine project, from exploration to development to production to reclamation, and also taxation. Shown in Table 17-1 is a schematic interpretation of the four mineral-rights agreements from which foreign and local mining companies can choose: Mineral Production Sharing (MPSA), Joint Venture (JV) with Government, Co-Production Sharing (CPS), and Financial and Technical Assistance Agreement (FTAA). As currently envisioned, the FTAA approach would be 100% foreign. It is worth noting that the Philippine National Government's approach to environmental regulation, while not fully up to United States standards in all areas, is similar to them. It is expected that over the long term, the Philippine environmental standards will match those of the United States

The basic 60/40 ownership rule, where Filipinos would own 60% and foreigners 40%, is still in effect for mineral resource development and utilization, with no immediate possibility of amendment. However, both the House and the Senate versions of the new Mining Act have an FTAA which is intended to soften the impact of the 60/40 rule. The contractors (foreign or local mining companies) in MPSA's, CPS's, JV's, and/or FTAA's will be entitled to the applicable fiscal and non-fiscal incentives as provided by Executive Order No. 226, more commonly called the Omnibus Investments Code of 1987. The Board of Investments (BOI) administers these various incentives, which include certain tax holidays and duty-free importation of certain major mining and processing equipment for specified time periods.

In summary, the monitoring of mining law developments in a number of emerging Asia Pacific countries indicates a marked trend toward increasing regulatory liberalization; the Philippines is one of these. The peace and order situation in the Philippines has also improved substantially under the present Ramos administration. The Philippine government is making a strong effort to attract foreign mining investors. Currently, Australian and Canadian mining companies are assessing minerals exploration and joint-venture opportunities in the Philippines.

**Table 1** Philippine Mining Act 1995
How to Acquire Mineral Rights for Metallic and Non-Metallic Resources

*Prospecting Permit*
2 years — can be extended; 200 blocks —16,200 hectares;
Approved work program — Subject to relinquishment — Declaration of Feasibility

| | MPSA | Joint-Venture Agreement Organize JV company w/gov't | Co-Production Agreement | FTAA 100% Foreign |
|---|---|---|---|---|
| Gov't Input | Mineral resource | Mineral resource<br>Equity shares<br>Possibly technology<br>Possibly personnel<br>Other agreed terms | Mineral resource<br>Possibly funds<br>Possibly technology<br>Possibly personnel<br>Other agreed terms | Mineral resource |
| Contractor's Input | Funds<br>Technology<br>Personnel<br>Management | Equity shares<br>Technology<br>Some personnel<br>Management<br>Other agreed terms | Funds<br>Technology<br>Personnel<br>Management<br>Other agreed terms | Funds<br>Technology<br>Personnel<br>Management |
| Gov't Shares | % of gross out put<br>Y1 to Y3—1.0%<br>Y4 to Y5—1.5%<br>Y6 on—2%<br>Taxes | % of gross out put to be negotiated, plus equity earnings, or share of profits<br>Taxes | % of gross out put to be negotiated, plus profit shares or equity earnings<br>Taxes | % of gross output to be negotiated, gov't share shall include income tax, excise tax, special allowance, & other taxes/duties/fees under existing law |
| Incentives | Current BOI | Current BOI | Current BOI | Current BOI<br>Payment of gov't share begins after contractor fully recovers pre-operating |

Notes: House of Representatives' version. A contractor can apply directly for MPSA or any of the other modes of mineral agreements. Maximum area 100 blocks or 8,100 hectares. Gross output — operating income less S/R/F/I. Life of mineral agreements 25 years, renewable for another 25 years.

### 17.3.3 THE LATIN AMERICAN COUNTRIES
**by A. L. Kuestermeyer**

Global awareness of the environment is now a priority issue for governments around the world, including those of Latin America. The status of environmental regulations and standards pertaining to the mining industry in Latin American countries can best be described as very dynamic — with evolving policies, standards, administration, and enforcement thereof. Terminology, which characterizes this dynamic state, would be "in transition, evolving or being formulated." In most countries, the legal framework is in place with various agencies being designated for coordination, administration and enforcement. Currently, environmental regulations and standards tend to be more qualitative, than quantitative, with only general standards and few specifics. A common denominator that is widely being accepted and put in place in these countries is the submission of and conformance to environmental impact studies.

For this overview, the five countries have been selected as being representative of environmental attitudes in Latin America: Bolivia, Chile, Mexico, Peru, and Venezuela. Table 2 summarizes a comparison of the status of environmental regulations and standards and primary regulatory/permitting authorities. The following sections present an overview for each of the selected countries.

#### 17.3.3.1 Bolivia

Currently, the environmental regulations for Bolivia are being drafted under the guidance of the Counsel for Sustainable Development. This counsel is presided over

**Table 2** Comparison of Environmental Regulations in Selected Latin American Countries

| Country | Status of Environmental Regulations and Standards | Regulatory/Permitting Agencies |
|---|---|---|
| Bolivia | In transition — new Environmental Law No. 1333 passed in 1992; regulations and standards being drafted by Council for Sustainable Development | Ministry of Sustainable Development Law and Environment; Ministry of Human Development; and Ministry of Economic Development |
| Chile | Rapidly evolving — government drafting environmental policy to combine economic growth and environmental protection | Servicio Nacional de Geología y Minera (SERNAGEOMIN); Superintendencia de Servicios Sanitarios; plus several other federal and regional ministries and agencies. |
| Mexico | Being formulated by representatives of SEDESOL, CAMIMEX, and SEMIP. | Ministry of Social Development (SEDESOL) comprised of National Ecology Institute (INECO) and Office of Attorney General for Environment |
| Peru | Legislation revised 1993 — evolving | Consejo Nacional de Medio Ambiente (CONAMA); Dirección General de Asuntos Ambientales |
| Venezuela | Regulations covering all aspects (air, water, emissions and effluents) of submission of environmental studies | Regional offices of the Ministry of Environment |

by the President of Bolivia. The Counsel for Sustainable Development is comprised of representatives from three cabinet level ministries: Ministry of Sustainable Development and Environment, Ministry of Human Development, and Ministry of Economic Development. The lead ministry in the drafting of environmental regulations is the Ministry of Sustainable Development and Environment. The Counsel and Ministry of Mines have also sought input from the private mining industry sector. The World Bank is very active with the Bolivian government in the formulation of its environmental regulations as well as assisting in the assessment of the cleanup, and funding thereof, of old and existing mines. It is perceived that the resultant environmental regulations will be close to international standards, and will probably be very close to those of the World Bank. There are several positive environmental actions currently taking place in Bolivia to promote foreign investment. For example, the Swedish Geological Society is currently conducting baseline environmental studies in Bolivia.

As it is presently envisioned, the Ministry of Sustainable Development and Environment will be the lead agency for environmental matters. It is unclear at this time what roles other agencies, including the Ministry of Mines, will play regarding environmental matters for the mining industry.

#### 17.3.3.2 Chile

Environmental regulations pertaining to the mining industry in Chile are in a dynamic state and are evolving rapidly. The legal framework for Chile's environmental regulations was passed in March 1994. This framework sets forth responsibilities under the guidance of the National Committee for the Environment to the respective agencies for enforcement, monitoring and administering of environmental regulations. The intent of this legislation is to streamline the environmental permitting process. In the past, the various environmental laws and standards relevant to the mining industry are quite complex, often overlapping between ministries and agencies and lacking a clear cut process. The jurisdiction limits between each ministry or agency are not clearly defined sometimes resulting in inter-agency conflicts. Chile has an estimated 2,000 regulations for environmental issues addressing specific industries. Most of these focus on sanitation and property ownership, with only a few addressing air and water quality and emission standards.

There are several governmental agencies that currently administer environmental regulations pertaining to the mining industry in Chile. Under this system, there exist overlaps between agencies resulting in the duplication of environmental jurisdiction. Primary environmental agencies in Chile include:

*Servicio Nacional de Geologia y Minera* (SERNAGEOMIN): approval of mining method, tailings dam construction, waste dumps, and heap leach projects.

*Superintendencia de Servicios Sanitarios*: control of

liquid industrial residues.

*Ministry of Public Health*: monitors the quality of drinking water and air quality, food, the work environment, and public health.

*Ministry of Public Works* comprised: General Water Authority oversees compliance with the Water Code, and National Water and Waste Works Service monitors drinking water quality and sewage.

*Ministry of Agriculture* comprised: National Forestry Corporation for land and wildlife protection; Division of Protection of Reusable National Resources sets out legal regulations of air, water and soil; and Agricultural and Ranching Service for monitoring sanitary conditions and enforcing laws on hunting.

*Ministry of National Property* operates in agreement with other ministries to protect the biosphere and ecological problems.

*Ministry of Labor* monitors working conditions in agreement with the Ministry of Mines and the Ministry of Public Health.

*National Planning Office* is an agency of the President that coordinates working and development plans for various environmental related projects.

*Servicio Regional de Salud*: Environmental Impact Report, sewage and waste disposal system approval.

#### 17.3.3.3 Mexico

The power and authority for environmental matters in Mexico are jointly held by the Federal, State and Local governments. Almost of all Mexico's 31 states have adopted some form of environmental laws. However, at this time, the mining industry is being regulated by Federal environmental laws and regulations enforced by Federal authorities. In essence, Mexico's industries are regulated by the three environmental laws: 1) the Maquiladora Decree, 2) the United States-Mexico Border Environmental Agreement, and 3) the General Law of Ecological Balance and Protection to the Environment (LGEEPA). LGEEPA, which took effect on March 1, 1988, provides the legal framework and general guidelines for the formulation of environmental regulations and standards in accordance with the Mexican Constitution, and is the primary legislation pertaining to the mining industry. Currently, SEDESOL, CAMIMEX (representing the interests of the private mining industry sector), and SEMIP (representing the interests of the government for development of the mining industry) are in the process of formulating environmental regulations and standards for the mining industry with the assistance of outside organizations such as the World Bank. It is believed that the majority of the environmental regulations and standards will be issued by SEDESOL that will be comparable to World Bank and internationally accepted standards.

Ministry of Social Development (SEDESOL) [Note: Successor to Secretaria de Desarrollo Urbano y Ecologia (SEDUE)] has the objective to establish departments within the Federal Government for dealing with environmental pollution and the depletion of natural resources. SEDESOL's environmental functions are divided between two autonomous agencies: 1) National Ecology Institute (INECO), and 2) the Office of the Attorney General for Environmental Protection. INECO is responsible for researching, formulation, establishing and evaluating Mexico's environmental standards, policies, and programs; conservation of natural resources; and increasing technical expertise at the respective state levels.

The Office of the Attorney General for Environmental Protection is responsible for enforcement of LGEEPA, environmental regulations and standards; investigation, prosecution, and resolution of non-compliance with environmental regulations and standards; providing support for state and local environmental authorities; and responding to public complaints and demands regarding environmental non-compliance and activities harmful to the environment.

In addition to SEDESOL, other ministries and agencies with specific areas of environmental responsibilities include the Ministry of Agriculture and Water Resources, Secretary of Salubridad and Asistencia, Secretary of Pesca, Secretary of Communications and Transportation, and Secretary of Tourism.

#### 17.3.3.4 Peru

In 1993, environmental legislation was enacted establishing Peru's national environmental protection agency, Consejo Nacional de Medio Ambiente (CONAMA). At present, this legislation is not being enforced. Simultaneously, this legislation established a national environmental system, Sistema Nacional Ambiento (SNA). Under this system, CONAMA will act as the national environmental agency overseeing and interfacing with DGAA, regional and local government levels through SNA. Environmental legislation in the form of The Codigo del Medio Ambiente ("the Code") was originally passed in September of 1990. The Code was disputed by both mining companies and environmental groups as it provided no objective standards by which to measure environmental compliance. This legislation was revised by the Peruvian government in 1993. This legislation provides the basis for environmental controls and standards. Additional

guidance to specific guidelines or maximum allowable limits are being developed. There are two basic environmental issues associated with the Peruvian mining industry: 1) environmental cleanup of existing mining and metallurgical operations and 2) control of future emissions from existing and new operations.

The lead environmental regulatory entity for the mining and metallurgical industries is the Ministry of Mines. "Direccion Generales de Asuntos Ambientales" (DGAA), an agency of the Ministry of Mines and Energy, is charged with administration of environmental regulations. DGAA was created with the responsibility for developing environmental policies and the legal framework for the mining, metallurgical and electricity industries. In addition to DGAA, there are primarily five other regulatory authorities with environmental responsibilities which could impact a mining project. These are Ministry of Agriculture; Ministry of Health; Ministry of Industry; Instituto Nacional del Proteccion del Medio Ambiente (INAPMAS), an affiliate of the Ministry of Health for occupational health and safety); and Officina Nacional de Evaluacion de Recursos Naturales (ONERN), an agency related to the Ministry of Agriculture for national resource use planning.

#### 17.3.3.5 Venezuela

Environmental regulations and standards in Venezuela cover all aspects (air, water, waste management/hazardous materials, reclamation/closure plans) of environmental protection in Venezuela. Many of these regulations and standards are set for specific areas or environmental concerns (for example, discharges into or from a specific lake or waterway). These regulations tend to be more qualitative, rather than quantitative. The Organic Law of the Environment contains a series of chapters relating to environmental control and reclamation of areas relating to mining activities. In order to be granted authorization for mine development, the developer must prepare a series of environmental studies (in effect, an Environmental Impact Statement) requested by the Ministry of Environment. These studies must be completed by a Forestry Engineer duly registered in the Engineering College and backed by a financial guarantee. The studies must address specific areas including complete details related to the development of the mine, areas which will be affected by waste and ore movement, original and final topographies, reclamation plan and final program for reforestation. Environmental compliance for a specific mining operations is ultimately based on the acceptance of and conformance to the approved environmental studies. The "standards" for these studies are continuing to evolve.

Regional offices of the Ministry of Environment are charged with environmental matters relating to mining development under the aforementioned Organic Law of the Environment. Authorization for mining development must also be received from the regional Ministry of Energy and Mines office.

#### 17.3.3.6 Conclusions

Each of the selected countries is taking essential steps in implement environmental regulations and standards for the mining industry.

| Country | Remarks/Comments |
|---|---|
| Bolivia | In transition — new Environmental Law No. 1333 passed in 1992; regulations and standards being drafted by Counsel for Sustainable Development. |
| Chile | Rapidly evolving — legal framework for environmental legislation was recently passed in March 1994 with the National Committee for the Environment in charge of delegating responsibilities for Chile's various industries. Numerous agencies in place for monitoring and enforcing Chile's environmental regulations. |
| Mexico | Being formulated by representatives of SEDESOL, CAMIMEX, AND SEMIP. It is envisioned that the majority of the new environmental regulations and standards will be issued. |
| Peru | In transition — recent establishment of CONAMA as Peru's national environmental protection agency and SNA as national environmental system. Ministry of Mines and Energy will continue to be lead agency responsible for developing environmental policies and the legal framework for the mining, metallurgical and electricity industries. |
| Venezuela | Submission of and conformance to environmental studies is important consideration to mine development. "Standards" for these studies are continuing to evolve. |

### 17.3.4 ASIA AND PACIFIC RIM COUNTRIES
**by D. Malhotra**

Environmental regulations for selected countries are summarized in Table 3.

The following section presents an overview for these countries.

**Table 3** Environmental Regulations in Asia-Pacific Rim Countries

| Country | Status of Environmental Regulations and Standards | Regulatory/Permitting Agencies |
|---|---|---|
| China | Protection Law of 1989<br>Law on the Prevention and Control of Air Pollution, 1987<br>Law on the Prevention and Control of Water Pollution, 1984<br>Regulations on the Prevention and Control of Noise Pollution, 1989 | Environmental Protection Agency |
| India | Mining Act of 1957 and subsequent amendments legislate environmental protection<br>Water (Prevention and Control of Pollution) Act 1974 (latest amendment, 1988)<br>Air (Prevention and Control of Pollution) Act 1981 (latest amendment, 1988)<br>Environmental (Protection) Act 1986<br>Forest (Conservation) Act 1980 (amended 1988) | Ministry of Environment and Forests |
| Indonesia | Mining Law 1967, Article 30<br>Environmental Management Act 1982<br>Regulation 29/1986 covers environmental impact<br>Act 11/1974 regulates water pollution/quality<br>Regulation 20/1990 covers management of polluted waters | Ministry for Population and Environment |
| Malaysia | Mining Enactment FMS Cap. 147<br>Environmental Quality Act 1974 | Department of Mines; Ministry of Science, Technology and the Environment |
| Papua New Guinea | Environmental Planning Act, 1978<br>Environmental Contaminants Act, 1978<br>Conservation Areas Act, 197<br>Water Resources Act, 1982<br>National Parks Act, 1982 | Department of Environment and Conservation |
| Thailand | National Reserved Forest Act, 1964<br>Improvement and Conservation of National Environmental Quality Act, 1975 (amended 1978) | Ministry of Agriculture and Cooperatives<br>National Environmental Board |

#### 17.3.4.1 China

China is rich in mineral resources. There are about 120,000 mines, of which about 6,000 are large-scale, state-owned mines. Prior to 1980, the mining industry and the government emphasized the production of metals needed for the development of China's economy and neglected environmental and technological issues. Hence, the negative environmental effects are due to obsolete technology and work practices.

Though China has an Environmental Protection Agency, it has not enforced approved environmental practices in the mining sector. It is considering adopting the United States EPA model for the mining sector.

#### 17.3.4.2 India

The mining industry in India was primarily government-owned. However, small-scale mining is privately owned. There are estimated to be over 4,400 mines exploiting 52 minerals. The government changed its mineral policy in 1993 with the idea of privatizing the mining sector. For the first time, majority foreign ownership is allowed in India. The government is attempting to develop a "one-window" approach for sanctioning environmental permits for new projects. An application for a mining lease must contain an environmental management plan within the mining plan. The management plan should cover baseline information, an environmental impact statement, and an environmental management plan. An assessment of the environmental impact of the proposed mining operation, as well as remediation and rehabilitation strategies, are required. Descriptions of monitoring procedures and mechanisms are also required. Generally, the leases are granted in three to six months, unless the land under consideration is in forest or other sensitive areas.

In order to encourage good environmental practices,

the government provides incentives such as income tax exemptions and an accelerated depreciation allowance for monitoring equipment. However, in case of environmental damage, the law permits heavy fines and, if justified, jail sentences.

#### 17.3.4.3 Indonesia

The government of Indonesia mandates that mineral exploration be done in harmony with the environment. It has developed mandatory measures related to environmental aspects of mining operations; hence, all mining companies are required to present environmental assessment reports.

Several additional regulations besides those given in Table 17-3 have been enacted by the government. At present, no specific legislation exists for air quality, but draft standards are being reviewed and would be enacted in the near future.

Though a well-established system of fines and penalties is in effect for failing to meet mandatory environmental standards, a severe shortage of technical personnel in environmental management makes it difficult to enforce these regulations. The problems of enforcement were compounded by the fact that the number of small-scale gold mines, mostly illegal, was estimated at more than 150,000 at the peak of gold mining activity.

#### 17.3.4.4 Malaysia

Malaysia had 168 mines operating in June 1991. All 13 states and two federal territories have their own mining laws. The Mining Enactment, FMC Cap. 147, is common to all the states and encompasses environmental issues related to proper management of water and operation of mines in a safe and orderly manner not causing damage to occupiers of other lands. The Environmental Quality Act of 1974 is applicable to mining only if the operation covers more than 250 hectares. It is mandatory to submit an environmental impact assessment for approval to the Director General of the Environment for any new project in the mining area.

#### 17.3.4.5 Papua New Guinea

Modern exploration started in the 1960's with the development of the Panguna deposit on Bougainville, though the first gold rush occurred in 1878. The history of environmental regulation in the country closely follows that of Australia.

Mining-related environmental matters are legislated under several acts listed in Table 3. Before a mining license is issued, an environmental plan detailing measures for environmental safeguarding, as well as rehabilitation plans, must be submitted as part of the feasibility study to the Department of Environment and Conservation.

The government requires that operating companies be responsible for their own environmental monitoring program. The reason is that the government does not have either trained personnel or funds to do so itself. The companies submit the reports twice a year, and government officials visit the mine site periodically.

#### 17.3.4.6 Thailand

The mining industry is state-owned and exploration and development are managed by the Department of Mineral Resources (DMR). Prior to actual mining activity, a mining lease is required. An environmental impact assessment (EIA) must be presented along with the lease application to the DMR. If the EIA meets the requirements of the DMR, it will forward the report to the Office of the National Environmental Board (ONEB) for approval. ONEB will outline environmental conditions to be followed by the operator as part of the approval. Hence, these conditions become part of the lease and are incorporated into the mining plan.

#### 17.3.4.7 Other Asian Countries

There are several countries in the region where either mineral resources have not been exploited or they do not contribute significantly to economic development. Hence, mining and environmental laws are in their infancy. These countries include Afghanistan, Bangladesh, Nepal, Pakistan, Sri Lanka, and Vietnam. Environmental regulations are currently being developed with the assistance of the United Nations or other non-profit organizations.

### 17.3.5 AUSTRALIA

Mining in Australia is controlled by state laws rather than at the national level. The environmental regulation system, though not as comprehensive as in the United States, has developed considerably in recent years. All states require EIS's when issuing mining permits. Selected areas such as nature preserves, aboriginal, and pastoral regions are not available for mineral exploration and development.

The general pattern of environmental controls is similar to those in the United States. Separate statutes exist for air pollution, water pollution, and waste disposal. Rehabilitation of the land surface following mining activity is mandatory. A bond is generally required to ensure that rehabilitation measures will be carried out.

### 17.3.6 AFRICA AND THE CIS COUNTRIES

Environmental laws in most of these countries, with the exception of South Africa, are in their infancy. In some countries, such as Zambia and Zaïre, laws may exist on paper, but are difficult to implement for several reasons. Most of the mines are designated as small-scale operations; miners/entrepreneurs are not formally trained in the use of modern technology for geological exploration, processing, and environmental safeguarding of land, water, and air — nor can they afford to spend capital for mitigation of environmental problems; and government policies/bureaucracy encourage illegal mining.

Recently, government policies have shifted toward privatization of mining activity and formulation of environmental policies related to mining activity. The laws are being formulated based on what the industrialized countries are doing. Privatization, especially in the CIS countries, is resulting in multi-national mineral companies forming joint ventures for exploration and development of resources. The joint venture partners will hopefully help in formulating environmental guidelines and implementing mitigation of environmental problems in mining. However, the general trend is to use the World Bank environmental guidelines as the base case; these guidelines are given in Appendix III. Several countries may have implemented stricter guidelines. The problem, as discussed earlier, is with the implementation and enforcement of the regulations.

As stated earlier, the sources of pollution problems remain the same, regardless of the location of the mine. The level of the contamination problem varies depending on the design considerations, selection of proper equipment, and mitigation efforts incorporated into the design and planning phase of development of the mineral resource.

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## Appendix I
## Mining and Environmental Guidelines adopted at The International Roundtable on Mining and the Environment

*June 1991, Berlin, Germany (United Nations, 1992a)*

### 1. Environmental Management Guidelines for Mining

Worldwide long-term economic development can best be achieved through the pursuit of sustainable development policies comprising a balance of economic, socio-cultural, and environmental protection measures. While taking into account global environmental concerns, each country should apply this concept to meet the needs of its environmental and economic circumstances.

Sustainable mining activities require good environmental stewardship in all activities, from exploration and processing to decommissioning and reclamation. Sustainability acknowledges the importance of integrating environmental and economic considerations into the decision-making process and the fact that the mineral deposits are unique in their occurrence. It recognizes the importance of mining to the social, economic, and material needs of society, in particular for developing countries, and that minerals, notably metals, offer great potential for use by future generations through increased recycling programs.

Sustainable mining under appropriate environmental guidelines is based on interaction between industry, governments, nongovernmental organizations, and the public, directed toward optimizing economic development while minimizing environmental degradation. The need for such guidelines is recognized by industry, governments, and international agencies. It is also recognized that the political will of governments, together with the commitment of industry management and of the community, are the essential conditions needed to enforce environmental legislation, and more importantly, to ensure compliance with all applicable laws for the protection of the environment, employees, and the public.

### 2. Environmental Guidelines for Action Addressed to the Mineral Sector

Governments, mining companies, and the minerals industries should, as a minimum, do the following:

1. Recognize environmental management as a high priority, notably during the licensing process and through the development and implementation of environmental management systems. These should include early and comprehensive environmental impact assessments, pollution control and other

preventive and mitigative measures, monitoring and auditing activities, and emergency response procedures.

2. Establish environmental accountability in industry and government at the highest management and policy-making levels.

3. Encourage employees at all levels to recognize their responsibility for environmental management and ensure that adequate resources, staff, and requisite training are available to implement environmental plans.

4. Ensure participation and dialogue with the affected community and other directly interested parties on the environmental aspects of all phases of mining activities.

5. Adopt best practices to minimize environmental degradation, notably in the absence of specific environmental regulations.

6. Adopt environmentally sound technologies in all phases of mining activities and increase the emphasis on the transfer of appropriate technologies that mitigate environmental impacts, including those from small-scale mining operations.

7. Seek to provide additional funds and innovative financial arrangements to improve the environmental performance of existing mining operations.

8. Adopt risk analysis and risk management in the development of regulations and in the design, operation, and decommissioning of mining activities, including the handling and disposal of hazardous mining and other wastes.

9. Reinforce the infrastructure, information systems service, training, and skills in environmental management in relation to mining activities.

10. Avoid the use of such environmental regulations that act as unnecessary barriers to trade and investments.

11. Recognize the linkages between ecology, socio-cultural conditions, and human health and safety, within both the workplace and the natural environment.

12. Evaluate and adopt, wherever appropriate, economic and administrative instruments such as tax incentive policies to encourage the reduction of pollutant emissions and the introduction of innovative technology.

13. Explore the feasibility of reciprocal agreements to reduce trans-boundary pollution.

14. Encourage long-term mining investment by having clear environmental standards, with stable and predictable environmental criteria and procedures.

## 3. Environmental Guidelines for Action Addressed to Development Assistance Agencies

Multilateral and bilateral assistance agencies have an essential role to play in furthering environmental management, particularly in developing nations, and in assisting these nations in programs to protect their environment, both nationally and as part of the global environmental system. Accordingly, they should do the following:

1. Accord high priority to the mitigation of environmental degradation associated with mining in developing countries to achieve high environmental performance.

2. Initiate, as an integral part of any exploration and mining project, environmental institution-building programs. Special support should be given to countries actively working to improve their environmental capabilities.

3. Require that all mining projects supported shall contain a training component that will include specific training on environmental awareness and its application to the mining sector.

4. Support increased research regarding the development of new processes with fewer environmental impacts, including recycling.

5. Support the development of activities that would mitigate adverse effects on the socio-cultural fabric and the ecosystem. To achieve this objective, international agencies should give priority to education and training that increase awareness of these issues and allow the affected communities to participate in decision-making.

6. In supporting mining projects, agencies should also take into account the following:

   Rehabilitation of populations displaced as a result of proposed project activity.

Environmental history of the country.
Large-scale impact on socio-cultural patterns of the affected population.
The overall economic balance of the project vis-à-vis its total environmental impact.
The impact on other natural resources and fragile, ecologically sensitive areas, e.g. protected forest lands, mangroves, wildlife parks, and neighboring water bodies, including the sea.

7. Promote conferences and policy research on environmental management practices and technologies and ensure the dissemination of this information.

8. Support and promote regional cooperative programs to achieve sustainable development of mineral resources.

9. Adopt environmentally safe methods of mining and processing for existing projects.

10. Increase and coordinate their assistance to developing nations in the field of environmental policy management.

## Appendix II
## List of Recommendations for Environmental Management of Mining and Mineral Resource Development for Consideration of ESCAP
*(United Nations, 1992a)*

ESCAP should

1. Encourage member countries to give priority to funding and implementing training programs in the environmental aspects of mineral resource development.

2. Encourage and assist its members to establish local-level information programs to develop the knowledge and attitudes required for the population to support environmental legislation and to develop an understanding of mining-related issues.

3. Develop mining environmental training programs designed to focus on three levels, namely, regional, national, and local, and to address both the specific skills and the interdisciplinary management capabilities required to integrate social, cultural, economic, technical, and environmental considerations.

4. Continue to organize workshops, seminars, and training courses on the environmental aspects of mining and mineral resource development.

5. Conduct study tours, technical missions, and field trips to countries that either have specific problems or that can demonstrate solutions to those issues, so as to encourage the transfer of technology and training.

6. Assist in establishing national training resource centers for mining and the environment.

7. Provide assistance in the development and impact assessment of environmental legislation in concerned countries.

8. Review institutional arrangements with regard to implementation and enforcement of mining environmental legislation among concerned countries so as to avoid overlap and duplication of effort.

9. Assist in the establishment of mechanisms for improving communication and cooperation within the mining sector at the national, provincial, district, and community levels.

10. Review the progress in the region with regard to the development of economic marketing and financial instruments for environmental management of mining operations for large-, intermediate-, and small-scale mining.

11. Assist concerned countries with a review of artisanal and small-scale mining issues.

12. Review the present status of and identify available options with regard to economic instruments to encourage long-term reclamation and decommissioning of mines.

13. Assist the member countries in implementing the Berlin guidelines for action in the mineral sector.

14. Encourage member countries to exchange information and expertise on environmental management in the mining sector on the basis of technical cooperation among developing countries.

15. Assist member countries to ensure that the mining sector is sustained through the development of efficient operations that protect the environment and use the maximum amounts of the available mineral resources with a minimum of waste.

## Appendix III
## World Bank Environmental Guidelines for Mining and Milling — Open Pit

### Tailings Disposal

Tailings must be disposed of in a manner that optimizes protection of human safety and the environment. On-land tailings impoundment systems must be designed and constructed in accordance with internationally recognized engineering practices, local seismic conditions, and precipitation conditions. On-land disposal systems should be designed to isolate acid leachate-generating material from oxidation or percolating water. Marine discharges of tailings must not have significant adverse effect on coastal resources. Riverine discharges are not acceptable unless the project sponsor provides thorough documentation regarding: 1) environmental analysis of alternatives, and 2) effects on aquatic resources and downstream users of riverine resources.

If the mining operation involves a series of open-pit operations, project sponsors must evaluate the feasibility of using abandoned open pits for tailings disposal.

#### *Liquid Effluents*

The following are guidelines for effluent discharged to receiving waters from tailings impoundments, mine drainage, sedimentation basins, sewage systems, and stormwater drainage. They do not apply to direct discharge of tailings to the marine environment.

| | |
|---|---|
| pH | 6 to 9 |
| BOD3 | 50 mg/l |
| Total suspended solids | 60 mg/l |
| Oil and grease | 10 mg/l |

Temperature Maximum of 5 degrees C above ambient (3 degrees C above ambient if receiving waters are greater than 28 degrees C) within a designated mixing zone

#### *Residual Heavy Metals*

The following are recommended target guidelines below which there is expected to be no risk for significant adverse impact on aquatic biota or human use. In cases where natural background concentrations exceed these levels, the discharge may contain concentrations up to natural background levels. Concentrations up to 110% of natural background can be accepted if no significant adverse impact can be demonstrated.

| | |
|---|---|
| Arsenic | 1.0 mg/l |
| Cadmium | 0.1 mg/l |
| Chromium (total) | 1.0 mg/l |
| Chromium (hexavalent) | 0.05 mg/l |
| Copper | 0.3 mg/l |
| Iron (total) | 2 mg/l |
| Lead | 0.6 mg/l |
| Mercury | 0.002 mg/l |
| Nickel | 0.5 mg/l |
| Zinc | 1.0 mg/l |

#### *Cyanide*

The following are recommended target guidelines below which there is expected to be no risk for significant adverse impact on aquatic biota or human use. In no case should the concentration in the receiving water outside of a designated mixing zone exceed 22µg/l (0.022 mg/l).

| | |
|---|---|
| Total | 1.0 mg/l |
| Weak acid dissociable | 0.5 mg/l |
| Free | 0.1 mg/l |

### Ambient Air Quality

#### *Particulates*

All components of above-ground material handling equipment such as belt conveyors and crushing systems should be covered, and all transfer points should be equipped with a suitable dust collector or other dust suppression measures. Ambient air qualityshould not exceed the following criteria for particulates (dust):

| | |
|---|---|
| Annual geometric mean | 100 $\mu g/m^3$ |
| Maximum 24-hour peak | 500 $\mu g/m^3$ |

#### *$SO_2$*

a) *Inside plant fence*:

| | |
|---|---|
| Annual arithmetic mean | 100 $\mu g/m^3$ |
| Maximum 24-hour peak | 1000 $\mu g/m^3$ |

b) *Outside plant fence*:

| | |
|---|---|
| Annual arithmetic mean | 100 $\mu g/m^3$ |
| Maximum 24-hour peak | 500 $\mu g/m^3$ |

#### *$NO_2$*

| | |
|---|---|
| Annual arithmetic mean | 100 $\mu g/m^3$ |

### Other Environmental Requirements

#### *Erosion and Sediment Control Plan*

Project sponsors are required to prepare and implement an erosion and sediment control plan. The plan should include measures appropriate to the situation to intercept,

divert, or otherwise reduce the stormwater runoff from exposed soil surfaces, tailings dams, and waste rock dumps. Project sponsors are encouraged to integrate vegetative and non-vegetative soil stabilization measures in the erosion control plan. Sediment control structures (e.g., detention/retention basins) should be installed to treat surface runoff prior to discharge to surface water bodies. All erosion control and sediment containment facilities must receive proper maintenance during their design life.

### *Mine Reclamation Plan*

Project sponsors are required to prepare and implement a mine reclamation plan. The plan should include reclamation of tailings deposits, any open pit areas, sedimentation basins, and abandoned mine, mill, and camp sites. The main objectives of the mine reclamation plan are:

- return the land to conditions capable of supporting prior land use or uses that are equal to or better than prior land use, to the extent practical and feasible; and
- eliminate significant adverse effects on adjacent water resources.

Mine reclamation plans should incorporate the following components:

- conserve, stockpile, and use topsoil for reclamation
- slopes of more than 30% should be recontoured to minimize erosion and runoff;
- native vegetation should be planted to prevent erosion and encourage self-sustaining development of a productive ecosystem on the reclaimed land;
- budget and schedule for pre- and post-abandonment reclamation activities
- plan views that show areas cleared, mined, refilled, and revegetated during each of the next 5 years and estimated activities at subsequent 5-year intervals.

### *Sewage Sludge Disposal*

Sewage sludge must be disposed of in an environmentally acceptable way in compliance with local laws and regulations. Project sponsors are encouraged to evaluate the environmental and health implications of using sewage sludge in reclaiming tailings deposits, waste rock dumps, and mined -out areas.

### *Solid Wastes Disposal*

Project sponsors will be encouraged to recycle or reclaim materials where possible. If recycling or reclaim is not practical, these wastes must be disposed of in an environmentally acceptable way in compliance with local laws and regulations. Solvents and similar hazardous materials must not be disposed of in a manner likely to result in soil or ground water contamination if groundwater is potentially useable for potable water or irrigation purposes. Waste rock dumps should be designed and engineered so that materials with high potential to generate acid leachate are isolated from oxidation or percolating water.

# Chapter 18

# ENVIRONMENTAL CASE STUDIES FROM THE HARD ROCK INDUSTRY

edited by F. R. Banta

## 18.1 INTRODUCTION

The five case studies presented in this chapter are examples of the efforts undertaken to correct impacts from past mining operations, to permit new mining operations and to set public policy regarding how hard rock mining is to be performed in the United States. These are good examples of how some of the toughest environmental issues have been handled by both the government and private sector. A brief description of each of the case studies is provided below.

The Iron Mountain case study, written by Kirk Nordstrom, discusses the Environmental Protection Agency's effort to clean up mine waste and acid drainage in Shasta County, California. The case describes efforts to define the problem and to develop technical solutions.

The Summitville case study, written by John Gormley and Barbara Filas, presents a history of the Summitville Mine and examines causes of a business and regulatory failure that occurred in the late 1980s and early 1990s. This study helps to put in perspective this much publicized case by providing background and technical information obtained from the public records.

Edward Haase, et al. describe the approach that Phelps Dodge took to control the generation of dust from tailings near Ajo, Arizona. The study, titled "Applying a Crushed Rock Veneer to Control Dust on Dry Tailing," is a good example of steps taken by a company to define a problem and seek appropriate solutions.

In their case study describing the permitting of the Alaska-Juneau Mine, Wade Martin and Lisa McDonald describe the complexity of obtaining approvals when several government jurisdictions are involved. The case highlights some of the pitfalls when trying to obtain approvals. These include issues regarding land ownership, overlapping jurisdictions and changes in the regulations during the permitting process.

"Oregon - Things Look Different Here" was written by Ivan Urnovitz. This case study describes the political process that unfolded during the development of the Oregon law which regulates chemical process mining. The case study is a good example of how groups work within the political process. It also provides lessons that may be useful for individuals and groups involved in legislative initiatives.

## 18.2 IRON MOUNTAIN

**by D. K. Nordstrom**

### 18.2.1 INTRODUCTION

Iron Mountain is located in Shasta County, California, approximately 9 miles northwest of the town of Redding (Figure 1) along the southeastern border of the Klamath Mountains. "Iron Mountain Mine" is really a collection of mines within Iron Mountain that include Old Mine, No. 8 Mine, Confidence-Complex, Brick Flat Open Pit, Mattie Mine, Richmond and Richmond Extension Mine, and Hornet Mine. Gold, silver, copper, zinc, iron, and pyrite were mined at various times during a one-hundred-year period beginning in the early 1860s and ending with the termination of open-pit mining in 1962. Iron Mountain was the largest producer of copper in the state of California, and now it produces some of the most acidic waters in the world. Approximately 730 tons of dissolved copper, zinc, and cadmium drain into Spring Creek every year, ultimately entering the Sacramento River below Shasta Dam and above Keswick Dam (Figure 1). At the confluence point of Spring Creek with the Sacramento River, the acid waters are neutralized upon mixing, the metals are precipitated, and large sediment piles have formed in Keswick Reservoir (Prokopovich, 1965). Metal discharges from Iron Mountain pose a potential threat to the residents of Redding, California because their source of drinking water is the Sacramento River below Keswick Dam. During periods of high runoff, sudden surges of acid mine waters into the Sacramento River have caused massive fish kills which state and federal agencies have investigated since 1939. The site was officially listed on the National Priorities List as a Superfund site in 1983 and has undergone partial remediation. Final remediation for the Boulder Creek Operable Unit is currently

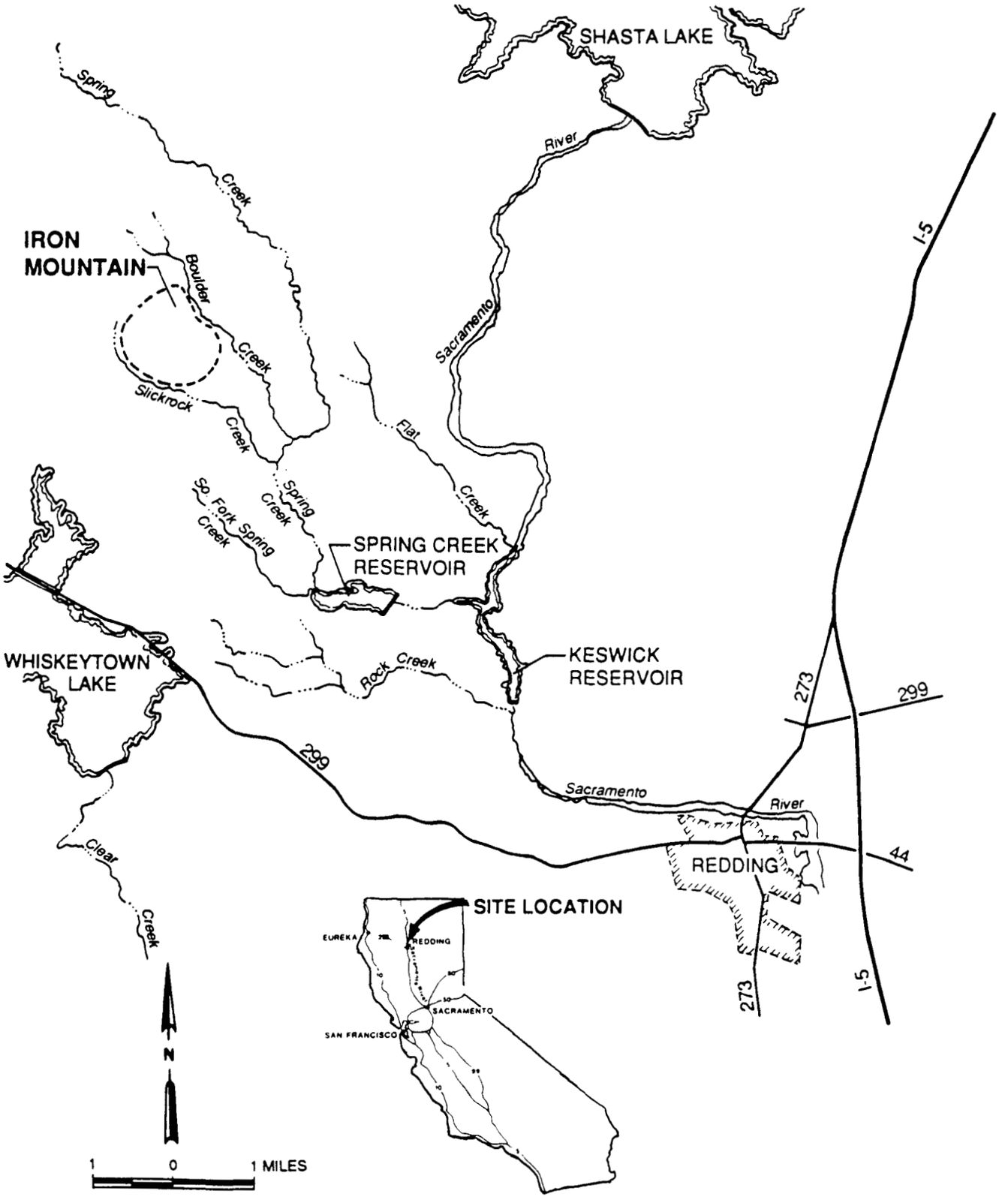



**Figure 1** Location of Iron Mountain Site.

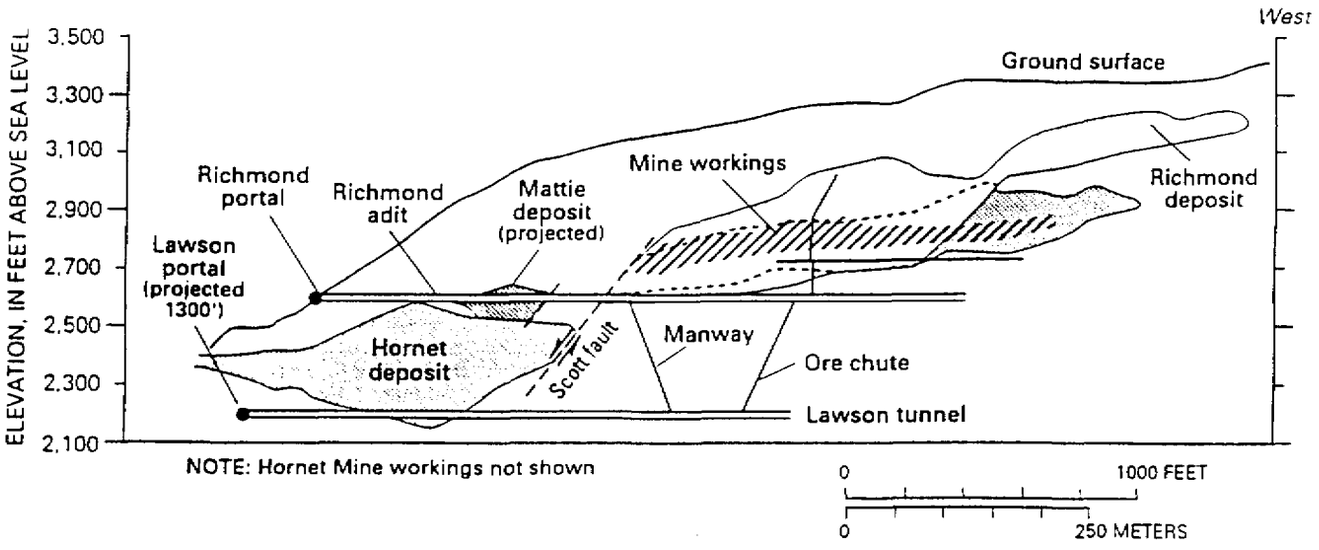



**Figure 2** Cross section through Iron Mountain, showing location of Richmond and Hornet Deposits, Richmond Adit, and Lawson Tunnel.

underway based on a second Record of Decision reached in September, 1992. Remediation on two more operable units is being planned.

### 18.2.2 HYDROLOGY AND GEOLOGY

The topography of Iron Mountain is steep and rugged; Iron Mountain rises about 3000 feet above the Sacramento Valley (approximately 3585 feet above sea level). The summers are hot and dry, the winters cool and rainy with occasional snow. Average annual rainfall at the top of Iron Mountain is estimated to be about the same as that measured at Shasta Dam: 60 inches over a 47- year period (range on annual average for 1944-90 is 28-130 inches; Alpers and others, 1992). Slickrock Creek and Boulder Creek drain the south and north sides of Iron Mountain, respectively. These two tributaries of Spring Creek carry the acid mine drainage and eroding waste and tailings piles from the mountain and the Spring Creek drainage transports them to the Sacramento River (Figure 1).

Before reaching the Sacramento River, Spring Creek is retained by the Spring Creek Debris Dam built in 1963 as part of the Central Valley Project. The releases from this dam are metered at an amount that should be sufficiently diluted by Shasta Dam releases so that no fish kills should occur. On several occasions since 1963, however, the capacity of Spring Creek Reservoir has been exceeded and uncontrolled releases over the spillway have caused fish kills. During February/March, 1992, an additional 100,000 acre-feet of water were released from Shasta Dam to provide the necessary dilution of a Spring Creek Reservoir spill and to prevent fish kills below Keswick Dam on the Sacramento River. This event occurred when deliveries of water to farmers from the Central Valley Project were at an all-time low due to 6 years of consecutive drought, so the cost to the U.S. Bureau of Reclamation in terms of lost revenue was substantial. Natural landslides as well as erosion of waste piles and tailings piles has also occurred on the 4,400 acres of mining property.

The mineral deposits are primarily massive sulfides, composed of large single masses of up to 95% pyrite with variable amounts of chalcopyrite and sphalerite to average about 1% copper and about 2% zinc. Some disseminated sulfides occur along the south side of Iron Mountain. Trace quantities of several other metals and metalloids occur in the mineral deposits including gold, silver, lead, cadmium, arsenic, antimony, vanadium, cobalt, and thallium (based on relative concentrations of these constituents in the acid effluent). The deposits are of the Kuroko type having been formed along an island-arc in a marine environment (Albers and Bain, 1985). The country rock is the Balaklala rhyolite, a spilitized Devonian rhyolite that has undergone regional metamorphism during episodes of tectonic collisions of oceanic crust with continental crust. The nature of the altered igneous bedrock gives rise to a predominance of fracture-flow hydrology at Iron Mountain. The Copley greenstone, an altered basalt, underlies the rhyolite and is approximately contemporaneous. Part of the region shown in Figure 1 to the south of Iron Mountain is the Mule Mountain stock, a trondhjemite-albite granite, considered to be cogenetic with the Balaklala rhyolite (Albers and others, 1981).

The mineral composition of the rhyolite is albite, sericite, quartz, kaolinite, epidote, chlorite, and minor calcite. Studies by Kinkel and others (1956), by Reed

(1984), and those in the special issue of Economic Geology (1985, vol. 80, no. 8) have documented the chemical composition of both the ore minerals and the non-ore minerals. These studies also provide information on relative abundances of minerals and isotopic compositions.

Weathering of massive sulfides near the surface has given rise to a large gossan outcrop at the top of Iron Mountain, enriched in gold and silver. The extent of the exposure suggests that significant quantities of sulfides were oxidized during weathering and eroded before humans discovered the site. Some of the gossan material is found several hundred feet below the surface (Kinkel, and others, 1956). Secondary enrichment in the upper zones of the massive sulfides and just below the gossan resulted in high concentrations of copper (5-10%) and silver (about 1 oz/ton). These observations suggest that large quantities of metals have been mobilized over geologic time.

Three main massive sulfide mineral bodies, known as the Brick Flat, the Richmond, and the Hornet occur at Iron Mountain. These are thought to have been a single massive sulfide body about a half-mile long (well over a half-mile if the offset Old Mine mineral deposit is included) over 200 feet wide and over 200 feet high but offset by two normal faults (see Figure 2). All three of these bodies have been mined and the consequences of mining include altered groundwater conditions and highly contaminated surface waters originating from portal effluent waters.

### 18.2.3 MINING HISTORY

A brief history of mining has been compiled from the review by Kett (1947), the reports of CH2M Hill contracted to the U.S. Environmental Protection Agency (EPA), and various publications of the California Department of Mines and Geology.

Gossan outcropping was discovered in the 1860s and Iron Mountain was secured as an iron mine, although nothing was mined at that time. It was not until 1879 with the discovery of silver in the gossan that plans for mining began. From 1879 to 1894 silver was mined from the gossan by three partners and in 1894 it was sold to British interests who formed the Mountain Mining Company, Ltd. in 1895. Large massive sulfide deposits were discovered beneath the gossan in 1895, and smelters were built at nearby Keswick to process the ore which was transported on a narrow-gauge railroad from Iron Mountain to Keswick. In 1897, the property was transferred to Mountain Copper Company, Ltd. of London, which maintained the operations until 1967 when it was purchased by Stauffer Chemical Company. Iron Mountain Mines, Inc. took over the property from Stauffer at the end of 1976.

Copper mining ceased in 1919 due to a decrease in the market price of copper and only very limited and intermittent copper mining took place until World War II, when the U.S. Government subsidized the production of copper and zinc. About 5.2 million tons of sulfide ore have been mined by underground methods from Iron Mountain. From 1955 to 1962, 9.5 million tons of waste from the top of Iron Mountain was removed, and an 600,000 tons of pyrite was open-pit mined for sulfuric acid production. More than 2.6 million tons of gossan were mined for gold and silver. Most of the gossan was mined and processed by cyanide extraction from 1929-1942. Copper cementation was also used to extract copper from the effluent mine waters. From 1962 to the present it has been the only active process for metal recovery but it has also served as a remediation measure to decrease the discharge of copper to the Sacramento River.

### 18.2.4 ENVIRONMENTAL CONTAMINATION

Acidic mine waters contain three essential ingredients: pyrite, oxygen, and water. Although these are necessary constituents, the amount and rate of acid production can depend on many factors such as the concentration of pyrite, the temperature, the availability of alkalinity-producing or neutralizing agents (such as carbonate strata), the oxygen transport rate, the water flow rate and flow path, and the microbial growth rate conditions (also see Chapter 13).

Conditions at Iron Mountain are nearly optimal for the maximum production of acid mine waters from pyrite oxidation. The concentration of pyrite is nearly 100% in single large masses excavated by tunnels, man ways, and stopes that allow rapid transport of gaseous oxygen by advection. The massive sulfides are at or above the water table so that moisture and oxygen are always present. The airflow is probably aided by thermally driven convective cells due to the high heat output from pyrite oxidation. About 1,500 kilojoules of heat are released per mole (or about 120 grams) of pyrite. The average discharge from the Richmond portal indicates that about 2,400 moles of pyrite oxidize every hour, producing about 1 kilowatt of power or almost 9,000 kilowatts per year! In the early days of mining the Iron Mountain massive sulfides, fires were frequent and before proper ventilation was installed, temperatures of 430°F (221°C) were recorded at the ore surface (Wright, 1906).

The presence of the mine workings draws down the water table and pulls water toward the sulfide deposits at Iron Mountain where the pyrite oxidation reaction occurs. The resulting acid mine waters drain by gravity flow out the major portals of the Richmond mine, the Hornet mine (Lawson tunnel), the Old Mine, and the No. 8 mine. Sulfide oxidation in the Richmond mine workings has led to the most acidic effluent (pH = 0.02 -

1.5) and the highest concentrations of metals and sulfate for any surface water in the area; sulfate has been measured as high as 118 grams per liter (Alpers and others, 1992). In addition, the Richmond portal discharge has had the highest recorded flow rates (as high as 800 gallons per minute) of any mine portal on Iron Mountain. Note that the major cations are iron, aluminum, and zinc, and that most trace metals are present at very high concentrations. There is very little capacity of the bedrock to neutralize these highly acidic waters. Other important discharges of metals are the seep from the vicinity of the Old Mine and No. 8 mine portals, the "Big Seep" discharge in Slickrock Creek, and discharges from the Brick Flat open pit. These sources, as well as downstream sites on Spring Creek, have been monitored and the relative contribution of each site to the total pollution load for copper, zinc, and cadmium has been established. Just under 2,000 pounds of these three metals are leaving the site per day, about 300 tons per year. In terms of pyrite weathering it has been estimated that 2,500 tons of pyrite are oxidizing every year from the Richmond mine workings alone (Nordstrom and Alpers, written communication, 1990).

During the second Remedial Investigation phase (1986-1992) of EPA's Superfund activities, the Richmond tunnel and part of the Richmond mine workings were made accessible to underground surveys. On September 11, 1990, water and mineral samples were collected during one of these surveys that resulted in the discovery of extremely acidic seeps with pH values as low as -3.4 and a total dissolved solids concentration of about 935 grams per liter. These acid iron-sulfate waters were precipitating or effloresecing soluble iron-sulfate salts, often coating tunnel walls and muck piles with a colorful array. These waters are the most acidic ever reported anywhere in the world. The only other recorded pH values of natural waters comparable in magnitude are acid crater lakes found in Japan, New Zealand, Alaska, and Costa Rica (e.g. pH $\leq$ 0, Rowe, 1991). The development of such extreme acidic conditions is due to optimal conditions for pyrite oxidation combined with considerable evaporation from the heat released during oxidation and several years of drought conditions in California. The formation of extensive efflorescent salts means that acid solutions are being temporarily stored in a solid form until climatic conditions become wetter. Wet climate conditions will cause dissolution of the salts and some flushing of the stored acidity out of the mine workings. Rapid increases of copper concentrations up to a factor of 2 or 3 have been reported as a result of heavy rainstorm events early in the wet season (Alpers and others, 1992).

Waters with high concentrations of metals, especially copper, zinc, and cadmium, have drained from the mine portals and leached from tailings and waste piles, entering Boulder and Slickrock Creeks and joining the Spring Creek drainage. The Spring Creek Reservoir (built in 1963) receives the discharges from Boulder and Slickrock Creeks with some dilution and iron oxidation. Waters stored in Spring Creek Reservoir typically have pH values in the range of 2.5 - 3.5, but they are not always well-mixed and often show chemical gradients with depth. Detailed temporal depth measurements to investigate the seasonal patterns have not been done. From the reservoir, the waters are released in controlled amounts so that the dilution with water released upstream from Shasta Dam prevents fish kills (Lewis, 1963). Over twenty fish kill events have occurred since 1963 with at least 47,000 trout killed during one week in 1967 (Nordstrom and others, 1977). The fish kills have occurred because the reservoir capacity has been overwhelmed by high-rainfall events and a large load of metals discharged. These high metal flows, even during low-flow conditions, have led to adverse aquatic conditions in Keswick Reservoir and the Sacramento River. Water-quality objectives for the Sacramento River basin, based on laboratory and on-site toxicity studies of chinook salmon, have been adopted and approved by the Regional Water Quality Control Board (RWQCB), the California State Water Resources Control Board and the EPA to protect against both chronic and acute toxicity to aquatic life. Using these criteria, both acute and chronic toxicity, studies on chinook salmon, steelhead, and rainbow trout in the Sacramento River system have shown both actual and potential harm to these species from the acid mine drainage originating at Iron Mountain (EPA, 1992).

### 18.2.5 INVESTIGATIONS AND REMEDIATION

The first ore processing for copper was open-air heap roasting on timbers burned along the south and southeastern slopes of Democrat Mountain just upslope from the mouth of Spring Creek. In 1895 smelters were built nearby in the Spring Creek drainage. The heap roasting and the smelter operations resulted in toxic emissions that created air pollution, destroyed vegetation for miles around, contaminated soils, increased soil erosion, and increased turbidity and sedimentation rates in the Sacramento River (see Chapter 2, Figure 12). Volatile constituents likely to have been released into the air include arsenic, antimony, and lesser amounts of lead, cadmium, and zinc. Lawsuits were filed by private parties and by the U.S. Forest Reserve (now the U.S. Forest Service) and by 1907 all the smelters had shut down. The ore was then shipped to Martinez for smelting and refining. The lack of regulatory action from 1919-1942 probably reflects the economic difficulties of the Great Depression and the general lack of mining. Gossan mining, however, was very active during this period of history, but this would not have effected any production

of acid mine waters.

From 1939 to the present, various studies of the environmental impact of Iron Mountain have been conducted by the California Department of Fish and Game, the U.S. Fish and Wildlife Service, the RWQCB, the U.S. Geological Survey, the U.S. Bureau of Reclamation, and the EPA. Since 1983 studies have been conducted as part of the Superfund investigations authorized by the Comprehensive Environmental Recovery Compensation and Liability Act (CERCLA). These studies have documented discharges of metal from Iron Mountain, the occurrence of fish kills, the results of toxicity tests on anadramous fish in the Sacramento River, the lack of benthic and aquatic organisms in parts of the drainage system, the siltation problems of the drainage, the geology, hydrology, and geochemistry of the area, and the effects of water management engineering practices on the drainage system.

In 1950, Keswick Reservoir was completed to provide further flood control and hydroelectric power below Shasta Dam. Much sediment deposition occurred in the Keswick Reservoir and the Spring Creek Debris Dam was constructed to reduce these high sedimentation rates as well as to provide some regulation for the acid mine drainage entering the Sacramento River (Prokopovich, 1965). Continued fish kills have kept the RWQCB actively pursuing remediation of the site. Following a thesis study at the site (Nordstrom, 1977), a cleanup and abatement order was issued to the mine owner, Stauffer Chemical Company. On December 17, 1976, the property was purchased by Iron Mountain Mines, Inc., the present owners. From 1977 to 1989 six orders were issued to reduce toxic metal discharges that were in violation of state law. The orders to cease and desist as well as for emergency treatment measures have been through both the Shasta County and the State of California courts. Stauffer Chemical Company has became part of Rhone-Poulenc who then became liable for the site under CERCLA.

Iron Mountain was officially listed on the EPA's National Priority List for Superfund in 1983 and the first remedial investigation/feasibility study (RI/FS) began. The remedial investigation report (1985a) identified the five major point sources of pollution discharges through a comprehensive surface water sampling survey. The greatest discharge source was identified as the Richmond portal effluent. EPA (1985a) also documented the occurrence of increased concentrations of copper, zinc, and cadmium from portal effluents following heavy rainstorm events and related this phenomenon to rapid flow of surface water into the mine workings through areas of subsidence. The feasibility study (EPA, 1985b) considered more than a dozen alternative treatment possibilities and estimated the costs and anticipated benefits from each individual alternative as well as several possible combinations. The alternate options are listed below in simplified form:

A. No action.

B. Diversion of surface flows: divert upper Spring Creek to Flat Creek, upper Slickrock Creek around Big Seep, and South Fork Spring Creek to Rock Creek.

C. Lime/limestone neutralization: treat major point sources with conventional neutralization treatment plant.

D. Capping: implement partial or complete capping of the mountain to prevent infiltration to the underground mine workings by laying down an impermeable barrier.

E. Enlargement of the Spring Creek Debris Dam.

F. Intercept groundwaters through a system of drainage tunnels and drillholes surrounding the ore body.

G. Mine plugging.

H. On-site leaching and mineral extraction technologies (proposed by owners).

I. Combined alternatives.

A Record of Decision was issued by EPA (1986) that initiated five main recommendations:

A. Partial capping of cracked and caved ground above the Richmond ore body.

B. Construction of surface water diversions for upper Spring Creek, Slickrock Creek, and South Fork Spring Creek.

C. Initiate hydrogeologic studies and produce a ground water model for the site. This step would include rehabilitation of the Richmond mine for subsurface investigations. The subsurface investigations were motivated by the decision to test and demonstrate the feasibility of filling mine workings with low-density cellular concrete.

D. Install perimeter controls as necessary to avoid direct contact with contaminants.

E. Evaluate other source controls as appropriate based on the hydrogeologic investigations.

At that time, mine plugging was not considered a serious option because of questions relating to the

physical integrity of the mountain to contain the mine water. When Rhone-Poulenc acquired Stauffers assets through a complicated and proprietary arrangement with ICI Americas, ICI Americas began working on the remediation possibilities and mine plugging was seriously reconsidered. The initial alternative from private industry was to plug the Richmond workings and to allow them to fill up and flood the ore body to prevent further oxidation. Subsequent investigations by the U.S. Geological Survey and by CH2M Hill for the EPA demonstrated that a mine pool of about 20 million cubic feet would be created and would have a composition very similar to the present Richmond effluent composition. This acid mine pool would be sitting on top of the current water table and would travel to Boulder Creek through the bedrock in something less than 100 years. This concern led to the development of a highly refined plugging scenario in which lime would be added before plugging, a lime slurry and various additives would be injected to chemically neutralize and immobilize the acid waters and their dissolved metals. Considerable debate has ensued as to the effectiveness and costs of such a procedure. Indeed, the most difficult task has been to assign defendable risks and to develop methods that would evaluate the effectiveness of any of the proposed alternative treatments and their various combinations.

The EPA has evaluated the modified mine plugging alternative as part of the second RI/FS completed in 1992 (EPA, 1992). The EPA has also considered air sealing but has favored a complete capping treatment as the most cost effective solution in conjunction with the surface water diversions that have already been initiated. Emergency treatment procedures which collect Richmond portal effluent during periods of high flow and neutralize it in a temporary lime neutralization plant near the portal have been instituted. The capacity of this plant was increased from 60 to 140 gallons per minute in December, 1992. This plant will be removed once a more permanent solution has been found. Meanwhile, the EPA and the responsible parties are currently in legal contention over the appropriate treatment to be used and the consequent costs. Some question of the federal governments share of the liability has also arisen because of the network of dams built by the U.S. Bureau of Reclamation in the drainages receiving the acid mine waters.

### 18.2.6 CONCLUDING REMARKS

Control and remediation of the mine waste contamination at Iron Mountain, including prevention of some of the most acidic mine waters in the world, has proven to be an extraordinarily difficult and complex task. The physical and chemical nature of the site with all of its heterogeneities, complexities, and unknown aspects, the difficulty in assessing the effectiveness of any alternative or combined treatment, and the difficulty of assessing the relative risks and costs of alternative treatments and their contingencies all contribute to the formidable challenge of remediation. Hence, there is no clear solution to the problem and opposing parties will have inevitable differences of opinion on how to proceed and how much it should cost. Under such circumstances, it would seem prudent to proceed with remediation in stages with the most risk-free and least expensive treatments (especially in terms of operating costs) while continuing to monitor the site so that evaluations can be revised and improved.

Modern methods of mining can rehabilitate an area during production and after mining has ended with a considerable reduction of overall environmental remediation costs. The experience gained in studying Iron Mountain certainly underscores this fact. Estimated costs of cleanup at Iron Mountain start at about $25 million and exceed $100 million (1985 dollars) for the most effective combination of treatments.

The story of this site is not yet over after 100 years of mining activity and 54 years of investigation and regulation. However, more progress has been made than almost any other mining Superfund site in the United States. The recommended remedial measures may be very site-specific, but the general strategy on how the site was investigated and the difficulties uncovered during the Superfund investigations should provide insight and examples that will be useful for other mine sites.

## 18.3 THE SUMMITVILLE MINE: BUILD-UP TO CRISIS

**by B. A. Filas and J. T. Gormley**

### 18.3.1 INTRODUCTION

In December 1992, Summitville Consolidated Mining Company, Inc. (SCMCI) declared bankruptcy and notified the State of Colorado that it would abandon the mine, located at an elevation of about 11,500 feet in the San Juan Mountains in southwestern Colorado (Figure 3). SCMCI began its development in 1984. Mining ceased at Summitville in October 1991, the gold heap leach operations continued until March 1992, then the mine operations proceeded into the closure and reclamation phase. Through the spring and summer of 1992, an Amended Settlement Agreement was negotiated among SCMCI and its parent companies, Galactic Resources, Inc. and Galactic Resources Limited (hereinafter all referred to as Galactic); the Colorado Department of Natural Resources, Division of Minerals

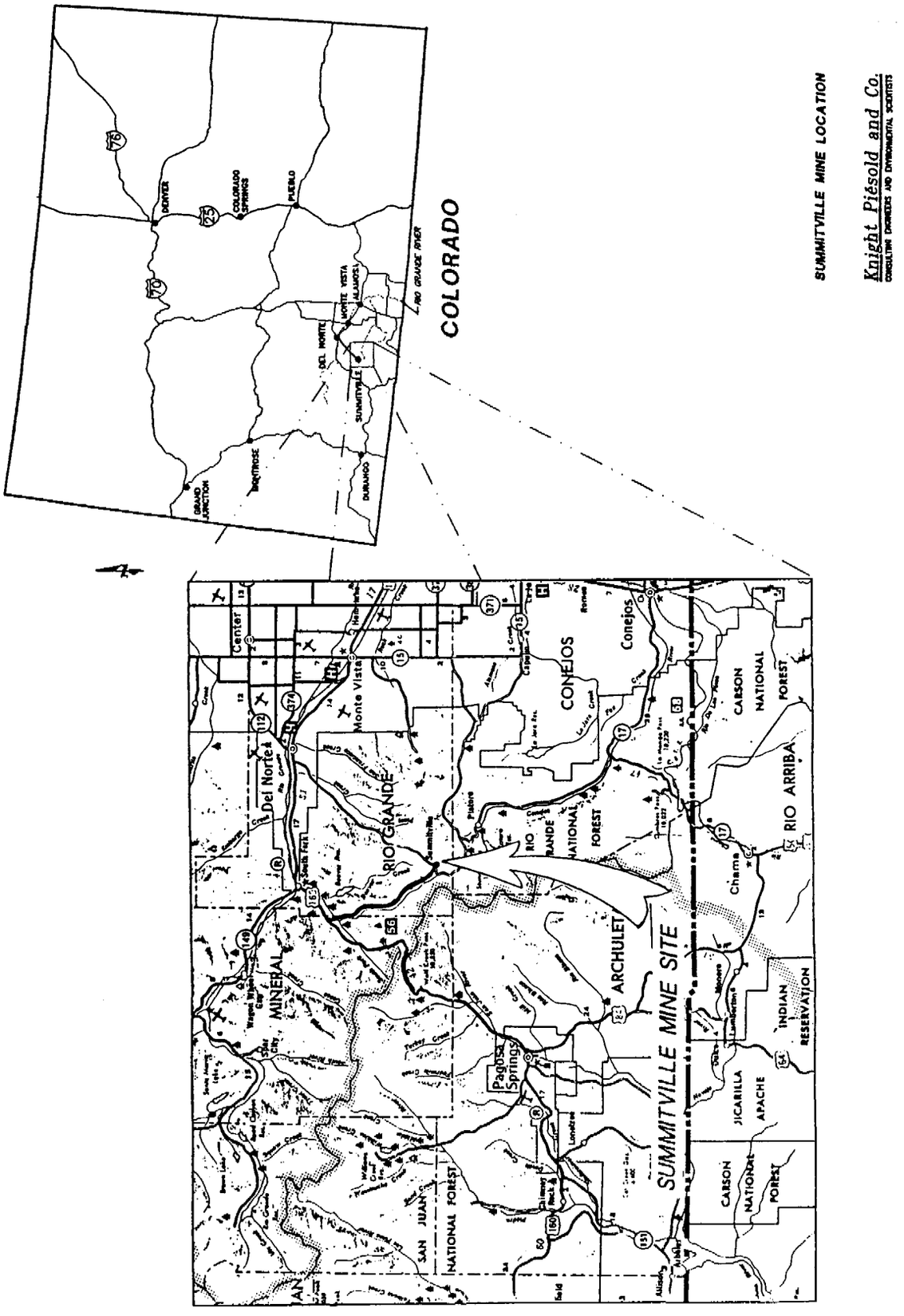



**Figure 3** Summitville Mine Location.

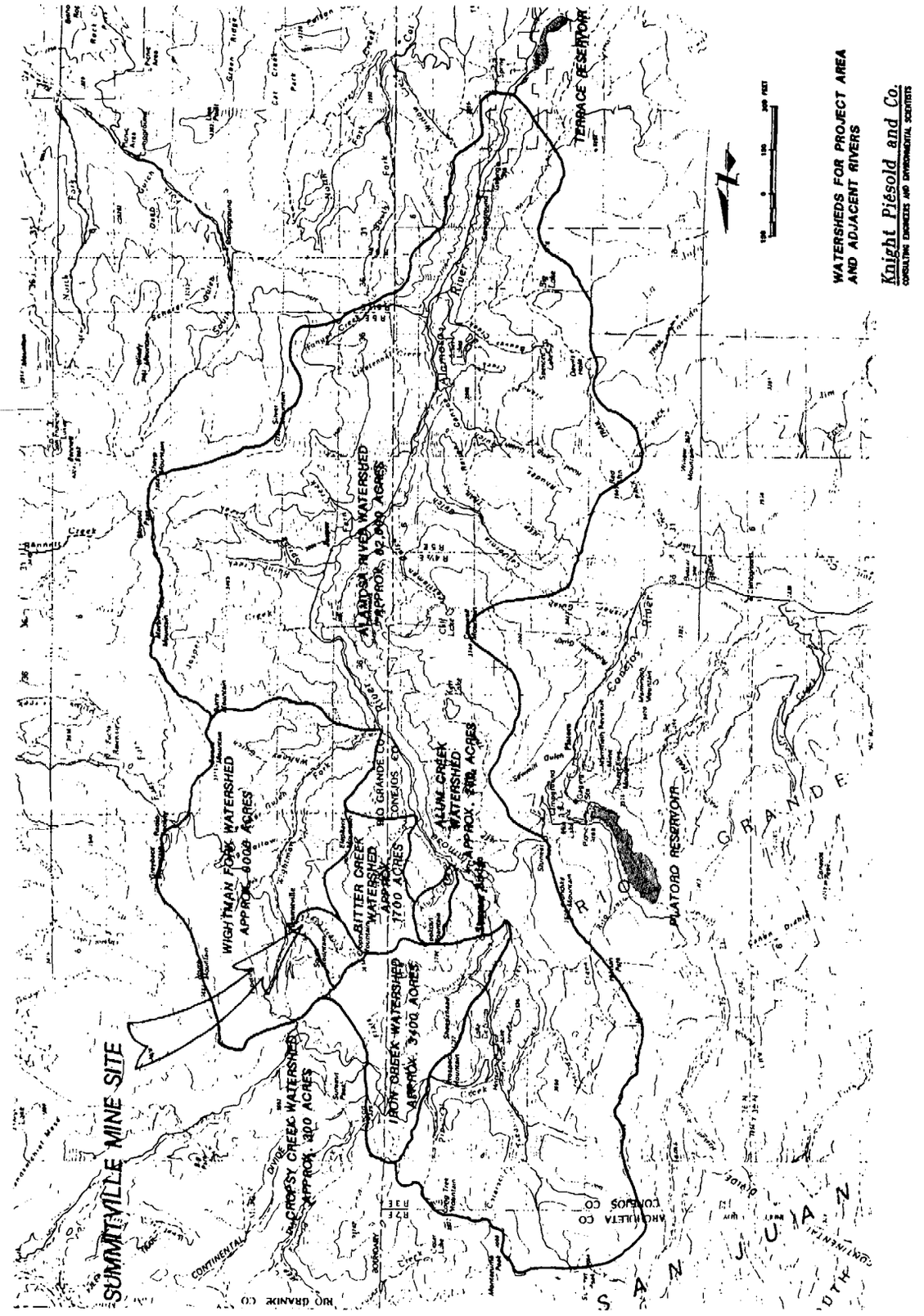



**Figure 4** Watersheds for Project Area and Adjacent Rivers.

and Geology (DMG)(formerly the Mined Land Reclamation Division); the State of Colorado, represented by DMG; and the Colorado Department of Health, Water Quality Control Division (WQCD).

Just days before the bankruptcy notice, the Mines Remedial Measures Plan was submitted to DMG indicating a first-phase closure and reclamation cost of $20 million, and total reclamation costs estimated in excess of $40 million. Among other items, closure included detoxification of the heap and the maintenance/treatment of site discharges to Wightman Fork, tributary to the Alamosa River; in particular, discharges from the heap leach pad and waste dump, and the Reynolds Tunnel, a century-old drainage tunnel that had been a key part of Summitville's history. Summitville's location near the confluence of several watersheds is shown in Figure 4.

The State did not have the financial resources or regulatory mechanism to respond to the abandonment. Consequently, Colorado requested the United States' Environmental Protection Agency (EPA) to assume site maintenance responsibilities under the emergency provisions of Superfund. EPA responded and assumed maintenance of the site on December 15, 1992, the day that Galactic abandoned the site.

EPA continues to maintain the site at a reported cost of $40,000 per day. EPA is proceeding through the Superfund process; site maintenance and reclamation has passed from emergency action to the remediation stage. Following remediation, Summitville will go into long-term maintenance that will be the responsibility of the State. At the time of this writing, EPA has listed the site on the National Priorities List and is attempting to identify and pursue Potentially Responsible Parties; the State is investigating any legal recourse that it may have against the Galactic companies, all of which have declared bankruptcy.

### 18.3.2 PROJECT DESCRIPTION

The Summitville Mine is located in an historic mining district in south-central Colorado, about 25 miles southwest of Del Norte in Rio Grande County (Figure 5). The mine is positioned on the northeastern flank of South Mountain in the San Juan Mountains. The district is somewhat unique in that mining occurs high in the San Juan Mountain range and the Alamosa River-Rio Grande watershed, at an elevation of about 11,500 feet. Figure 5 shows the extent of the underground workings at Summitville (note position of Reynolds Tunnel).

The Summitville Mine is located in the upper reaches of the Wightman Fork and Cropsy Creek watersheds. The Cropsy Creek drainage generally marks the southern and eastern extent of the mine area. An unnamed drainage off the north-northwest face of South Mountain establishes the approximate western boundary, and Wightman Fork in the valley bottom to the north establishes the nominal northern extent (Figure 6).

Wightman Fork flows easterly to its confluence with the Alamosa River, about four miles downstream (Figure 5). Terrace Reservoir is located about 13 miles downstream from the Wightman Fork/Alamosa River confluence. The Wightman Fork drainage is approximately 9,000 acres or 15 percent of the Alamosa River watershed above Terrace Reservoir. Cropsy Creek, a subdrainage of Wightman Fork within the mine area, drains approximately 300 acres. The Alamosa River is tributary to the Rio Grande River system.

### 18.3.3 PRE-GALACTIC MINING HISTORY

The Summitville Mining District was reportedly discovered in 1870 by placer miners James D. Wightman and others who staked claims and panned for gold in gravel deposits in what is now known as Wightman Fork. Lode claims were subsequently staked in 1872 and the first significant underground production from the District commenced in 1873. Early underground mine development consisted of driving networks of tunnels (adits) and raises that followed the ore mineralization. Often, drainage tunnels were driven below the main mine workings so the ground water could be drained from the workings to the surface.

Gold milling commenced in 1875. Oxidized ore was crushed and gold was recovered by amalgamation in as many as 11 mills that were built in Summitville by 1884. By the end of 1887, most of the oxide ore had been mined out. The underlying, lower-grade sulfide ores were difficult to mill and concentrate. Production declined.

In 1897, the Reynolds Tunnel was driven into the Tewksbury vein, located below the central portion of the contemporary Summitville pit (Figure 5). This drainage tunnel was completed in about 1906; its portal is at the lowest elevation of the historic drainage tunnels. The Reynolds Tunnel, the Iowa Tunnel and several other historic drainage tunnels still exist today; they are hydraulically connected to both surface and underground workings.

A major gold find occurred in 1926 when lessees struck high grade ore on the Little Annie claims. In 1934, the District entered the most productive period of its history. A 100 ton-per-day flotation/cyanidation mill and gold retort was installed in 1934. In 1939, battery-powered motor haulage was used in the Reynolds Tunnel when it was active; the rails and rolling stock were reportedly in good repair. Most of the workings were dry, probably due to the drainage provided by tunnels like the Iowa and Reynolds.

From about 1949 until 1954, the District was reportedly idle, but it was the target of several surface prospecting and exploration programs during the 1950s.

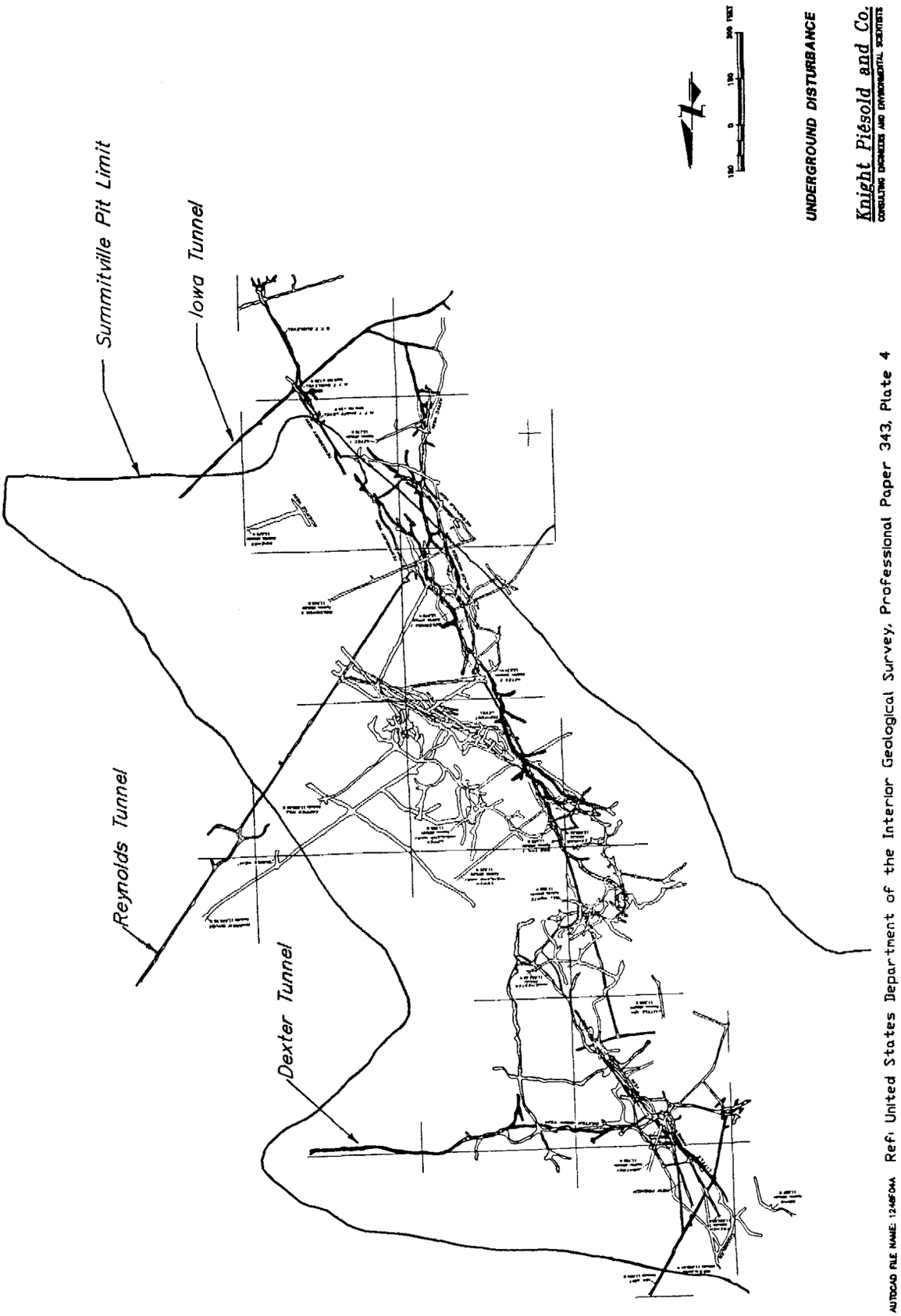



**Figure 5** Underground Disturbance.

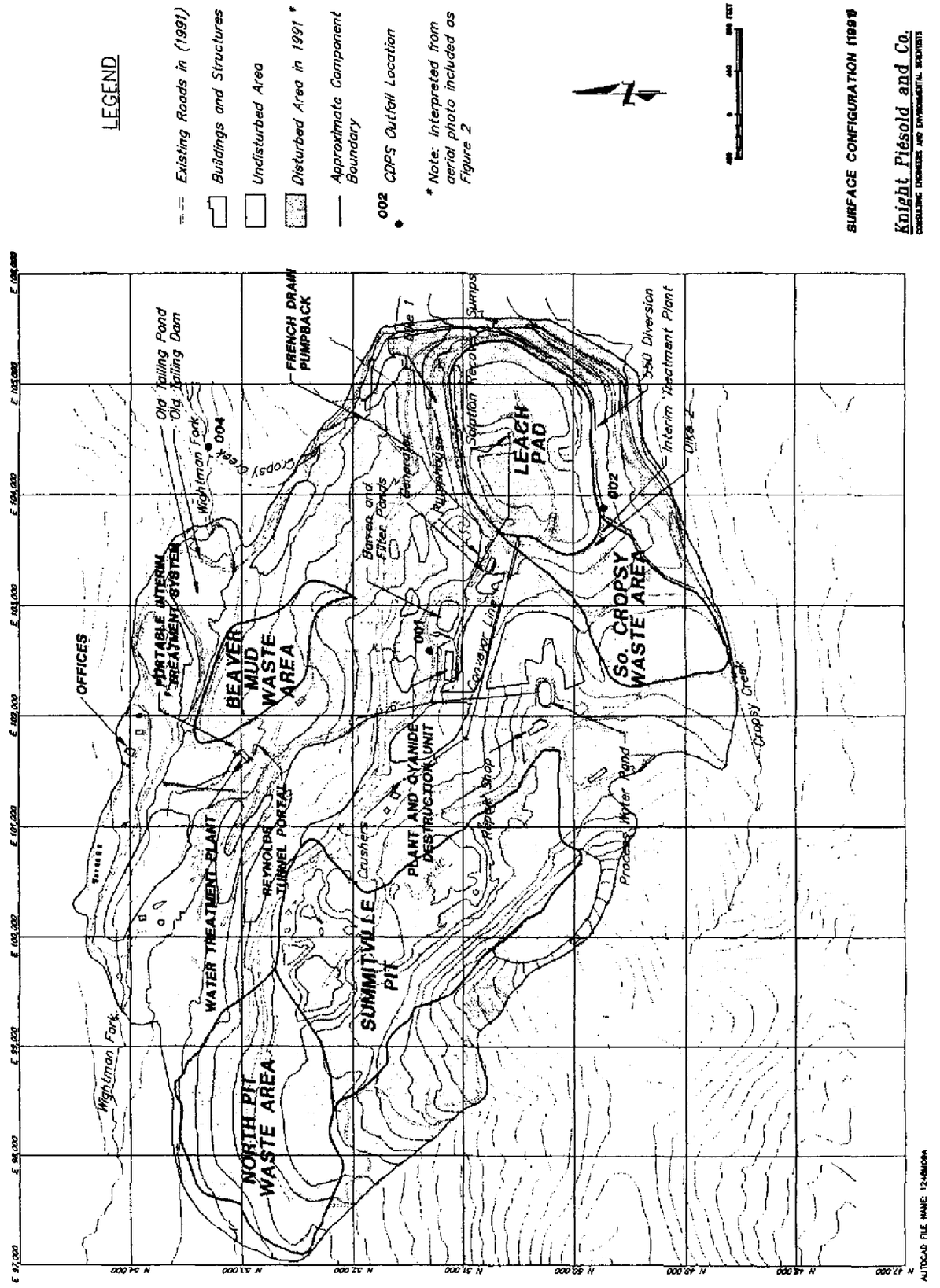



**Figure 6** Surface Configuration (1991).

In 1962, copper, gold and silver were produced from the Reynolds Tunnel. By 1963, exploration drilling and another general rehabilitation of the underground mine workings were underway. Exploration and rehabilitation activities continued through 1970, including sinking a shaft on the Missionary vein in pursuit of copper ore. A mill was opened in May of 1971 that produced 300 tons-per-month of copper concentrate. The operation reported 12,500 tons of copper concentrate for the year. Copper production was terminated in June of 1972 after a period of part-time operation.

In 1977, exploration drilling was again underway; an extensive drilling program was conducted in the late 1970s or early 1980s to define a wide-spread economically minable gold deposit. Galactic Resources, Inc. obtained the Summitville lease in 1984. Galactic planned to develop the identified ore deposit for commercial-scale open pit mining, cyanide heap leaching and gold recovery.

## 18.3.4 HISTORIC WATER QUALITY

Water quality in the Summitville area was first described in 1917. Sulfate and acidic conditions were identified on Alum, Iron and Bitter Creeks. These creeks do not drain the Summitville Mine area but are tributary to the Alamosa River upstream from the Wightman Fork confluence (Figure 4). No evidence of mining was identified in these drainages. In the Summitville area, local ground water was causing the formation of stalactites and stalagmites of iron oxide in the Iowa Tunnel, an indication of the oxidation of iron-sulfide mineralization.

Dewatered filtrate from the 1934 flotation/cyanidation mill was discharged directly to Wightman Fork. The mill tailing was retained in Wightman Fork by a series of dams. While the flotation/cyanidation mill was active, water quality in the Alamosa River was reportedly impacted by Alum and Iron Creeks to the extent that additional impact from Wightman Fork was not considered important.

The repeated replacement of 16- and 30-pound (per foot) mine rail documents the historical presence of acid mine drainage in the Reynolds Tunnel. In late 1949, a mine inspector estimated that the discharge from the Reynolds Tunnel ranged from 100 to 200 gallons per minute (gpm). He further observed that the water deteriorated the mine rail quickly; a bridle for a rail switch was reduced to paper thinness within three weeks from action of the "copper water".

## 18.3.5 GALACTIC ACTIVITIES, 1984 THROUGH 1992

Galactic conducted pilot-scale heap leach tests during the summer of 1984. Approximately 16,600 tons were processed in the pilot test program. That August, Galactic applied for permits for a full-scale mining operation. Permitting and construction activities occurred in 1984 and 1985. Mining began in the Summitville pit in 1986. The pit is approximately 73 acres and covers the historic underground workings (Figure 6). Many of the underground openings, including the Iowa Tunnel, were intercepted by the pit mining activities. There is acid drainage flowing from the Iowa Tunnel into the pit.

The Reynolds Tunnel dewatered the underground workings before, during and after open pit mining. However, flow rates and metal loading have increased since the onset of open pit mining activities. The Reynolds Tunnel is approximately 400 feet below the bottom of the Summitville pit. While pH has been consistently acidic both before and after Galactic activities, the total dissolved solids concentration increased by over 320 percent, from 854 mg/l to 3,624 mg/l, since the onset of open pit mining; copper concentration increased by over 460 percent, from 28 mg/l to 157 mg/l.

### 18.3.5.1 Ore Production and Leaching

The leach pad is located in the original Cropsy Creek drainage and affects about 50 acres. The leach pad system is based on a valley fill design. Containment dikes are constructed of earth fill and waste rock on the upstream and downstream ends of the facility. (All Galactic facilities are shown in Figure 6.) The basin between the two dikes and the inside faces of the dikes were lined with a composite soil/synthetic liner. Ore was then placed within the lined area for leaching. The pad is not a typical design. Rather than being free draining, fluids are contained on the pad and pumped from one of two wells located at low points in the pads basin.

A french drain network, consisting of gravelly rock and drain pipes, was constructed beneath the basin liner in the Cropsy Creek drainage to establish a preferential pathway for subsurface flows that may occur beneath the pad. The french drain system was overlain by the leach pad liner system. In ascending order above the french drain was a 16-inch-thick low-permeability clay liner, a leachate collection and recovery system, a synthetic liner, a friction sand layer, a geotextile, an 18-inch layer of crushed, screened ore and a final coarse layer of ore.

Leach pad construction commenced in late 1984. It was constructed in phases until it was completed in early 1988. In early 1986, Galactic continued with leach pad construction after being cautioned by its heap leach pad design consultant of the risks associated with winter construction. On March 5, and again in April of 1986, pad liners were damaged by avalanches. The designer subsequently subcontracted to a testing firm to certify the

synthetic liner integrity. The liner was certified on May 21, 1986, with the exception of those areas that could not be inspected due to snow accumulations. Also excluded from the certification were the liners on the east slope and pad bottom, which had been damaged by several avalanches. No records have been identified that provide follow-up certification of those areas that were excluded in the May 21, 1986 document.

The site was inspected by DMG on April 2, 1986, and again on May 29, 1986. At that time Galactic was testing the pad liner for leaks. Pad loading commenced in May of 1986. The original pad design called for a compartmentalized pad with a maximum heap height of 60 feet. In June of 1986, the facility was redesigned to a single cell pad with a maximum heap height of 300 feet. The additional design height reduced the surface area required to accommodate the production tonnage.

Application of leach solution began on June 5, 1986. Within five days, cyanide solution was detected in the leak detection system beneath the primary liner. Thirteen days after the initial solution application, cyanide was detected in the french drain solution beneath the secondary liner. Despite leach pad liner repairs, cyanide continued to be detected in the french drain system. Galactic subsequently proposed to install a permanent sump and pumpback system to recover the contaminated solutions in the french drain. The State approved the system for construction in October 1986. Solutions recovered from the sump could be pumped either to the treatment plant or back onto the heap.

The leach pad design anticipated minimal hydraulic head on the liner system. The leach pad was actively operated between 1986 and 1992, during which time solutions volumes within the structure gradually built up hydraulic heads in excess of 100 feet. The solution that will discharge through a liner breach is proportional to the hydraulic head on the liner. While geosynthetic liners are often considered suitable for withstanding high hydraulic head, the high head condition in the Summitville leach pad resulted in more seepage through the liner breaches than would have occurred had Galactic operated the system with the low head called for by the original design.

Between June and October of 1987, at least nine cyanide spills occurred from the french drain sump and pumpback system. The spills resulted in the documented discharge of some 85,000 gallons of cyanide-contaminated water into Cropsy Creek. Cyanide spills from the french drain sump also occurred in September and November of 1991. Records indicate the spills were caused by either pump or pipeline failures. Two seeps were later identified along the toe of the downstream pad embankment in August of 1991. WQCD and DMG engaged in a series of enforcement actions for these discharges and other permit violations. Cyanide solution application was terminated on March 31, 1992.

#### 18.3.5.2 The South Cropsy Waste Disposal Area

The South Cropsy waste area is positioned in the original Cropsy Creek drainage just upgradient from the leach pad (Figure 4). The original development plans and permit anticipated the leach pad to include the areas now occupied by both the leach pad and South Cropsy waste area. The design change for the leach pad from a 60-foot to a 300-foot height resulted in a substantially reduced area requirement to accommodate the required tonnage. This left available space upgradient of the leach pad in the original Cropsy Creek drainage; it was used for waste rock disposal.

Construction of the South Cropsy waste area proceeded adjacent to the leach pad. The upstream dike of the leach pad constitutes the downstream toe of the Cropsy waste area. The sequence of events associated with the development of the South Cropsy waste area occurred essentially in reverse of a normal process. The disposal area was constructed in 1986, then the design and permitting documents were submitted to DMG after the fact on April 10, 1987. Colorado law requires that mine operators define site development plans before field implementation. Galactic constructed the waste disposal area first, then submitted designs and gained regulatory approval for the facility. This action constituted a violation of the permit conditions and resulted in enforcement action by DMG.

Foundation preparation and construction occurred during or prior to the spring of 1986. A similar french drain system was installed to provide underdrainage from the existing seeps, springs and wetland areas in the Cropsy basin as was installed beneath the leach pad. Apparently, the waste rock area preparation did not include a flow barrier between the underdrains and the waste rock that would be placed over them. The South Cropsy waste area french drain and the leach pad french drain were connected such that the South Cropsy waste area underdrainage passes beneath the leach pad. The combined South Cropsy waste area and leach pad underdrainage flow to the french drain sump. In mid-1993, water quality at the sump was about 30 parts per million (ppm) cyanide, with a pH of about 3.

Records are unclear as to when acidic seepage was first observed from the South Cropsy waste area. However, a discharge outfall was applied for in June of 1991 for direct discharge from the South Cropsy waste area into the 550 Diversion Ditch on Cropsy Creek. A lime precipitation treatment facility was constructed between the South Cropsy waste area and the leach pad in anticipation of a July, 1991 start-up. Starting in early August, 1991, the treated seepage from the South Cropsy waste area could not meet effluent limitations for discharge into the 550 Diversion Ditch. The seepage was therefore coursed into the leach pad for on-site

containment. The Cropsy seepage flowing into the leach pad has varied in chemical characteristics over time. In 1992, the pH was reportedly as low as 2.2. The seepage has typically been acid. Copper and iron are reportedly the primary elements of concern from this drainage.

### 18.3.5.3 Water Balance, Treatment and Land Application

The heap leach pad and associated solution management ponds were designed for no off-site discharge. The earliest computed water balances assumed that snow accumulations on the leach pad would be isolated from the heap by means of an interim cover during the winter months. Galactic opted not to cover the heaps during the winter. The snow melt added significant water that was not accounted for in the water balance.

The installation of the french drain system beneath the leach pad and Cropsy waste area was intended to intercept undisturbed ground water and direct it beneath the main containment dike to discharge downstream. Because the cyanide leakage from the leach pad persisted even after Galactic's efforts to seal the leakage, the french drain recovery sump was installed to recover the shallow ground water and reintroduce it into the process water circuit. When Cropsy waste dump and discharges could not be adequately treated, they were routed to the heap leach pad. These french drain and Cropsy discharges were unaccounted-for additions to the pads water balance.

Pad operations, allowable discharges and climatic conditions each contributed to a growing Summitville water balance crisis. Consequently, Galactic changed its operating plan from a no-discharge to a discharging facility. A water discharge permit was applied for in 1988 and received in 1989. With the approval of the discharge permit in May of 1989, Galactic proceeded with the installation and operation of a water treatment system. The system was unable to meet the effluent limitations on silver imposed by the WQCD discharge permit. As a result, Galactic pumped the treated water back to the heap leach pad, which again exacerbated the water balance problem.

Galactic then planned for land application of the treated process solutions as a method of further treatment and disposal. As a result of Senate Bill 181 (June, 1989), DMG became the "implementing agency" for mining-related ground water permits. DMG elected to permit the land application system. Land application commenced in a five-acre site south of Wightman Fork near the mine office. In July of 1990, the land application system was malfunctioning, resulting in overland flow directly into Wightman Fork. At about this time, the regulatory agencies had received anonymous telephone calls advising of unpermitted discharges associated with the Summitville operations. Enforcement actions were taken by the agencies for unpermitted discharges, failure to minimize hydrologic balance problems, failure to handle acid forming material and for overload of the land application system. Land application was discontinued on October 30, 1991.

### 18.3.5.4 Settlement Agreements

Settlement agreements were negotiated in July of 1991 and again in July of 1992 among Galactic and the jurisdictional agencies. Key issues addressed in the agreements included the acid drainage from the South Cropsy waste area; unpermitted point source discharges from the land application system into Wightman Fork; water sampling protocol; unpermitted discharges from the french drain pumpback system; a requirement to update the water treatment plan; treatment of the Reynolds Tunnel discharge; revisions to the reclamation plans and bond amount; and Galactics inability to meet discharge criteria.

The amended agreement established the "bubble concept" for the water quality point of compliance. With the bubble concept, several drainages within a defined area may be directed to one location on the boundary; only the discharge at that location is permitted. A single point of compliance was identified on Wightman Fork downstream from the project discharges and Cropsy Creek confluence in lieu of compliance points at each discrete discharge location. The amended agreement also adjusted the financial warranty with the Mined Land Reclamation Board.

### 18.3.5.5 Financial Assurances

The mining permit issued to Galactic in October, 1984 required a reclamation bond in the amount of $1,304,509. The bond amount considered costs for surface grading and shaping, clay caps on waste rock and heap residue, and revegetation. No provisions for heap detoxification or water treatment were explicitly included with the estimate.

In August, 1989, the Board required Galactic to post an additional surety of $913,801. This adjustment to the bond included the cost for a one-time rinse of the heap. It was posted in the form of a salvage credit. The bond still excluded cost for water treatment.

Finding that significant modifications would be required to the reclamation plan, the Board later requested an additional $5,000,000 bond, which would bring the total surety amount to $7,218,310. This additional bond was posted on June 21, 1992 in the form of $4,000,000 cash and a $1,000,000 promissory note. The $5,000,000 was not based on a specific bond calculation, but was included with the language of the Amended Settlement Agreement. Of the $5,000,000, $2,500,000 was held in a "Special Account", which, according to the Amended Settlement Agreement, would be released following

execution of reclamation activities during the summer of 1992. The $2,500,000 balance remained as a closure/reclamation surety, but still was not based on a detailed cost estimate.

By the fall of 1992, Galactic had completed site grading and commenced to treat waters from the Reynolds Tunnel. Based on this reclamation work, Galactic requested release of the $2,500,000 in the Special Account. By November of 1992, Galactic had gained release of the $1,000,000 promissory note and a total of $1,500,000 of surety funds held in the Special Account as provided for by the Amended Settlement Agreement. This brought the surety balance to $4,718,310, just prior to Galactics bankruptcy declaration.

## 18.3.6 BUILD-UP TO CRISIS

A few aspects of the build-up to crisis at the Summitville Mine are apparent from this historical briefing. Discussions of these aspects follow.

### 18.3.6.1 Acid Drainage from the Reynolds Tunnel

The 50 to 200 gpm acid drainage from the Reynolds Tunnel was not a matter that was addressed in the 1984 Galactic mine permit application. The permittee asserted that there would be no effect on the Reynolds Tunnel drainage from the open pit mine operations.

Neither Galactic nor the State acknowledged the historic evidence of the acid drainage during the permitting process. Historic records suggested a connection between surface prospects and underground workings well before Galactics presence on site. However, there was also no consideration given to the prospect that the same rocks that produced the acid drainage from the Reynolds Tunnel may produce acid drainage from surface-mined wastes disposal areas. Consequently, the pit was excavated without consideration of its effect on the underground mine discharge, and the Cropsy waste area was developed and permitted without considerations given to the generation of acid rock drainage.

It wasn't until 1992 that Galactic acknowledged the obvious--that surface mining adversely changed the quantity and chemistry of the Reynolds Tunnel drainage. Galactic was not obligated to treat the acid drainage from the Reynolds Tunnel until execution of the Amended Settlement Agreement in July 1992. The Reynolds Tunnel drainage was historically, and also during Galactics tenure on site, the Districts largest contributor of dissolved metals and low pH waters to the Wightman Fork tributary of the Alamosa River.

### 18.3.6.2 Construction Quality Control

Severe winters occur at Summitville. Despite the engineers' counseling to the contrary, Galactic insisted on liner installation during severe winter conditions. Construction quality control could not be conducted in areas that were damaged by avalanches or covered with snow. Despite the partial certification, the pad was apparently acknowledged by State inspectors as certified for loading and operation.

Almost immediately, cyanide solution was detected at the leak detection system beneath the primary liner, then in the underdrainage system beneath the secondary liner. Galactic efforts to stop the leaks failed. As an alternative to repairing the leaks, Galactic proposed the installation of a permanent sump and pumpback system, which the State approved. There were no requests for treatment of the water from the permanent sump for discharge, nor was there an immediate reanalysis of the heap leach pads water balance.

### 18.3.6.3 Design vs. Operations, or No Design at All

The leach pad design called for minimal hydraulic head on the liner. With all of the complications with the "no-discharge" system, high heads on the liner were more the rule than the exception. This condition exacerbated the problem of leaks in the liner system.

The initial water balance analyses assumed the prevention of snow melt infiltration into the heap or the removal of snow from the heap. Neither covering of the heap nor snow removal from the heap was ever an operational practice.

The same water balance analyses did not account for pumpback of the french drain discharge. The pumpback situation was further exacerbated when the unpermitted South Cropsy waste area underdrains were tied directly into the pads french drain. Excess water within the heap became an even more severe problem when the Cropsy surface drainage was directed into the pad area. Further, the addition of the Cropsy acid drainage to the heap leach pad system could only interfere with the chemistry of the solution water and the eventual plans for treatment and discharge of solution waters.

Finally, a water balance in April, 1988 identified the eminent risk of over-topping the main dike that contained the heap leach pad. An effort to permit and operate a treatment plant followed.

### 18.3.6.4 Water Treatment and Discharge

The WQCD became involved in the permitting process when Galactic applied for a permit to treat and release excess process water. The discharge permit was approved

in May, 1989. DMG approved the installation of the treatment plant in April of 1989. Discharge from the treatment plant couldn't meet WQCD requirements, so the in-system water build-up continued.

Galactic attempted to resolve its failure to meet WQCD's discharge requirements by applying for land disposal of the treated process solutions. The method of land disposal did not require a discharge permit from WQCD. Land disposal was under DMG purview. Within a year, WQCD inspected the site and found the land disposal system to be yielding over-land flow and thus, within its jurisdiction. Penalties were assessed and the land disposal system was shut down. Again, Galactic resorted to the in-system water buildup because the operator could not achieve a permittable discharge.

After Galactics failed attempts at discharging treated waters WQCD and DMG entered into a cooperative effort to obtain a Settlement Agreement and Compliance Plan from Galactic.

### 18.3.6.5 Bonding

At the time of Galactics bankruptcy, the State of Colorado held a surety of less than $5 million. The cost of reclamation, which only became known a few days before Galactics notice to declare bankruptcy, was estimated to be over $40 million (it is now estimated at well over $40 million). Earlier reclamation cost/surety estimates by the State were apparently derived on the assumption that the mining and reclamation operations would be in compliance with the law. Also, Colorado law did not allow for bonding of water treatment cost, which constituted a substantial portion of the estimate.

The State requested increased surety from Galactic in mid-1992, when it was determined that the in-place reclamation plan needed modification; however, the increase was not based on a detailed cost estimate, nor did it include water treatment cost according to the existing law. The more rigorous computation of costs for reclaiming the Summitville Mine based on actual conditions occurred as a result of the 1992 Settlement Agreement and Compliance Plan.

### 18.3.7 CONCLUSION

The Summitville Mine situation is the manifestation of decisions, actions, rules and procedures that were not unilaterally determined by any one party. There are many lessons to be learned from the Summitville experience, and the incident will likely be used for case studies of what can go wrong at a mine site. The Summitville Mine experience will no doubt influence permitting and enforcement under existing regulations, as well as the promulgation of new rules and regulations on mining. Certainly in Colorado, the Mined Land Reclamation Act of 1993 was inspired to prevent the occurrence of another Summitville.

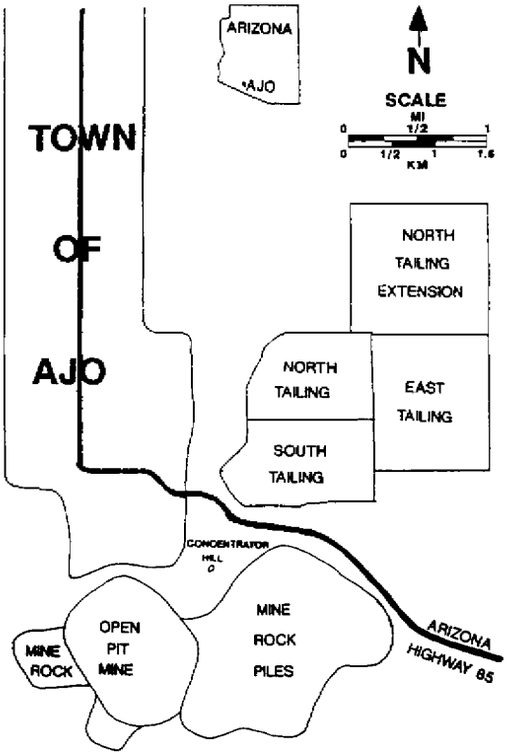



**Figure 7** Tailing piles and mine at Ajo.

## 18.4 APPLYING A CRUSHED ROCK VENEER TO CONTROL DUST ON DRY TAILING

**by J. L. Armstrong, E. F. Haase and E. M. Schern**

### 18.4.1 INTRODUCTION

Tailing impoundment surfaces are potential sources of airborne particulates. Active impoundments are generally not a concern since moist tailing do not give rise to particulates although dry segments of active tailing may be sources of dust under some conditions.

Inactive tailing surfaces vary considerably in their tendencies to form hard crusts that are resistant to wind erosion. Copper tailing which contain significant pyrite have been observed to form hard and stable crusts that are highly resistant to wind erosion when left essentially undisturbed. Research in South Africa indicates that a minimum of 0.7% pyrite was essential for the formation of hard crusts (Donaldson, 1960). Large surface areas of dry and poorly crusted tailing may become major sources of airborne particulates under strong wind conditions. The following case study describes the development of a serious tailing dust problem and the voluntary actions

taken by Phelps Dodge Corporation (PDC) to eliminate it.

## 18.4.2 BACKGROUND

### 18.4.2.1 Site Location and History

Open pit copper mining was conducted for more than 60 years at PDC's New Cornelia Branch at Ajo in southwestern Arizona. Four tailing impoundments totaling about 1900 acres were constructed from 1922 until 1984 when the mine was deactivated (Figure 7). Construction on the North and South Dams ceased in the mid-1960s. East Dam construction began in 1961 and ceased in 1980. Construction of the North Dam Extension occurred between 1980 and 1984.

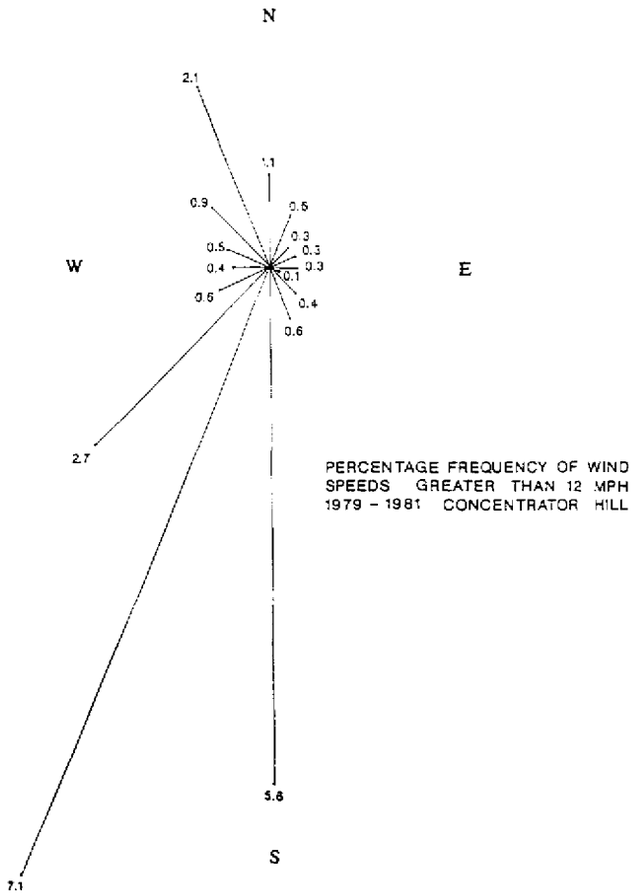



**Figure 8** Three-year average wind rose.

### 18.4.2.2 Problem Identification

Thin crusts formed on the tailing surfaces at Ajo as they dried. However, many factors combined to break portions of the dry crust and the sand and silt-sized particles became a major source of airborne dust under strong wind conditions. Tailing particles tended to collect as wind-driven deposition scattered across the dry impoundments or as major dunes on the leeward slopes of the dams.

Tests have shown that wind speeds of about 12 mph are required to initiate soil movement (Brady, 1974). Movement at higher wind speeds is proportional to the third power of the wind velocity. Thus, the potential quantity of tailing carried by the wind increases rapidly at higher wind speeds. Moving particles are a major contributor to additional dust by dislodging crusted particles through surface creep and saltation.

Prevailing winds at Ajo are from the south-southwest. Weakest winds are from the east, favoring the townsite location which is about 0.3 to 1.5 miles west of the tailing impoundments (Figures 7 and 8). However, on rare occasions particulate matter reached parts of the townsite or related roads in the area.

Embankments were raised by upstream construction over earthen starter dams. Construction resulted in tailing accumulations to heights more than 220 ft above the natural terrain which decreases in elevation from southwest to northeast in the general direction of the prevailing winds (Table 1). The total perimeter length of tailing slopes is nearly 11 miles, including both exterior slopes and slopes between tailing impoundments. Overall slopes are 3.3 horizontal to 1 vertical.

**Table 1** Tailings dam and pond heights (ft.)

| Impoundment | Pond Elevation | Appropriate Dam Height Above Natural Terrain |
|---|---|---|
| South | 1,855± | 100 to 180 |
| North | 1,819 | 80 to 220 |
| East | 1,810± | 160 to 220 |
| North Extension | 1,618± | 0 to 80 |

**Table 2** Area of tailing ponds and slopes (acres)

| Impoundment | Top | Slope | Total |
|---|---|---|---|
| South | 310 | 145 | 455 |
| North | 254 | 93 | 347 |
| East | 335 | 165 | 500 |
| North Extension | 553 | 45 | 598 |
| **Total** | 1,452 | 448 | 1,900 |

The two oldest, highest, and smallest impoundments (North and South Dams) are located closest to the town

(Tables 1 and 2). Wind erosion effects became evident in the late 1960s after the two impoundments were deactivated and dry surface crusts began to break down. The crustal breakdown was periodically ameliorated by infrequent tailing flows to the South Dam during periods of maintenance.

#### 18.4.2.3 Initial Control Strategy

To address the problem of increasing wind erosion, PDC initiated an experimental program in 1970 to grow vegetation on the inactive tailing impoundments. The program focused primarily on the North Dam and slowly expanded in scope to include the South Dam. It was suspended in 1984 when the mine was temporarily deactivated. Approximately 150 species of trees, forbs, and grasses were tested, but only a handful were found to adapt adequately in the inhospitable environment. Most successful was athel (*Tamarix aphylla*), an evergreen tree native to Africa.

More than 15,000 trees and shrubs were transplanted to the tailing and about 25 miles of irrigation pipes, ditches, and distribution lines for drip irrigation had been installed when planting activities were suspended. Initial plantings were concentrated on slopes facing the town, but the main focus of planting activity soon became the horizontal surfaces of the North Dam.

The main source of water for irrigation was sewage effluent from the town of Ajo's oxidation pond. The effluent also provided a supply of vital plant nutrients. Unaltered tailing are a generally inhospitable medium for plant growth because of the lack of available water, absence of soil structure and organic matter, and inadequate plant nutrients. Excess salinity and abrasion damage from saltating particles caused significant problems for many species. However, planting activities eventually led to successful tree growth that covered much of the North Dam. The rows of trees reduced the generation of airborne particulates.

Small scale experiments with wind screen barriers and surface chemical stabilizers were also conducted in the early 1980s to evaluate potential wind erosion control. Although beneficial effects were obtained, large scale applications were not considered feasible.

#### 18.4.2.4 The Problem Intensifies

In August 1984, the mine and mill at Ajo were temporarily deactivated for economic reasons and the remaining wet tailing surfaces began to dry and crust. Some of the vegetation on the North Dam continued to receive periodic irrigations of sewage effluent. However, cessation of mining activities resulted in a loss of approximately half of the town's population which significantly reduced water usage and the associated effluent.

As time passed the crusted tailing impoundment surfaces were slowly broken down, particularly by bombardment of saltating particles during strong wind events. Much of the dust appeared to emanate from the two largest impoundments which were essentially devoid of vegetation and were located farthest from the town.

Particle size analyses from shallow boring samples at Ajo indicate that tailing particles are dominated by silty fine sands. Tailing were discharged from berm crests with coarse fractions deposited near the berms and finer fractions toward the interior of the ponds. Liberation grinds to extract metals from most ores produce particle sizes that range from medium-sized sand to fine silt (Brawner and Campbell, 1973). A small fraction of particles at the fine end of the range may contribute to particulate matter under 10 microns in size ($PM_{10}$) for which a National Ambient Air Quality Standard exists. An exceedance of the 24-hour $PM_{10}$ standard was recorded at Ajo in August 1987, apparently associated with a nearby storm that produced exceptionally high winds.

The temporary closure of the mine at Ajo was extended and effects of blowing tailing on local visibility became more noticeable, occasionally reaching areas of the town during periods of high winds. Visibility and potential $PM_{10}$ effects led PDC to evaluate strategies that could be implemented to provide additional controls on airborne tailing emissions. This voluntary program was conducted with the cooperation of the Office of Air Quality at the Arizona Department of Environmental Quality (DEQ). The PDC evaluation had the following objectives:

1) To eliminate particulate generation permanently and with minimal maintenance requirements.

2) To accommodate a quick reversion to active use of impoundments upon resumption of mining.

3) To approach natural conditions to the greatest extent feasible.

### 18.4.3 EVALUATION OF CONTROL ALTERNATIVES

Possible technologies to control tailing particulate emissions at Ajo were identified. This included an evaluation of apparent effectiveness and approximate costs of dust control measures used at other mines.

A preliminary evaluation indicated that a crushed rock veneer was a promising technology. This was more fully substantiated by contractors funded by Phelps Dodge to conduct a technical and economic evaluation of dust control technologies. The following general techniques were identified:

Soil or rock cover

Vegetation
Wind screen barriers
Crushed rock veneer
Chemical stabilization
Irrigation Cementing agents

The evaluations indicated that a rock veneer was the most economical method for long-term stabilization of the tailing impoundments.

## 18.4.4 CRUSHED ROCK VENEER

### 18.4.4.1 Description of Technology

The technology selected to control generation of dust at Ajo was a cover of crushed rock applied as a veneer on horizontal tailing surfaces at a nominal thickness of 2 in. This alternative met most of the objectives and was accomplished at a cost of less than $4 million. All-terrain, balloon-tired spreaders with 16-ton capacities were used to spread the rock which was first screened and crushed to minus 3 in. in diameter. The upper one-third of tailing dam slopes, on average, were covered to a thickness of approximately 6 in. by conventional dozer pushing and blading of minus 10 in.-diameter rock over the side. In some cases larger-sized rock was utilized if it was readily available.

To estimate the wind erosion potential before and after the application of a rock veneer on horizontal surfaces, a wind erosion equation was utilized to evaluate the changes in environmental parameters (Woodruff and Siddoway, 1965). The equation was developed originally by W. S. Chepil and other scientists at the Agricultural Research Service, U.S. Department of Agriculture, over a period of some 50 years, primarily to estimate soil loss due to wind erosion from agricultural fields in the Great Plains. Dry tailing impoundments were considered to bear enough similarity to fields to make application of the equation worthwhile.

The amount of erosion can be expressed in terms of equivalent variables as:

$$E = f(I,K,C,L,V) \qquad (18.4.4.1\text{-}1)$$

where:

E = Amount of wind erosion in tons/acre/year.

I = Soil Erodibility Index expressing potential soil loss in tons/acre/year from a wide, unsheltered, bare, smooth and non-crusted surface. The value varies from zero to 310 and increases as the percentage of soil fractions finer than 0.84 mm in diameter increases. The value decreases as the amount of surface crusting increases.

K = Soil Ridge Roughness Factor expressing surface roughness in the form of ridges or small undulations. It varies from about 0.5 to 1 with the higher value indicating an absence of ridges.

C = Climatic Factor expressing wind, moisture, and temperature conditions for a particular geographic location. It varies between zero to more than 150%, with higher values in more arid environments.

L = Length of Unsheltered Distance along the prevailing wind direction. It varies from 10 to 10,000 ft.

V = Equivalent Quantity of Vegetative Cover. It varies from zero to 18,000 lbs/acre.

Values for these equivalent variables are applied to charts and graphs contained in Agriculture Handbook No. 346 to solve the equation (Chepil et al., 1962; Skidmore and Woodruff, 1968). The wind erosion equation was solved for the two extreme horizontal surface conditions that best represent the four Ajo tailing impoundments:

A. The extensively vegetated North Dam (254 acres); and

B. The relatively smooth and barren North Dam Extension (553 acres).

Values of wind erosion (E) for the unvegetated East Dam (335 acres) would approximate those from the North Dam Extension. Values of E for the South Dam (310 acres) would probably be about 10% less because it is partially vegetated.

Application of the equation indicated that the rock veneer reduces wind erosion on the vegetated North Dam from 160 to zero tons/acre/year. The wind erosion reduction resulting from the rock veneer on the barren North Dam Extension is from 300 to 0.6 tons/acre/year. These significant decreases are primarily attributable to reductions in the Soil Erodibility Index (I). Crusted surfaces containing more than 80% particles greater than 0.84 mm in diameter yield wind erosion losses of zero based on the equation. These conditions are expected to occur on rock-armored tailing surfaces following the first significant rainfall after application.

The wind erosion equation applies to all particle sizes that can be moved by wind. A relatively small percentage of these would consist of fine particulates with a diameter of less than 10 microns. The equation addresses material losses and not emissions. Thus, prior to the application of crushed rock, much of the tailing material was merely moved from one tailing area and deposited in another, as in dune formation. However, the relatively small amounts of fine particulates in suspension had the

potential of being carried great distances by exceptionally strong winds.

The wind erosion equation was developed partly from wind tunnel and agricultural field measurements in Kansas and was not developed specifically for application to tailing impoundments. Nevertheless, conservative application of the equation to Ajo tailing indicated that erosion potential was reduced more than 99% on horizontal surfaces covered with the rock veneer. It is clear that this technology solves any problems related to annoyance, visibility degradation, or fine particulate emissions, including $PM_{10}$, that may have existed previously.

### 18.4.4.2 Preparation and Application

The source of rock for the rock veneer was the non-ore stockpile approximately 1600 ft south of the South Dam, across State Highway 85. Rock was loaded into a grizzly at the stockpile to provide minus 10 in. material. A shaker and screen separated the minus 3 in. material. This, in turn, was fed to a conveyor that was later joined to another conveyor from a crusher that down-sized the plus 3 in. material. Portable conveyors were used to transport the minus 3 in. product more than 600 ft over Highway 85 to a temporary storage pile.

35-ton dump trucks transported the rock to selected locations on the tailing impoundments. Prior to this step, hundreds of tons of alluvium were transported on to the impoundments to provide road bases for the 35-ton trucks. Extensive dozer and grader work was also necessary to smooth tailing surfaces that had been eroded by winds. In some cases, this involved knocking down pedestals (hoodoos) 10 ft or more in height that were left standing after surrounding areas were eroded away.

All-terrain, balloon-tired hauling equipment with 16-ton capacities were used to spread the crushed rock from rear-mounted spreader units. The high flotation tires could operate at bearing pressures of less than 10 psi. This allowed the equipment to function in soft tailing areas. It also minimized the risk of forcing rock into the tailing. In contrast, this risk is greatly increased when standard ground pressure equipment is used to dump and spread rock materials. Use of such equipment may require application of material much greater than 2 in. in thickness to provide a satisfactory cover.

Dump and blade methods to distribute crushed rock at Ajo were limited to minus 10 in. or sometimes larger crushed rock applied to a minimal 6 in. thickness at the tops of embankment slopes and over the sides. These stable areas contain the coarser tailing fractions which are less subject to erosion and transport by winds than the finer fractions of the pond interior. However, leeward north-facing slopes contained major dunes of loose tailing that could become airborne at relatively low wind speeds. Large areas of these slopes were covered with crushed rock, but coverage was restricted to areas of noncrusted tailing.

The initial coverage of horizontal tailing surfaces was accomplished in approximately six months. There was always a risk that high winds would result in blowing tailing that would cover areas where the crushed rock veneer had already been applied. In fact, more than 100 acres were partially or completely covered by tailing deposition and required additional applications of crushed rock. The events demonstrated that all nearby areas with loose tailing should be stabilized in order for a veneer of crushed rock to remain effective.

Crushed rock was broadcast on the tailing impoundments to provide a 100% cover. Fine material content in the non-ore stockpile varied considerably, but the contractor attempted to limit minus 1/4 in. material to no more than 25% of the crushed rock application. Pockets of fines sometimes made that difficult. When crushed rock was first applied, some fines were found at the surface, subject to movement by strong winds. With the first significant rainfall, the fine particulates tended to infiltrate and combine with other stony residues, which upon drying, helped form a rocky crust that simulates the natural desert pavement that characterizes this area of the Sonoran Desert. Silicates, lime, and gypsum may enhance long term crustal stability and erosion control by cementing together with stony residues in the crushed rock material (Fuller, 1972).

### 18.4.4.3 Vegetation Effects

The application of crushed rock on more than 1450 acres of flat tailing surfaces allowed existing areas with trees and other vegetation to remain essentially intact. Some slope vegetation was removed so that heavily eroded surfaces could be smoothed and crushed rock could be pushed over the sides. Rock-spreading equipment was operated close enough to trees to cover most open surfaces between trees and tree rows in flat areas.

It is anticipated that the crushed rock veneer will enhance environmental conditions for the continued growth of existing trees and other vegetation on the tailing. Control of airborne tailing virtually eliminated the sandblasting of vegetation by winds. The crushed rock veneer maximizes infiltration of rainfall and reducing evaporation of moisture from the surface. Acting together, these factors increase the amount and duration of moisture available to root systems. However, many trees must first recover from damaged root systems caused by leveling of the surface prior to application of crushed rock. This process cut and destroyed shallow surface feeder roots.

The crushed rock cover will also significantly reduce tailing surface "albedo". The white uncovered tailing are highly reflective and this may be one of the important reflectivity factors that affected the survival of some

**Table 3** $PM_{10}$ 24-hr. concentrations monitored once every 6 days 1/3 mile downwind of tailing ($mg/m^3$)

| | #1 Monitor | | #2 Monitor | |
|---|---|---|---|---|
| **Month** | **Mean** | **24-Hr. High** | **Mean** | **24-Hr. High** |
| Feb 92 | 5.8 | 7.3 | 6.6 | 8.9 |
| Mar 92 | 10.1 | 14.6 | 12.4 | 22.6 |
| Apr 92 | 12.5 | 22.4 | 13.9 | 28.5 |
| May 92 | 7.6 | 12.8 | 9.1 | 13.6 |
| June 92 | 14.4 | 18.0 | 14.7 | 18.9 |
| Jul 92 | 13.3 | 18.0 | 12.3 | 15.9 |
| Aug 92 | 10.4 | 12.1 | 9.7 | 14.6 |
| Sep 92 | 12.9 | 30.0 | 12.9 | 28.0 |
| Oct 92 | 11.1 | 16.2 | 10.9 | 16.3 |
| Nov 92 | 14.0 | 25.4 | 14.8 | 28.0 |
| Dec 92 | 9.1 | 22.3 | 9.6 | 22.1 |
| Jan 93 | 5.5 | 9.8 | 5.0 | 8.3 |
| Feb 93 | 7.6 | 15.1 | 7.2 | 14.8 |
| Mar 93 | 11.8 | 16.5 | 12.2 | 16.6 |

species that were planted experimentally in the past.

Although the primary purpose of the crushed rock veneer was stabilization to limit wind erosion, more than 1000 lbs of native plant seed mixed with alluvium was broadcast on about 50 acres of the surface in July 1991, to encourage growth that would more closely approach natural conditions. Approximately half of the seed mixture was broadcast with a humus-base fertilizer and soil conditioner. This project was designed to place small amounts of viable seed in various microenvironments with a view toward finding suitable plant growth conditions under the variety of seasonal and annual climatic conditions. Therefore, the seed mixture was buried in alluvium at various shallow depths among minus 3 in rock. Swaths of the seed mixture were spread on each of the four tailing impoundments. Typically, this included areas near the perimeter where overlying coarse tailing particles and areas near the low points where underlying tailing particles are less coarse and where runoff may tend to accumulate.

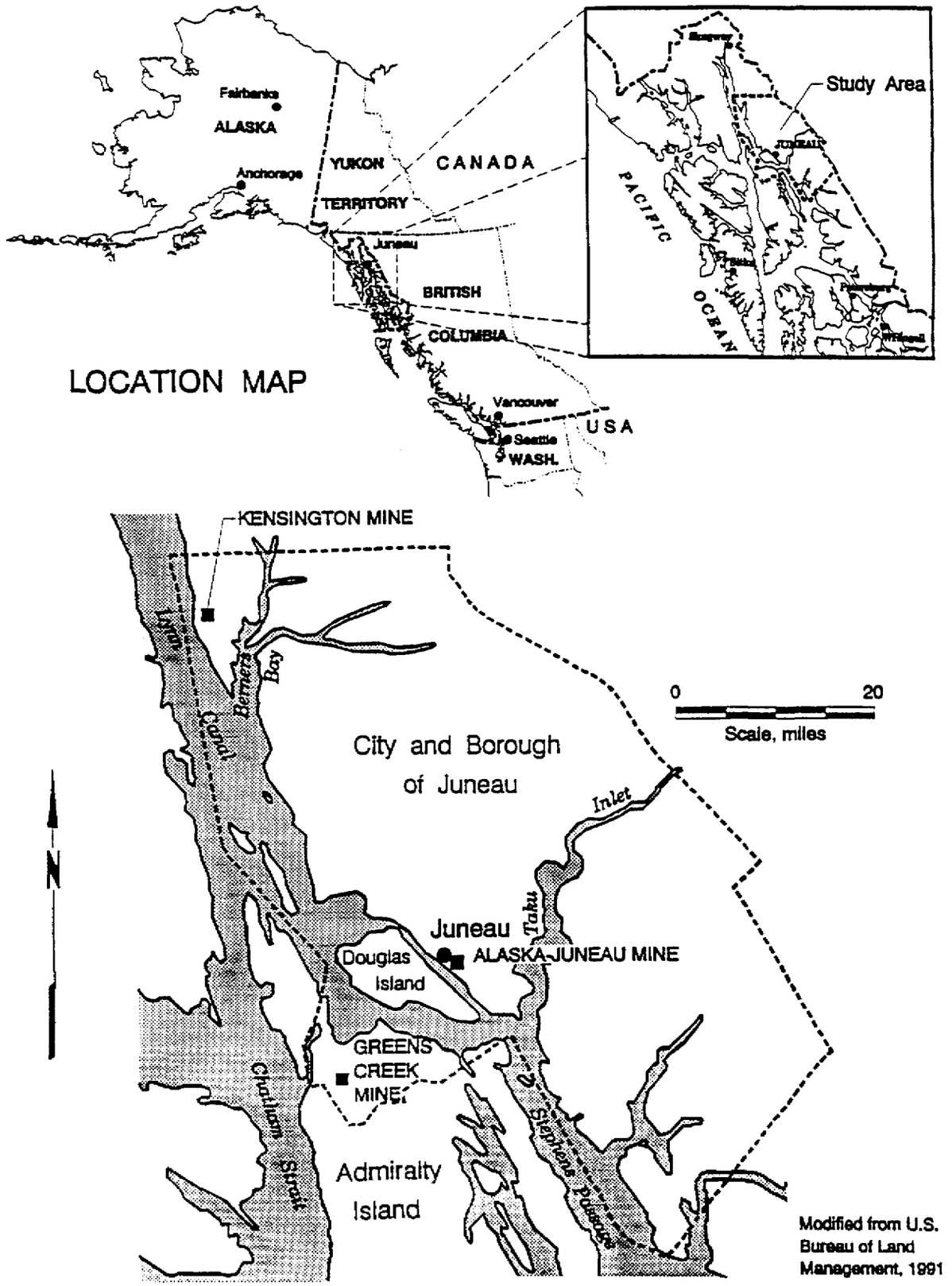
A seed mix of fifteen desert shrubs, herbs and grasses was selected with approximately half adapted to germination following winter rains and the others adapted to germination following summer rains. Both annuals and perennials were included. The goal was to establish a self-perpetuating source of native seed that would provide for seed dissemination to other areas of tailing in the future.

About half of mean annual rainfall occurs during the summer from July through September, usually associated with thunderstorm activity. Winter storms are typically less intense and of longer duration. About one third of mean annual rainfall occurs from December through March. Mean daily maximum temperatures exceed 100°F in July and August and are not much less in June and September (Sellers and Hill, 1974).

Seed production from plants that may grow on the covered tailing can be expected to vary greatly from year to year, largely because of variation in rainfall quantity and seasonality. Seeds of annual plants in particular may lay dormant for many years in the natural desert before germinating. Perennial plant establishment typically occurs infrequently and only in years when moisture and other environmental conditions are favorable (Shreve, 1951).

### 18.4.5 RESULTS AND DISCUSSION

Approximately 85%, or 1600 out of 1900 acres, of tailing at Ajo were covered with crushed rock between May 1990, and October 1991. All horizontal surfaces, about 1450 acres, were covered with a nominal 2 in. rock veneer that is similar to the natural desert pavement that occurs in the area. Approximately 66% of slope surfaces, about 150 acres, were covered with 6 in. or more of rock. Rock cover was only applied to slopes characterized by loose windblown tailing disposition such as dunes. Non-covered slopes are characterized by surface crusting and




Source: McDonald and Martin, 1992

**Figure 9** Mining activities in the Juneau area.

relatively coarse tailing particle sizes with little potential for wind erosion.

Total cost to implement the project on 1600 acres was $3.8 million or about $2375 per acre covered. Inefficiencies involved in covering dune slopes increased costs significantly, about five times more than horizontal surfaces on a per-acre basis. The 1450 acres of horizontal surfaces were covered with a rock veneer for approximately $2.5 million, between $1700 and $1800 per acre.

Significant rainfall over the winter and spring months of 1992 was followed by flowering and seed production from several annual desert plant species broadcast in the summer of 1991. Successful plant growth was limited to areas that received seed mixtures broadcast along with a humus-base soil conditioner, indicating that future self-perpetuating plant growth will be limited by the lack of organic matter in the tailing as well as available moisture.

Observations in the months following project completion indicated that very little particulate matter emanated from surfaces covered with rock veneer at wind speeds of 20 to 25 mph. Visibility degradation, annoyance to people living in the area, and potential $PM_{10}$ emissions were no longer a problem.

The voluntary project was nearly half-completed in November 1990, when the Ajo area was designated non-attainment for $PM_{10}$ by operation of the 1990 Clean Air Act Amendments. The designation was based on one recorded exceedance between 1985 and 1990. In a cooperative program with the Arizona Department of Environmental Quality (ADEQ), Phelps Dodge Corporation agreed to operate two dichotomous $PM_{10}$ samplers at least once every 6 days over a 3-year period as part of the State Implementation Plan (SIP) to demonstrate $PM_{10}$ attainment downwind from the tailing.

Monitoring activities began in February 1992 and results are shown in Table 3. The highest 24-hr concentration recorded was 30.0 $mg/m^3$. This is well below the National Ambient Air Quality Standard of 150 $mg/m^3$ and indicates that $PM_{10}$ tailing emissions are controlled effectively.

## 18.5 THE MINE PERMITTING PROCESS: A CASE STUDY OF THE ALASKA-JUNEAU MINE

**by W. E. Martin and L. A. McDonald**

### 18.5.1 INTRODUCTION

A study of the Alaska-Juneau Mine (A-J) provides insight into the effects of the mine permitting process on project development. Some of the more important issues highlighted by the permitting of the A-J mine are: its location adjacent to an old established city (Juneau, see Figure 9); a long history of operation (first opened prior to 1900); permitting requirements under a local ordinance as well as the more common federal and state permitting regulations; major design changes from the original plan were required; socioeconomic impacts of the project; and a change in the ownership of the public lands from the federal to the state government. Each of these issues provides information of interest and importance for other mining projects.

### 18.5.2 MINE HISTORY

Gold was discovered in placer deposits in the Juneau area in the early 1880s. After further prospecting, the A-J Mining Company filed for thirteen patented lode claims in the Silver Bow Basin in 1897. These claims eventually materialized into the Alaska-Juneau (A-J) and Perseverance mines located adjacent to the town of Juneau. The A-J Mining Company began production at the A-J mine using a 30-stamp mill soon after the patents were filed. This mill was used until 1912 when it was replaced by a 50-stamp mill. The mine reached peak production of 13,000 tons a day in the 1920s after a number of improvements and the addition of a new ball mill. The Perseverance mine was originally operated by the Alaska Gastineau Gold Mining Company from 1912 to 1920. This property was purchased by the A-J Mining Company in 1934 and was mined as part of the A-J operation until 1944 when both operations closed due to labor shortages and increasing production costs associated with the war effort. All properties and facilities associated with the mine were purchased by Alaska Electric Light and Power Company (AEL&P) and the City and Borough of Juneau (CBJ) in 1972. At one time the A-J mine was one of the largest underground gold mines in the world.

Echo Bay Alaska, Inc. (EBA) is presently seeking approval to reopen the A-J mine. EBA plans to lease the mineralized property from AEL&P and CBJ. In addition, EBA will lease lands from the State of Alaska and AEL&P for surface facilities and lands from Alaska for underground and tailings facilities. The State of Alaska recently acquired the lands from the U.S. Bureau of Land Management (USBLM) based upon the Alaska Native Claims Settlement Act of 1971.

### 18.5.3 PROPOSED DEVELOPMENT

The essential elements of the proposal submitted by EBA states that the mine project has 46 million standard tons of proven and probable gold reserves at a grade of approximately .05 ounces/ton. The mine is scheduled to produce 22,500 st of ore per/day with the life of the mine estimated to be 13 years (US Bureau of Land Management [USBLM], 1992). The project includes a

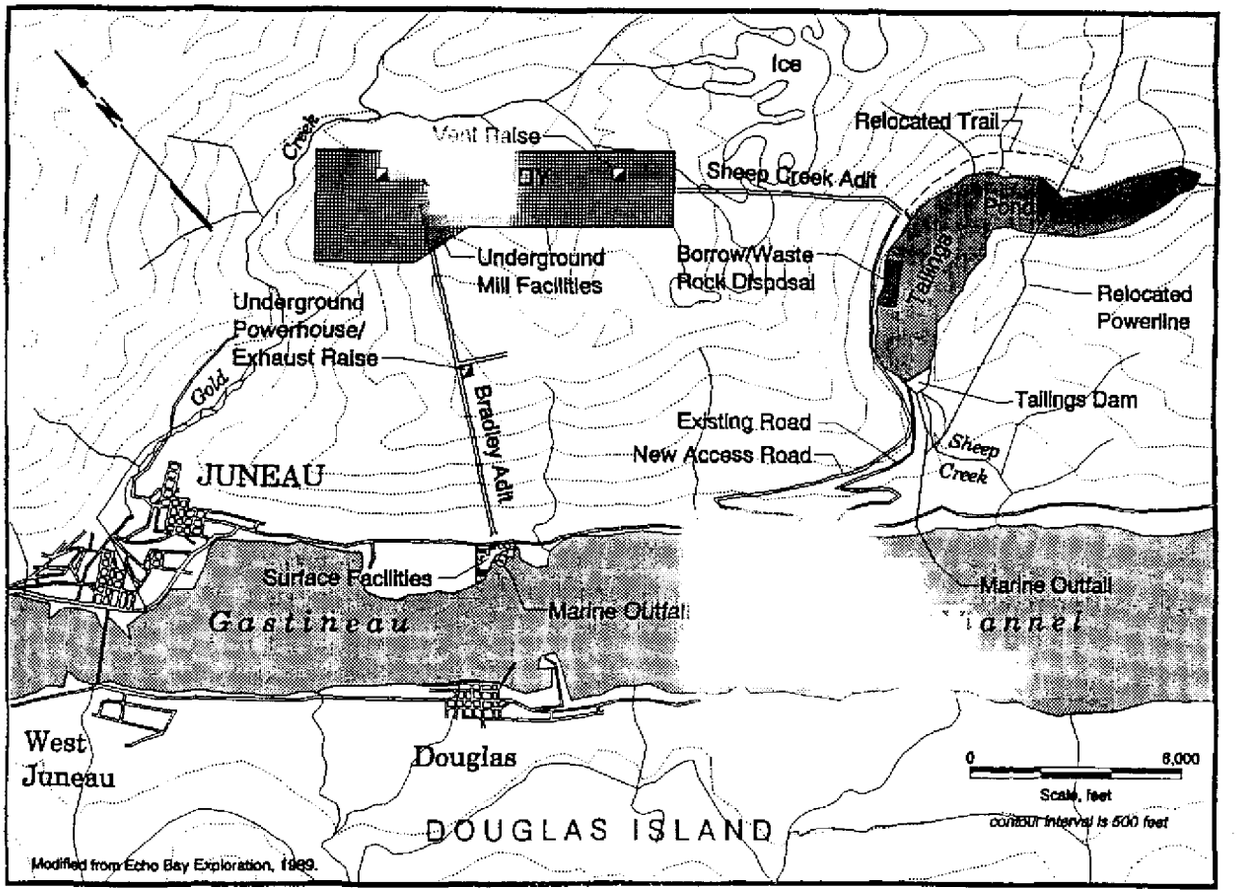



**Figure 10** Original A-J mine design.

surface processing and refining facility on a 30 acre site at Thane, southeast of Juneau (Figures 10 and 11). The Bradley Adit, a 2.7 mile tunnel, will connect the surface facility with an underground crushing facility located next to the ore body.

EBA will use the stoping under rock fill (SURF) mining method (USBLM, 1992) due to the low grade of the deposit. Ore will be mined from predetermined blocks in two steps. First, twenty-five percent of the ore will be removed to make room for the remaining broken ore. Then the remaining ore will be extracted by mechanical scoops after a sequenced mass blast. The predetermined blocks (unit stopes) are 160 feet along the direction of the ore body, 380 feet high and range from 40 to 550 feet in width (USBLM, 1992). The broken gold-bearing ore will then be transported to an underground mill where it is crushed and gravity separated. The remaining fine grain material is transported to the surface facility for further refining using a cyanide leaching process. It is proposed that the tailings be thickened into a slurry and pumped back through the Bradley adit to a tailings impoundment located in Sheep Creek valley. Excess waste rock will also be transported to a permanent disposal site in Sheep Creek valley. The project is fairly straightforward from an engineering point of view, but there are several non-engineering issues that must be considered that make the A-J project unique.

### 18.5.4 PERMITTING THE A-J MINE

Over the course of permitting the A-J mine, Echo Bay has been faced with a variety of unusual events. This section will address six permitting issues that provide interesting lessons for other mines and insight into the effectiveness and potential impact of the permitting process on mine development and operation.

#### 18.5.4.1 Reopening of a Mine

The A-J mine had previously operated for approximately 30 years and if it should reopen, it will have been at least 50 years since it last operated. Over this time dramatic changes have occurred, particularly regarding the attitudes of environmental impacts of mining. It appears that the area, which has traditionally been dominated by supporters of extractive industries, has now attracted a

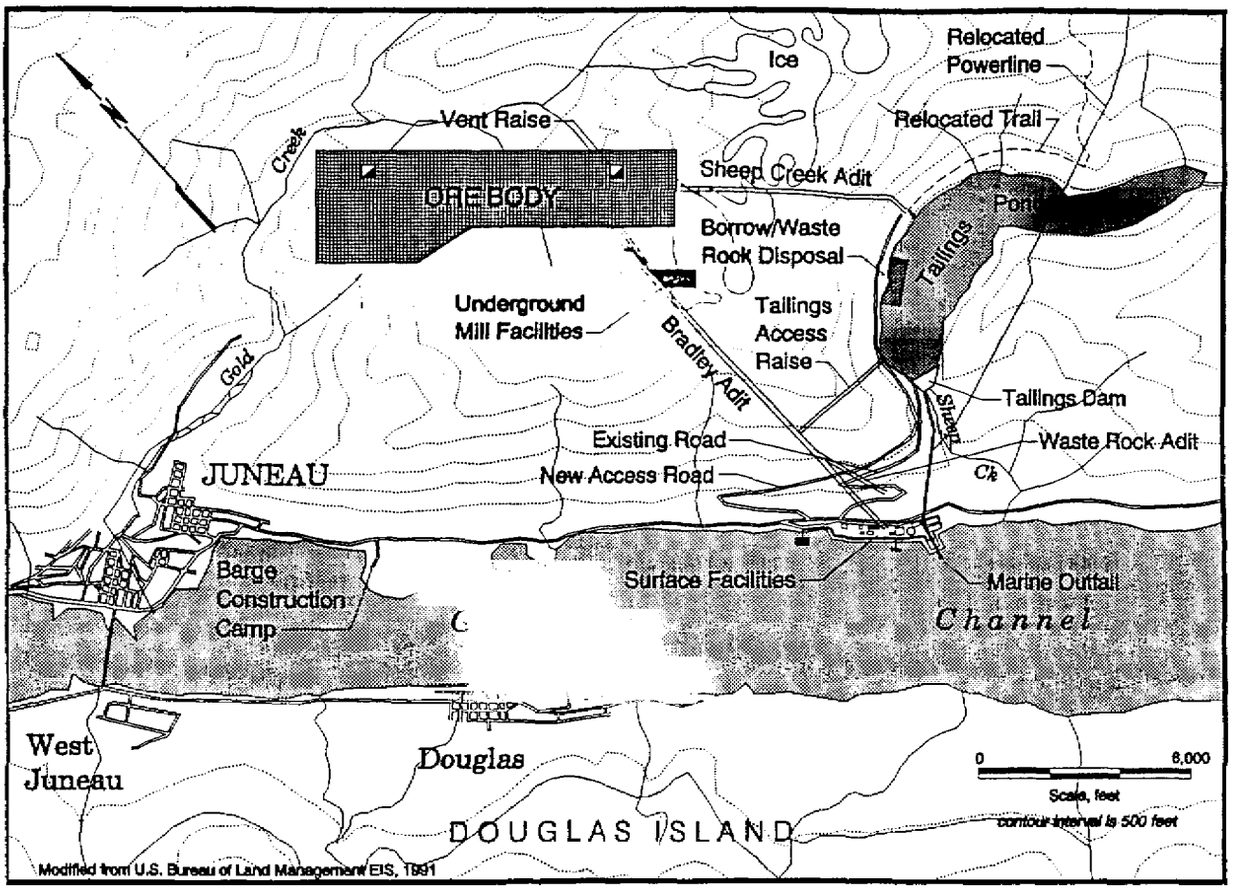



**Figure 11** A - J Mine design, 1992.

strong environmental component.

### 18.5.4.2 Development Within City Boundaries

The City and Borough of Juneau (CBJ) was the first local government in southeast Alaska to expand its influence in the environmental compliance process to include legal requirements designed to address environmental impacts prior to allowing development of a mine. State and local governments are allowed to set criteria which are more stringent than federal regulations as long as a right which has been granted by federal legislation is not rendered impossible to exercise by such laws (Laitos, 1985). The CBJ amended an ordinance which affects all exploration and mining activities within CBJ's jurisdiction on October 6, 1989 (CBJ Ordinance 89-47am, 1989). This ordinance is relevant to a number of mining operations and communities because the area within CBJ's jurisdiction is very large (see Figure 10). The City and Borough of Juneau is comparable in size to the State of Rhode Island. These amendments require mining and exploration activities within CBJ's boundary to obtain permits for large mines from CBJ. Large mine projects are ones which will disturb 20 or more acres, employ 75 or more or where there is a full Environmental Impact Statement involved (CBJ Ordinance 89-47am, 1989).

CBJ requires operators of large mining projects to submit an application for a mining permit in the form of a report containing specific information regarding mining operations which officials can use to determine if the operation complies with federal, state and local environmental requirements. Information included in the application consists of (CBJ Ordinance 89-47am):

- Description of the mine site and affected surface area including all roads, buildings and processing facilities;
- Time table of the proposed mining operation;
- Description of all reclamation operations;
- Description of methods used to control, treat and transport hazardous substances, sewage and solid waste; and
- Description of other potential environmental, health, safety and general welfare effects.

**Table 4** Summary of Federal Environmental Permits Required for Mining Projects in Southeast Alaska

| AGENCY | CWA | CAA | RCRA | OTHER |
|---|---|---|---|---|
| EPA | NPDES<br>SPCC<br>Review Section 404 Permit | PSD Approval | Notification of Hazardous Waste Activity | NEPA Compliance |
| COE | Section 404 Permit | | | NEPA Compliance<br>Section 10 (R&HA)<br>Section 103 (MPRSA) |
| USFWS | | | | Threatened and Endangered Species Clearance<br>Bald Eagle Protection Act Clearance |
| USFS | | | | NEPA Compliance<br>Special Use Permit<br>Reclamation Bond<br>Plan of Operations |
| USBLM | | | | NEPA Compliance<br>Right-of-Way Permit<br>Special Use Permit |

An additional requirement for a mining permit from CBJ is a financial warranty. The amount of the financial warranty will be determined by city officials using the advice of the engineering department and consideration of all financial warranties given to other agencies. Operators may be exempt from providing a financial warranty if officials determine that warranties already provided to other government agencies are sufficient to cover CBJ's requirements. The warranty will be reviewed annually to determine if the amount should be increased or decreased (CBJ Ordinance 89-47am).

A summary of major federal, state and local environmental permits and requirements for the A-J mine are listed in Tables 4, 5, and 6. There are additional requirements which Echo Bay will have to meet which are not listed in this summary.

### 18.5.4.3 Land Ownership Issues

While the USBLM was the lead agency throughout the NEPA process, current uncertainty of its continuing role dates back to the Alaska Statehood Act of 1959. When Alaska was admitted as a new state into the union the act specified that Alaska would be permitted to select 100 million acres of federal land for the state. Once the state began selecting land, controversy surfaced regarding claims by Alaskan natives. This was resolved by passage of the Alaska Native Claims Settlement Act (ANCSA) in 1971. Under ANCSA Alaskan Natives and Native Corporations were allotted approximately 44 million acres, 80 million acres were set aside for the federal government and the state selection process was permitted to continue. Other issues associated with land transfers in Alaska were addressed by Congress in the Alaska National Interest Lands Act of 1980. This act will not be addressed since it has little impact on the land ownership issues affecting the A-J mine. At this time, the state has selected land surrounding the A-J mine that was previously managed by the USBLM. Since the USBLM is no longer directly involved in the land management of the area, they have adopted the position that they have no standing to issue a record of decision (ROD) and have basically resigned from the process. At this time it is unclear which agency will issue a ROD or if multiple agencies will issue RODs.

### 18.5.4.4 State And Federal Roles

Another major delay of the A-J project has been the issuance of the National Pollution Discharge Elimination System (NPDES) permit. Currently the NPDES permit is being delayed due to the uncertainty regarding the standards set by the state of Alaska. Alaska is revising its water quality standards which must then be approved by the EPA under the Clean Water Act. Revision of state water quality standards is required every

**Table 5** Summary of Alaska State Environmental Permits Required For Mining Projects in Southeast Alaska

| AGENCY | CWA | CAA | RCRA | OTHER |
|---|---|---|---|---|
| ADEC | Certification of Reasonable Assurance<br><br>Oil Facility Discharge Contingency Plan | Air Quality Permit | Solid Waste Management Permit | Oil Facilities Approval of Financial Responsibility |
| ADGC | | | | Coastal Project Questionnaire<br>Coastal Management Program Certification |
| ADNR | | | | Water Right<br>Tidelands Lease<br>Permit to Modify or Construct a Dam<br>Right-of-WayPermit |
| ADF&G | | | | Fish Passage Permit<br>Fish Habitat<br>Approval of Coastal Zone Management |

**Table 6** Summary of CBJ Environmental Permits Required for Mining Projects in Southeast Alaska

| AGENCY | CWA | CAA | RCRA | OTHER |
|---|---|---|---|---|
| CBJ | | | | Mining Permit<br>Financial Warranty<br>NEPA Compliance |

three years by amendments made to the Clean Water Act, and this has delayed issuing the NPDES permit for A-J and several other projects.

### 18.5.4.5 Technical Design Changes

Another impact of the environmental permitting process on the A-J project are a number of design changes which were proposed by EBA as the project moved through the NEPA process. The majority of these changes can be attributed to the high degree of public scrutiny the project has experienced, mainly due to the close proximity of the project to Juneau and Douglas. Major design changes include: 1) moving milling operations to an underground site; 2) moving the surface facilities from the Rock Dump site four miles south to Thane; and 3) using liquefied petroleum gas (LPG) instead of diesel fuel for power generation. There were also a number of minor design changes which were initiated by the NEPA process which are discussed in the Draft EIS (USBLM, 1991).

Problems associated with leasing and the physical nature of the area along The Gastineau Channel, reduced the number of sites available for a milling facility. The location of any surface facilities at the North Rock Dump Site were eliminated from further consideration because of the ongoing litigation surrounding land ownership (Bank of California v. Hayes, IJU-82-2048 Civil Superior Court, First Judicial District at Juneau) (USBLM, 1989). The close proximity of Juneau and Douglas reduced the feasibility of placing a milling facility on the surface due to noise generation during operation. By moving the milling facility below ground, reduced noise and reduced intertidal and subtidal fill

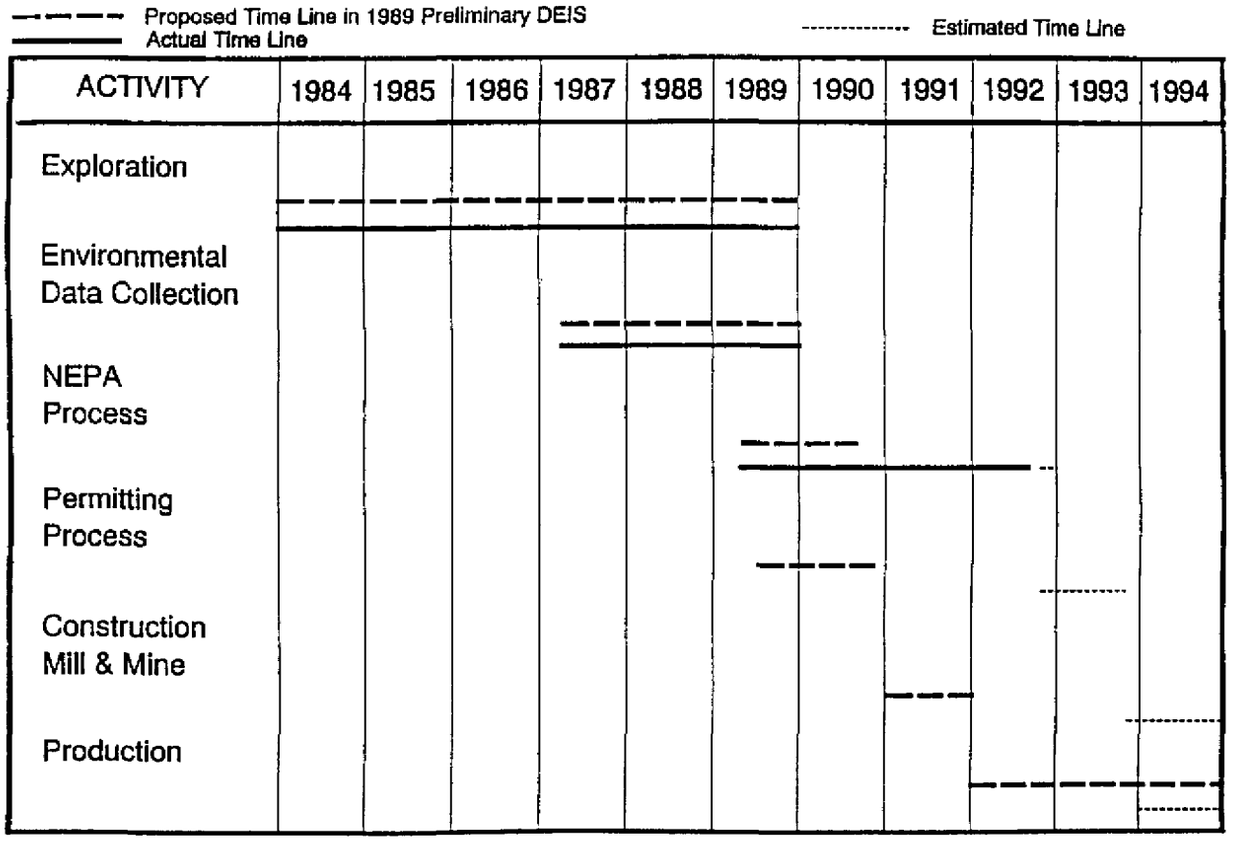



**Figure 12** Estimated timeline for the A - J Project.

requirements have been achieved.

### 18.5.4.6 Time Line Impacts

After several years of exploration and environmental baseline studies, EBA filed the necessary documents with the USBLM to begin the NEPA process in 1989. In addition, EBA filed a number of appropriate permit applications with federal, state and local agencies. A preliminary Draft EIS was completed in October, 1989 and the Final Draft EIS for general comment was released in January of 1991. The initial permits were amended and evaluated with the Final EIS, which was released in May, 1992.

Company officials are assuming that NEPA review and authorization of the project will be completed in 1993. This estimation may be optimistic since the land transfer between the USBLM and the state of Alaska has not been finalized. Even though the final EIS has been released, no ROD has been issued. At this time it is believed that either the EPA or Corps of Engineers (COE) will write the ROD, assuming they agree on the form it should take. If the COE and EPA disagree as to the form it is conceivable that *both* would issue RODs. Construction of the project is expected to take 30 months to complete which would allow gold production to commence sometime in 1995. The mine is expected to operate until 2008 with reclamation activities after closure to take approximately two years. The estimated, actual and proposed project time line are presented in Figure 12.

## 18.5.5 CONCLUSIONS

The NEPA process for the A-J mine began in 1989 and lasted well into 1992 and as of late 1993 there is still no ROD. During this process not only did the various governmental agencies involved have significant input but there were over 100 public meetings regarding the proposed project. This case highlights the potential issues that may need to be addressed by a firm considering developing a mine in a similar area. Although it is important for all affected parties to be fully informed and the various opinions addressed, it is also important that this process proceed in a timely and efficient manner. The A-J study illustrates the delays to which the permitting process can impact the development of a mining project.

## 18.6 OREGON - THINGS LOOK DIFFERENT HERE

(Development of the Oregon
Chemical Process Mining Act of 1991)
**by R. K. Urnovitz**

### 18.6.1 INTRODUCTION

The State of Oregon has a reputation for using uncompromising solutions to address environmental problems. When exploration activities for precious metals intensified in the late 1980s, a high level of concern arose regarding possible adverse impacts from mining operations that employed leaching technology. The mining community, led by the Oregon Mining Council (OMC), responded to the concerns of the public by attempting to educate people about mining and emphasizing the range of measures available to minimize or mitigate impacts to the environment. This initiated the lengthy political process that culminated in a new state statute addressing chemical process mining, House Bill 2244 (HB 2244), and three major rulemakings by the executive agencies.

The OMC made a good faith effort throughout the legislative process to work closely and constructively with the Governor's Office, the Legislature, state and federal agencies, and the public to develop a comprehensive, no-nonsense regulatory program for mining. It is fair to say that none of the parties involved, including several of the state agencies, are entirely satisfied with HB 2244. Nonetheless, support for the bill was given by all parties because the alternatives, such as litigation or a citizen's ballot initiative, were much less desirable. Even though the overall effort received mixed reviews, having all the interests attempting to overcome their own biases by working together in a constructive forum set a very important and positive precedent in the State of Oregon. The lesson can be applied to future activities heavily influenced by politics, though the approach used in Oregon is widely regarded by many in the mining industry as being very risky. This case study describes the key elements of the most critical component, the functioning of the Governors Mining Work Group (GMWG).

### 18.6.2 A BRIEF HISTORY

Mining of metallic minerals began in Oregon with placer gold deposits being worked before statehood was granted in 1859. The largest gold mine in the state, as of 1992, is a placer operation; the Bonanza Mine near Baker City in Baker County. Also, Cominco American has operated Glenbrook Nickel Company near Riddle since 1988, after taking over the 40 year old operation from Hannah Mining. In 1990, Formosa Exploration completed permitting of the Silver Creek Mine in Douglas County and began operations to extract copper and zinc. And, at the time of this writing, Plexus Resources, Inc. of Salt Lake City was in the midst of permitting the Bornite Project, a proposed underground copper mine, on lands administered by the U.S. Forest Service in Marion County.

A number of well established mining organizations represent the several districts of independent miners. The most notable of these are the Eastern Oregon Mining Association (EOMA) and Bohemia Mine Owners Association (BMOA), serving the mining district of the same name. The primary membership of these two groups is individuals and small mining companies that are involved in developing placer deposits. The Northwest Mining Association (NWMA) of Spokane, Washington, a longtime participant in Oregon mineral affairs, along with a relatively new organization, the Oregon Mining Council (OMC), addressed the concerns of the larger mine operators. All the mining groups work closely with each other on issues of common interest.

### 18.6.3 EARLY REGULATION

#### 18.6.3.1 1990: Rule-Making

The Oregon Department of Geology and Mineral Industries (DOGAMI) was responsible for an earlier successful effort at negotiated rulemaking. Both the NWMA and the Oregon Environmental Council (OEC), an environmental organization, participated in this process along with the Oregon Department of Water Resources (ODWR). The major discussion areas were surface reclamation and drill-hole abandonment. Discussions were frank, honest, and open. The parties acknowledged the value of educating one another on both policy and technical issues. Miners provided recognized experts to discuss how to avoid potential problems with exploration activities. The result was a successful rulemaking by DOGAMI, that also met the needs of ODWR. The OEC was fully involved from the beginning of that process and all available information was provided to them by the mining community.

Significantly, the final rules approved in 1990 were not appealed. This demonstrated that the groups involved in the rulemaking process believed that everyone had worked together in good-faith. More significantly, it indicated that even organizations with extremely different viewpoints could cooperate to assist the agencies in developing acceptable regulations.

From the perspective of the mining industry, the rules adopted by DOGAMI were reasonable and workable. ODWR felt the rules were protective of ground water quality, and it gained the benefit of receiving aquifer data generated during exploration operations. DOGAMI had a set of comprehensive and enforceable regulations that would minimize the impacts from exploration activities, which also satisfied the OEC.

This endeavor helped establish the model for the legislative activities that culminated in HB 2244.

Soon after the rulemaking for surface reclamation and drill hole abandonment, the environmental groups began working to increase the political pressure on gold mining. They focused on the Grassy Mountain Project of Atlas Precious Metals (Atlas) located in Malheur County, advocated a moratorium on permitting for any gold project that would use cyanide as a reagent, wanted the complete backfilling of all open-pits as a mandatory requirement of surface reclamation, and a severance tax of 15% of gross revenues.

The mining community recognized early on that a concerted educational effort had to be undertaken to avoid a complete ban on gold mining operations using cyanide heap leach technology. The most immediate result was the formation of the Oregon Mining Council (OMC) in March of 1990.

The first major public debate took place at the "Mining Issues Forum" sponsored by DOGAMI, held September 8, 1990, in Bend, Oregon. Virtually all the issues that were debated prior to the passage of HB 2244 were raised that day. These included:

- Wildlife mortality from cyanide exposure, particularly migratory birds;
- Surface reclamation standards, with linkage to land use;
- Preventing adverse impacts to ground and surface water quality from cyanide and acid rock drainage (low pH and mobilization of heavy metals);
- Mitigating adverse impacts on the local community (infrastructure, social services);
- Appropriateness of a severance tax on metallic mineral production;
- Inspection and enforcement;
- Bonding and surety requirements; and
- Coordination of multi-agency permitting and review procedures.

*18.6.3.1.1 Establishment of the Governors Mining Work Group*

Late in September of 1990, Governor Neil Goldschmidt created an ongoing forum for open discussion of mining related issues, the Governors Mining Work Group (GMWG). The key participants were the OMC, EOMA, DOGAMI, The Office of the Governor (Neil Goldschmidt from 1990 through 1991 and Barbara Roberts from 1991 through 1992), the OEC, the Wilderness Society, The Sierra Club, The Native Plants Society, the Oregon Department of Environmental Quality (ODEQ) and the Oregon Department of Fish & Wildlife (ODFW). Other groups that played a role were the Oregon Natural Resources Council (ONRC) and BMOA.

*18.6.3.1.2 Heap Leach Gold Mining Issues*

The mining community understood that the GMWG would be crucial in setting the tone for addressing issues during the legislative session. The miners tended to view the scope of issues as those directly affecting Oregon, whereas the environmental groups broadened the scope to include national mining issues pertaining to any adverse impacts attributed to poorly managed mining activities anywhere. This broadened scope increased general public interest in the legislative debates. An objective evaluation revealed some of the cases publicized by the environmental groups were relatively well documented and illustrated not only the concern, but also indicated possible constructive solutions that would be acceptable to the mining community. The OMC took the opportunity to provide additional details that completed the story begun by the environmental groups.

The core issues fell into these general categories:

- Prevention of avian mortalities & other adverse effects to wildlife;
- Adequate open pit reclamation standards;
- Protecting water quality from cyanide and acid rock drainage;
- Mine permit application review process; and
- Mitigating socioeconomic impacts to local communities.

**18.7.3.2 1991: A New Governor Takes Office**

Where Governor Goldschmidt was a moderate, the incoming Governor, Barbara Roberts, was decidedly liberal in her views. She enjoyed wide support among the environmental groups, as her stated public policy positions were very compatible with theirs. However, Governor Roberts did not receive a mandate from the voters. Her conservative opponents split their collective vote, allowing her to take office with less than 47% of the ballots cast. The conservative groundswell resulted in the Republicans gaining a slim majority in the Oregon House for the first time in twenty years. The Democrats retained control of the Oregon Senate.

The mining community recommended that the GMWG be continued as it appeared to be a useful forum for dialogue that would allow them an opportunity to help set the legislative agenda. Governor Roberts decided to continue the GMWG and appointed Ms. Martha Pagel as the new Chair.

## 18.6.4 THE LEGISLATIVE PROCESS

### 18.6.4.1 The Early Bills

The OMC was advised at the beginning of the session by both the Republican and Democratic leadership that a

mining bill was going to be passed and it was encouraged to fully participate in the process. Both DOGAMI and the environmental groups were prepared to submit legislative proposals. The OMC supported two DOGAMI items that were introduced in the House. One would make the use of white PVC pipe illegal when staking locations on federal lands. The other, HB 2244, proposed improvements in the states mine permitting process to better coordinate the responsibilities of the various state agencies.

HB 2244 began as a relatively modest attempt by DOGAMI to address several perceived shortcomings in the states mine regulatory program. In particular, they wanted to clearly provide for opportunities for public input and hearings in the DOGAMI permitting process and to evaluate socioeconomic impacts to local communities to determine if some form of mitigation should be considered.

The environmental groups developed a comprehensive mine regulation and reclamation proposal that was introduced on their behalf in the Senate, Senate Bill 1182 (SB 1182). It featured such provisions as mandatory backfilling to approximate original contour of all open pits, broad application of Best Available Control Technology (BACT), zero loss of wildlife due to mine operations, permit blocking for operators not in compliance with the law, citizen inspections of mines, and broad citizen suit provisions.

While the political wags suggested that the short title of SB 1182 bill should be "The Ban Mining In Oregon Act of 1991", no one joked about the serious implications for the mining community if the bill passed. OMC made it very clear that SB 1182 was completely unacceptable and unnecessary. Further complicating the situation was the threat by the ONRC to put a citizens initiative on the ballot and ask Oregonians to impose the terms of the bill if the proposal failed in the legislature. The mining industry wished to respond in a meaningful way to this initiative and OMC members believed that endorsing the DOGAMI proposals would adequately demonstrate that the industry wanted to continue to work in good faith with the state regulatory agencies. It was believed that this approach would be effective in dealing with radical proposals, while minimizing the political risks that the industry would have to take.

### 18.6.4.2 Action In The House

Early in the session the House Committee on Agriculture, Forestry & Natural Resources (Agriculture Committee) held hearings on DOGAMI's HB 2244. While a number of committee members were sympathetic to minings point of view, they were also sensitive to the concerns of the public as reported to them in the major newspapers.

The mining industry presented testimony supporting the basic concepts of HB 2244 and made suggestions for improvements. The Agriculture Committee asked OMC to submit language intended to strengthen and expand the original bill, especially in areas of wildlife protection. Since no language had been prepared, it was agreed to bring back material for consideration within a few days. The miners were pleased with this, as it appeared that the House would indeed be responsive to their concerns, as had been expected.

However, the legislator assigned the task of drafting the language decided to ask the GMWG to develop amendment language for the bill. By not having comprehensive language prepared at the time of the initial hearing, the mining community lost the opportunity to control the agenda. The Agriculture Committee soon expanded their request and asked the GMWG to attempt to reach a consensus on as many of the issues as possible and bring back outstanding items.

### 18.6.4.3 Negotiating Statutory Language

OMC recognized that the GMWG had become the keystone to the legislative effort, rather than the legislature itself. If OMC successfully worked with the GMWG, then there was a good chance of having an acceptable statute coming out of the legislature that the governor would sign. However, if miners did not work in good faith in the GMWG and were perceived as being obstructive, then the chance for a successful outcome for the mining interests would be diminished. By this time miners were beginning to accept that the Oregon permitting program would include a stringent and complex review process; but the price could be worth paying if the extremely difficult standards being proposed by the environmental groups were to be avoided.

As the center of action moved to the GMWG, Martha Pagel, as Chair, became the key player. She was tough minded, but fair in her approach. Preliminaries included setting the agenda and deciding who would participate in the negotiations. The GMWG had already started the agenda setting process, and the representation question was a problem only for the activist community. The limitation on the number of individuals that could be directly involved in the discussions was a practical consideration. It was necessary to maintaining continuity between meetings and to hold each group involved accountable for its statements and positions.

Remarkably, though emotions ran high from time to time, everyone directly involved in the negotiations remained civil and tried to respect other positions even while strenuously disagreeing. This allowed some bridges to be built between the various factions based on recognition that a good faith effort was being put forth. There was the usual posturing, especially at the early sessions, but by the end a level of trust had developed

that allowed real progress to be made.

At the same time as the GMWG was working, testimony had to be prepared and presented for hearings on other mining related bills, including SB 1182. In this testimony miners tried to send a clear message to the Senate and the activist community that OMC rejected the intent of SB 1182 in its entirety, and again emphasized that a permitting moratorium was unacceptable under any circumstances. It was stated that the bill did not represent a viable, reasonable approach to mine regulation. Even while this testimony was being delivered, everyone was aware that concepts from SB 1182 were going to find their way into the "consensus" item being worked on in the GMWG; but OMC was determined to make sure that the bill finally acted upon was an improved HB 2244 and not a pared down SB 1182.

About this time, some miners felt the threat of a referendum was becoming a secondary concern, since the possibility of a lengthy permitting moratorium seemed to be a far greater threat. By avoiding a moratorium, it was hoped to provide Atlas, as well as other OMC members, with an opportunity for getting projects on-line, since they were already well along in the existing permit process. The pace of events was accelerating, and OMC advised its members that they should prepare for a real *Nantucket Sleigh Ride*.

One major concession the mining industry obtained in the GMWG was to have HB 2244 apply only to chemical process mines. Specifically excluded were gravity beneficiation methods, such as placer operations and flotation mills. The primary reason that the GMWG accepted the concession was that the group had concluded during the Goldschmidt Administration, that the state agencies already had adequate statutory authority to regulate any aspect of mining that could create an adverse environmental impact. The irony of the situation was not lost on the mining community.

Consensus was reached in the GMWG on a large number of items. There was broad support and basic agreement on the substantive issues listed below. Complete closure eluded the GMWG so the outstanding items went to the legislature for its decision, as outlined below:

**Public Participation**

***Consensus:*** any permit review process must have adequate opportunity for public review and comments.

***No Consensus:*** number and length of appeals, and if the process should be stayed automatically for any and all appeals.

**Standards and Monitoring**

***Consensus:*** air and water quality should be protected, all applicable standards met, and monitoring is to be normal and necessary to confirm that standards are being achieved.

***No Consensus:*** whether mining companies should be allowed to perform any of the monitoring or should all such work be done by third party consultants under contract to the state, but paid for by the permit applicant.

**Wildlife**

***Consensus:*** all reasonable measures should be employed to minimize loss of wildlife directly attributable to mine operations, and a goal of no net loss of wildlife.

***No Consensus:*** whether the standard should be zero wildlife mortality with any loss of wildlife due to mining activities constituting a permit violation.

**Reclamation**

***Consensus:*** surface disturbances must be reclaimed and rehabilitated with the goal of leaving the site in a physically and chemically stable condition that does not pose a hazard to humans, livestock, or wildlife. Revegetation efforts should emphasize the use of native species, but the use of adaptive species for interim stabilization and areas that could be prone to erosion would be allowed. The final result should blend in with the surrounding terrain and support a stable and reasonably diverse plant community. It needs to be noted that the state agencies, especially DOGAMI, worked hard to convince everyone that nobody can *restore* a surface mining site; however, good reclamation would act as a catalyst so nature can complete the job in a fairly short time.

***No Consensus:*** whether backfilling of all pits and excavations and reshaping all sites to approximate original contour should be mandated.

In addition, the mining industry continued to have serious concerns regarding the following outstanding items, which were expressed in both the GMWG meetings and before the Agriculture Committee:

- Any kind of moratorium or other prohibition on mine permit processing.
- Requiring companies that had been acting under state agency direction to start over from the beginning of any new process that may be put in place. The inclusion of a fair and equitable means of allowing companies that were already "in-the-pipeline" to transition from the current ad hoc joint permit

approach to the proposed statute based consolidated permit process had to be a priority item for consideration in the final bill. The bottom line for the environmental groups on this issue centered on public involvement and full compliance with any new environmental standards. OMC pointed out that any projects being proposed on federal lands would meet the former requirement due to the NEPA process and would not be exempt from the latter.

The possibility of a dual EIS type project/permit approval process for projects on federal lands had to be avoided. OMC believed the state agencies should be required to enter into a Memorandum of Understanding with both the BLM and USFS in order to combine their respective EIS data collection and analysis requirements so the whole process would only have to be done once. This would be especially important for those projects that include both private or state and federal land ownership. For these reasons, OMC felt that the GMWG process could still benefit from the direct participation of the BLM and USFS and recommended that they be invited to participate.

The suggestion of federal participation in the GMWG was summarily dismissed by the Chair. It was stated that the federal agencies were not considered to be credible defenders of the environment by the administration. OMC could not pursue the matter further at that point, but presumed that this complete disregard for what appeared to be a legitimate role for the federal land management agencies, and the preemption authority of the federal government, was an ill omen for the final outcome of their endeavor.

The most contentious issues became the moratorium on permit processing proposal and mandatory pit backfilling at all mine sites. While the House committee remained somewhat supportive, it felt compelled to make sure that the bill was comprehensive and included rigorous, but ostensibly fair, standards. The House passed the measure in a form that was already far more rigorous than industry had hoped the final bill would be after its journey through the Senate. Even though the mandatory backfilling provisions were not included, miners thought they were facing a grim situation.

Soon after passing the House, HB 2244 was considered before the Senate Agriculture and Natural Resources Committee. Where the House had always been somewhat sympathetic to the concerns of the mining industry, the Senate had always been less than enthusiastic about the prospect of large scale mining ventures coming to the state. Nonetheless, the Senate Committee did allow the industry an opportunity to present its case. A very thorough and well thought-out presentation was made to assure the Senate committee that OMC was taking the issues seriously and was working in good faith to put together a stringent, but practicable program. To OMCs surprise, miners were assured by the committee Chair that it was not his intention to pass a measure that would prevent mining from occurring in Oregon. Even more astonishing, the Senate only dealt with two substantive matters, which had been considered and dropped by the House. These were the long standing moratorium issue and the appeal provisions that included automatic permit stays. The Senate, taking a cue from the House, sent these items back to the GMWG in a last attempt to reach a consensus.

In an effort to gather additional political strength to counter that of the environmental groups, OMC reviewed its options to see what could be done to rally public support. For example, many mining people felt that a more aggressive public education program needed to be implemented. However, the time frame involved was not sufficient to significantly expand the existing effort that the OMC budget included such as slide show lectures to civic groups, radio talk shows, working with newspaper editorial boards, and distribution of brochures. It was reluctantly admitted that the program OMC could afford versus the one it needed, full page newspaper ads and television spots, would do little good in the near term.

In the end, the Senate committee agreed to only a few amendments to the House version of the bill. The items that resulted in the most intensive lobbying were the permit moratorium and automatic permit stay pending the final resolution of appeals of any permit provisions. The conference committee resolved their differences by retaining the permit moratorium while regulations were promulgated and reducing the length of time that appeals would take, but retained the automatic stay of permit provision.

#### 18.6.4.4 What Everyone Thought HB 2244 Meant

As is often the case, consensus had been reached on a number of items through finessing the meanings of certain terms. This was, of course, done quite consciously and all the parties were sure that their wording would provide them the upper hand during the regulatory development process. This would, however, result in interpretations of the act so disparate, that it would be hard to believe that people had read the same provision of the enabling statute when rulemaking began.

The following summarizes the most widely held interpretation of HB 2244. The bill consolidated the application requirements of the various state agencies that deal with mines into a single permitting process so as to allow better coordination among the agencies and to set up a mechanism to resolve conflicting regulatory

requirements. Pursuant to Section 37 of the bill, permit applications under this program would not be accepted before October 1, 1991, to allow time for the completion of an emergency rulemaking by DOGAMI, which was designated as the lead state agency for the new permitting process, as well the other state agencies involved. However, all the rule promulgations were not actually completed until September of 1992. The bill also provided for strict environmental standards in Section 4, including an objective of zero wildlife mortality, the use of pit backfilling to address environmental impacts that cannot be mitigated any other way, and the use of best available and practicable technology to meet environmental standards. Section 21 provided for automatic suspension of approved permits if appealed. A very high level of citizen participation was requested by the environmental groups and supported by the state agencies. Civil penalty provisions, Section 24c, were also incorporated.

Applicants are now liable for fully reimbursing the state agencies for any costs directly related to processing an application, including agencies that have only an advisory role to an agency issuing a permit. This is a trend in all of Oregon's permitting programs and is not unique to mining.

The provisions of HB 2244 *do not apply* to mine operations employing flotation or gravity processes, dredge and placer operations, very small mines regardless of beneficiation process employed, or exploration activities. These operations continue to be regulated under existing regulatory programs.

Signed into law by Governor Barbara Roberts in July of 1991, HB 2244 triggered a wave of regulatory promulgations made necessary to meet the provisions of the statute. The most important were those by the Oregon Department of Geology and Mineral Industries (DOGAMI), the Oregon Department of Environmental Quality (ODEQ), Oregon Department of Water Resources (ODWR), and the Oregon Department of Fish & Wildlife (ODFW), including;

- DOGAMI rulemaking to address the consolidated permit procedures and requirements for both mitigation and the state environmental assessment.
- Development of a Memorandum of Understanding between DOGAMI and the federal land management agencies to minimize duplication and overlap during the permitting process.
- ODFW rulemaking describing the process for determining the wildlife protection measures to be utilized and habitat mitigation requirements.
- Other state agencies, such as ODWR, amended their regulations so that they are consistent with the terms of HB 2244, but these were not considered major actions.
- The establishment of a special commission, the Mineral Tax Task Force, chaired by DOGAMI, to look into the question of whether some sort of severance tax on the industry is necessary or feasible.
- The completion of Rules by ODEQ addressing waste materials such as tailings and spent ore.

It will not be easy or inexpensive to permit a gold mine that uses a cyanide process in Oregon, but it can be done.

## 18.6.5 ANALYSIS OF THE OREGON EXPERIENCE

Hindsight always allows for the realization of how those involved could have gained more (or lost less) than they actually did. This can be said of events in Oregon. The reality of the situation, however, demands that the mining community accept that what is talked about is matters of degree, not a revolutionary difference in the outcome. Complete avoidance of new legislation would very likely have meant facing a statewide referendum on the issues. Those who have fought ballot initiatives in South Dakota and California know first hand the uncertainty and monetary cost such a struggle entails. This would have been a no-win situation for the mining industry. The path chosen did allow the industry to earn the respect, however grudging, of the environmental groups and state regulatory community. It resulted in the Governor publicly stating that she would oppose an anti-mining referendum. The mining community in general also gained credibility in the state legislature on both sides of the aisle. This will serve the mining industry well in the future, as these achievements can only be made by acting in good faith.

Oregon will remain one of the most difficult states in which to permit and operate a mine. The tradition of public involvement, recently enhanced by the environmental groups so that it is truly invasive, and deep aversion to risk means that any proposal will be very closely scrutinized, and all concerns, both real and imagined, will have to be addressed in some manner. However, the most effective approach to this situation is to meet it head-on by making sure that details in a proposed operating plan are not overlooked or given short shrift. Early and full involvement in the planning and development stages of a project by a representative cross section of people living in affected communities, not just the environmental groups, and keeping elected officials informed will allow mining companies to clear the hurdles. Complete openness is one of the keys to gaining and keeping the credibility needed to bridging the gaps that exist between industry and those who would

truly prefer to see no further development.

### 18.6.6 APPLYING THE LESSONS LEARNED

Though Oregon may represent an extreme, the basic thrust taken by the Oregon environmental groups is not unique. Much of the Oregon experience is applicable to situations in other venues. Though not all that was learned is new or improved, it serves to underscore the point that potential opportunities are still being missed by the mining community.

What is the bottom line? The evidence strongly suggests that industry must become more pro-active in its approach, rather than continually reacting to outside pressures. Traditionally, miners have not embraced the pro-active style of addressing political issues. Taking a defensive posture usually brought about the desired result. But as times change, and the issues become more driven, at least ostensibly, by scientific concerns and the application of practicable technological solutions, the mining community has become increasingly isolated and vulnerable. Miners are the experts in the art and science of mining, yet the mining industry has allowed non-miners to set the agenda and define the terms of the ongoing debate. For mining to remain feasible in the future, particularly in the United States, a new strategy is necessary. The industry must overcome the risks inherent with using any sort of new approach and assume the position of leadership that it rightfully should have. The pacesetter role must not be abdicated to government agencies or other special interest groups, though the legitimacy of their involvement is undeniable. If it is, the result will be an increasingly hostile political and regulatory framework that will devolve to the point of being a *de facto* ban on mining. Despite the tough sledding in Oregon, the pro-active approach is proving to be effective and should be embraced by the mining community.

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# Chapter 19
# CURRENT AND PROJECTED ISSUES

edited by P. Keppler

## 19.1 INTRODUCTION

Environmental laws and regulations can (and do) change rapidly in response to public concerns and environmental accidents or disasters (e.g., Three Mile Island, Love Canal, and Bhopal). Also, the status of the economy has a significant impact on environmental legislation. For example, in the early 1990s, the economic recession in the United States and other countries had a chilling effect on major new environmental legislation. Bills to reauthorize and substantially amend the Clean Water Act and the Resource Conservation and Recovery Act or Solid Waste Act were hotly debated in Congress and were not enacted in part because of concerns about the economic impacts of such legislation. These issues will be discussed in more detail below.

In 1992, the election of Bill Clinton and Al Gore as President and Vice President, respectively, as well as a number of new Representatives and Senators in the Congress, was expected to have a significant impact on Federal legislation and regulations affecting the mining industry. With a Democratic Administration and a Democratic majority in the Congress, it was anticipated that several environmental laws and a new mining act would be passed in the 1993-94 Congressional session. With the Republicans regaining a majority in the House and Senate in 1994, it appeared as though there would be a major rollback of environmental requirements in order to "get government off industry's back" and keep the United States a leader in the new world economy. At this writing (Spring 1996), neither of these scenarios has come to pass and we have maintained the status quo for all of the major environmental laws and the 1872 Mining Law. It is evident that regardless of the political rhetoric, the fundamental principles of environmental protection and resource conservation held by most Americans, including the miners, manage to prevail and prevent significant shifts in national environmental policy.

In this Chapter, the authors have attempted to look at major trends in the environmental area and their impact on the mining industry. They focused on issues believed likely to affect the domestic mining industry for a number of years or decades to come. This Chapter is organized under the following subjects:

- Public perception of the mining industry and its environmental impacts.
- How the mining industry has and is likely to respond to public pressures and environmental legislation.
- The main emerging environmental issues for the mining industry.
- The relationship among Federal, State and local governments and the trend toward more local control over mining and other development.
- The impact of growing environmental awareness and concern in other countries and the international community generally.
- The economic impact of environmental regulations on the mining industry.
- The significance of the move toward pollution prevention and source reduction.

Furthermore, several acknowledged experts, with differing backgrounds, have also provided "vision statements" as broad outlines of existing situations and anticipated environmental events affecting the mining industry.

## 19.2 PUBLIC AWARENESS AND CONCERNS

**by J. L. Danni**

*The Denver Post* joined other newspapers and magazines by recently stating in an editorial that mining on Federal lands should be subject to more regulation and higher fees or royalties. National and local environmental organizations have been successful in portraying the choice as "wildlife, water quality or recreation" on the one hand versus "prospectors operating under rules developed in the nineteenth century" on the other. Some of these environmental groups are well-funded while others exist day-to-day due to the tenacity and single-mindedness of their membership.

On the national level, environmentalism has clearly become big business. The *Chronicle of Philanthropy*

reports that environmental and animal welfare groups collected $3.15 billion in contributions in 1990. Fund raising is the life blood of active environmental organizations and fund raising requires emotional issues and adversaries. On both counts, the mining industry often fills the bill. *The Congressional Quarterly* has estimated the combined clout of the 13 environmental groups who regularly lobby Congress to be almost $240 million with a combined professional staff of nearly 3,000. They are supported by nearly 9 million members who all too often view mining as the environmental menace that motivates their members and brings in contributions.

Complementing the large national organizations are numerous local and regional citizen groups. These groups tend to be politically sophisticated and are often more effective than the national groups in affecting the outcome of local natural resource development projects. Stung by accusations of being isolated from the main stream, national groups have refocused their outreach programs to tap the grassroots enthusiasm of regional and local organizations. Further, national groups have become sensitive to charges that they are predominantly white, upper middle-class organizations and have started exploring inroads to minority groups.

Organizations supporting the mining industry do not enjoy the same broad base of support as many of the national environmental groups. However, taking a page from those very organizations, the mining industry has begun building on local and regional bases of support and actively encouraging grassroots organizations. The industry has argued that the choices are not clear and simple, that public policy decisions are not just "trees versus jobs." Arguing for multiple use and development of natural resources on federal lands, as well as including the welfare of people into the political decision-making process, pro-industry organizations have begun to make some gains in public perception.

Most Americans now consider themselves to be, if not environmentalists, at least environmentally aware. The sensitivity and concern about environmental issues is unprecedented in the history of this nation. The response of the mining industry to this phenomenon has typically been to focus on "educating the public" to appreciate the benefits of modern society derived from mining. While education is an essential component for determining the survivability of the mining industry, the broader question as stated by E. S. Woolard, Jr., Chairman of E. I. Du Pont de Nemours & Co., Inc., is "Will industry be assimilated into the mainstream of world environmental awareness in a positive way?"

There is an alarming tendency to look at environmental policy issues in terms of black and white — good and evil. While this may benefit fund raising for both sides, it does not benefit a society which demands environmental protection and the products of the mining industry. A substantial portion of media coverage is devoted to environmental issues and all too often the villain is the mining industry or the forest products industry. Negative media coverage has increased not only because of changes in society's belief system, but also because resource development is no longer geographically isolated from public scrutiny. Mining and forestry are highly visible activities even in the less populated parts of the country which are accessed by broad spectrum of outdoor enthusiasts.

Resource development, particularly mining, has been perceived for generations as an inherently necessary component of growth and progress. However, during the past generation, that linkage in the minds of many Americans has been severely weakened to the extent that when mining is considered at all by the public at large, it is often thought of as environmentally disruptive and worse yet, unnecessary for the greater good of society. Compounding this negative perception has been public concerns of metals in the environment and the chemicals used in the mineral extraction processes. Reports of lead poisoning, cyanide-related wildlife deaths and black lung disease in coal miners have all tarnished and for the most part outweighed any favorable articles on the mining industry. Furthermore, there is an ever increasing lack of understanding and appreciation by the public of the role of minerals in their lives.

Many persons who intellectually accept the necessity of mining in society do so only if the activity is out of sight and sound of their neighborhood, favorite hiking trail, historical sight and so forth. In a highly mobile and urbanized society, the "backyard or neighborhood" can encompass a far reaching geographical area. Historically, the mining industry has not ignored public opinion or conducted business in an unacceptable manner based on environmental standards of the times. Rather, miners correctly assumed that public opinion mirrored industry opinion in the need to exploit minerals for the American economy to grow, for the West to become civilized, and to provide jobs in the process.

The mining industry has on occasion been labeled as isolationist and quite conservative. This is somewhat ironic given that the industry is at the mercy of world markets it does not and cannot control. If the industry was perceived as isolationist, it was because mining typically took place far from established urbanized centers. Perhaps compounding the perception of isolationism was the industry's sense of pride and accomplishment in tackling and overcoming long odds to develop projects under often difficult conditions. The image of the miner as an entrepreneur and rugged individualist still appeals to many supporters of the industry today. The competitive, sometimes secretive nature of minerals exploration has also perpetuated the perception of isolationism.

If mining convention agendas and session topics are

any indication, the industry today is very much aware of sensitive environmental issues and related public policy debates. Any comparison of mining trade association convention agendas of a decade ago to those of today reveals an exponential increase to topics related to the environment. The industry also has begun to take such discussion topics from the hand-wringing stage to the problem resolution stage.

There is also a certain process similarity between national environmental organizations and national trade associations and their respective regional and local counterparts. The statement that "all politics is local" is true to the extent that the organizations closest to local issues can be the most effective. Regional or local issues can often be more readily quantified, constituency groups are smaller, and issue resolution is more attainable. While resolutions or successes achieved at the local level often leave unresolved the broader national policy issues, they do provide a reason to believe that environmental problems facing the industry are not insurmountable.

Professor and historian Duane A. Smith, author of *Mining America - The Industry and the Environment, 1800 - 1980*, writes:

> *"The shouting, the name calling, and the public condemnation left their scars on mining and shaped the industry's responses in the 1970s. Mining has not forgotten that upheaval. Defenders hoped that the corner had been turned and that an environmental consciousness had been awakened. Critics, on the other hand, did not believe that the decade of the 60's could erase positions that had been hardened by centuries of exploitation of minerals and (of) the land."*

That debate continues unabated to this day.

It should be unarguable, however, that the mining industry has become very sensitive to public opinion and supportive of overt efforts to shape public policy and problem solving to address environmental issues. The industry recognizes that even when jobs are considered in public policy discussions, if the debate ends in only a choice between jobs and the environment, the environment will win 9 out of 10 times. With such long odds, the challenge is to find and develop solutions to difficult environmental issues before the choices are reduced to such simplistic alternatives.

It is revealing to review mining company annual reports from recent years. Many annual reports now feature environmental accomplishments and discuss the company's environmental challenges. A generation ago it was virtually unheard of for a mining company to receive recognition or awards for environmental stewardship. Today, not only do mining companies receive such awards, they aggressively compete for them.

The mining industry recognizes that it has a shrinking political constituency. National elected officials from historic mining states no longer automatically support the industry. The National Mining Association estimates that there are about 100 members of Congress who can be considered "friendly" toward the mining industry. Perhaps another 100 have some understanding of mining or a recognition of the essential nature of the industry. But even in the most favorable of political situations, the industry is far short of majority support. The challenge to the industry is to recognize that it is a political minority and to develop the operational abilities and political relationships necessary to survive as a minority. This includes an increased level of communication and cooperation between mining and its constituents, including suppliers to the industry and the end-users of its products.

Perhaps even more encouraging to skeptical observers of the industry is the degree to which environmental consciousness has begun to pervade all levels of management. In the recent past, industry leaders perceived the need to address environmental and public policy issues and responded by creating appropriate programs and functions within their respective companies. Since that time, a broader corporate involvement in and appreciation of environmental issues has gradually been accepted by senior managers throughout the industry. There is reason to believe that such commitment has gone beyond simply lip service to a reflection of fundamental operational changes.

The mining industry of the 1990s has had to become increasingly adept at compromise and negotiation as it relates to industry survival. However, an intimidating and growing array of difficult environmental issues continue to confront the mining industry. The eventual response to those environmental challenges will shape the mining industry as it attempts to do business into the 21st century. How will the industry deal with these challenges and operate within the next century? This is the question posed to several authorities with quite different backgrounds and perspectives. The following is their "vision of the environmental future of the mining industry."

### 19.2.1 THE RISKS OF DEVELOPING NEW MINERAL RESOURCES
**by A. Born**

From the middle of the 19th century until the middle of the 20th century, development of the mineral wealth of the United States was actively encouraged by national and, later, state governmental policies. This support was understandable, as the massive industrial development that occurred in the United States during the period was due to the availability of abundant, relatively cheap mineral resources, including fuels.

The development of mineral resources was carried out in accordance with the perceptions of the day — with people caught up in the dynamics of the expansionist period. Mine designers and builders, particularly during the first half of the period, were preoccupied with matching the extractive technologies to the peculiarities of the orebody and the physical setting. Public sentiment was heavily biased toward job availability, and issues such as uncontained tailing or placement of waste rock where most convenient were seldom, if ever, raised, much less dwelled upon. Mining waste was not considered "environmental pollution" (the term had not yet been invented), but was looked upon as a necessary, localized consequence of the mine that provided jobs and economic security.

Starting in the 1950s, a "back to the land" ethic evolved in the United States and other developed countries. This movement grew during the 1960s, and when the Vietnam War ended, a very sophisticated, well organized anti-war political movement formed the basis of several activist environmental organizations. The good part of the movement was helping develop a national consensus calling for improvement of the environment we all live in — which was long overdue. Despite media excesses, contrived health scares and other doomsday scenarios, and many instances of wasted resources, the movement has worked to the overall betterment of the nation's physical environment.

However, as mining activities are excellent media targets, especially if located in relatively pristine mountain settings — which, frequently is the case — an entire generation has been led to believe mining is inherently destructive, serves no real purpose, and that it cannot be made compatible with the modern environmental ethic. Efforts made by the minerals industry to dispel this public perception have been scattered, localized, and ineffective.

At this writing, the regulation of mining waste (tailing, waste rock) treatment and disposal is moving through the rule-making process. The EPA has for years agonized over how to regulate these low-toxicity, high-volume wastes. Being a politically sensitive issue, EPA and other Federal agencies have not been inclined to move quickly to regulate mining wastes and generate a lot of industry (and some political) ire. This issue will continue to be studied, first to determine the extent and nature of any contamination and, secondly — and one can only hope — to develop an economic, practical approach to ameliorating any problems discovered.

Major new mineral developments, especially those on public lands, are subject to regulations and permit conditions covering the mine life from pre-engineering through eventual closure and reclamation. Essentially all of the conditions imposed are based on current technology, and thus technically attainable. The problems arise in the time required to obtain all the required permits, and in the aggregated costs of the environmental control conditions plus the post-closure costs. The mineral deposit must be of adequate grade and tonnage to handle the conventional costs plus the very significant environmental burden, while returning sufficient profit to justify the capital investment.

Further, there is always the possibility that, for whatever reason (e.g., community resistance, presence of endangered species, legal challenges extending the permitting period, etc.), the permits to develop the property may not be obtained in a timely way or at all. Another possibility is that unreasonable technical or economic conditions may be imposed for meeting some environmental or reclamation requirement. If the project is abandoned during the permitting process, a heavy economic penalty can fall to the developer.

Current attempts to effect major changes in the 1872 General Mining Law could compound the environmental permitting/cost risks. As the risks rise, at some point prudent investors will no longer support expensive domestic exploration programs that are restricted as to where and under what conditions they can take place, and whose otherwise economic discoveries may not be developable in any event. As existing mineral reserves are mined out and not replaced through exploration, domestic minerals production could be replaced by imported material, and eventually the domestic hardrock mining industry could become insignificant.

Having sown the seeds of pessimism on the future of hardrock mining in the United States, we can now discuss how to cope with what is obviously a very difficult situation. We have a model in the coal mining industry's response to the Surface Mining Control and Reclamation Act of 1977. While viewed by some at the time as an unmanageable calamity, the industry has learned to live with the law, and in doing so has greatly improved its image in the public eye. Innovative reclamation and post-mining land use efforts have resulted in excellent wildlife habitat and recreational opportunities on reclaimed lands. We can carry this comparison so far, however, as the greater diversity in hardrock mining creates special circumstances and problems not present at surface coal mines.

However, the minerals industry is technology-based and is managed by persons who are skilled and experienced in various technical and scientific disciplines. The industry needs to use these skills to be more innovative in the environmental aspects of both mining and ore beneficiation. In the past, industry has let EPA take the initiative in proposing treatment methods which then lead to numeric standards. EPA has some capabilities in engineering and treatment technology, but I submit that expertise is not equal to the industry's and EPA should not be in the position of telling mining companies not only what they must do in the regulatory area, but how to do it as well.

For example, is there a substance that could economically be added to tailing in the milling process that would inhibit oxidation of sulfides present and reduce the short- or long-term acid-forming potential? Are there environmentally benign lixiviants that could be used in in-situ leaching? We should be posing like questions to ourselves, most particularly in the planning phase for new projects. It is comfortable to go with the known treatment technology, but we should be a very large step ahead of EPA and other regulatory agencies which lack the professional resources of the minerals industry.

Second, we *must* start the difficult and time-consuming task of correcting the public misconceptions about the environmental effects of minerals production. We probably have lost that opportunity with the current generation of pre-teens and young adults, so a grass-roots effort should begin with the current second graders. This must be a pragmatic, accurate portrayal of the industry demonstrating that it can function compatibly with a clean and healthy environment and that it provides the starting materials for the necessities of life that we take for granted.

I am personally convinced that, despite the constraints and challenges faced by the domestic minerals industry, it will remain viable for not only the next 20 years, but on into the distant future. More metals and other materials will be recovered through recycling or reworking existing residual mining deposits, but there will always be a need for new, virgin materials, and there will always be entrepreneurs willing to accept the risks of developing new sources.

### 19.2.2 MINING VIEWS THE ENVIRONMENT
**by D. A. Smith**

"They left it [Appalachia] in wreckage, now they promise to develop the Northern Plains. They will leave it in ruins." The mining industry reeled under attacks such as this in the in 1960s, 1970s and 1980s. It did not help when some spokesmen rebutted with equally inflammatory comments. "The mining industry has nothing to apologize for, . . . An open pit mine is a beautiful thing to look at." Or even more emotional was that infamous bumper sticker: "Ban Mining! Let the Bastards Freeze in the Dark."

The mining industry can no longer present such a knee-jerk reaction to criticism. It has a long and proud heritage of environmental concern and conservation. Even back in the 19th century when mining reigned king of all it surveyed in the West, there existed those voices within the industry who spoke for concern beyond production and profit.

The respected mining engineer and writer, Rossiter Raymond, warned about wasting coal, iron, lead, gold, silver and other minerals: "A waste of them is a waste forever." The *Engineering and Mining Journal,* April 15, 1876, observed, "The operations of the miner are always attended with more or less damage to the land." The editor however, did not present any solutions to the problem. Mining reporter J. Ross Browne as early as 1868 told his readers that the miner retained his right to the product of his labor, "but has he a right to deprive others of the benefits to be derived from the treasures of the earth, placed there for a common good?"

The industry stood tall in these, and later, generations and not until the 1950s would it finally be challenged seriously by environmentalists. Unfortunately, mining was not prepared for the onslaught and spent several miserable decades fighting a rear guard action. The still small voices of the nineteenth century that had not generally been heeded, now commanded more attention. Yet it took a generation for the industry finally to convince itself of the need for environmental concern. Such a delay should not have been unexpected; since the days of the Roman empire mining had always had its way with the environment. The amazing thing is that it proved able to adapt so quickly after all those centuries of unchallenged exploitation.

There will be no turning back the clock now, nor will it do any good to yearn for a golden age, nor rage against the "loudmouth, anti-establishment, leftist leaning, rabble rousing ecologists." The industry must realize and accommodate to the situation of the 1990s, a condition that obviously will continue into the 21st century.

Fortunately in the past 20 years the industry has come to appreciate the need for environmental awareness. What must be accomplished now, however, is better public relations regarding what mining is doing and plans environmentally. Abraham Lincoln back in 1858 understood this when he replied to Stephen Douglas during their first Illinois senatorial debate, "In this and like communities, public sentiment is everything. With public sentiment nothing can fail; without it nothing can succeed." The public must be made aware because in the last analysis, they remain the ones who will pay for the environmental policies that local, state and federal governments enforce.

The road to reach a balance between environmental concerns, mining interests and public awareness has been long and costly. What the industry has to do, and must plan for in the future is demonstrated in many agreements reached in the past decade. If it does not heed these lessons, more painful and costly lawsuits will follow.

The fight over mine wastes in Ouray and San Miguel Counties, Colorado, which pitted the Idarado Mining Company against the Colorado Health Department, provides an excellent example for the industry. This

involved one of the State's major mining districts (Red Mountain) that had been active for nearly a century when the last mine closed in the 1970s. After nine years of lawsuits and negotiations, the *Denver Post*, May 22, 1992, reported that a "precedent-setting agreement has been struck to clean up vast, river-polluting mine wastes near Telluride and Ouray."

The three-volume blueprint for cleanup focused on everything from revegetating twelve mining dumps, to controlling water runoff, and protecting historic structures. Idarado would spend at least $15 million on cleanup and pay the State another $5.2 million for damages and costs of overseeing the work. Bonds would be posted to guarantee the work and cover alternative cleanup if vegetation failed. Said an Idarado spokesman, "It's really a win-win situation for both sides. It's a win for the local communities also. It minimizes disruption to them and to the environment."

On a smaller scale, the Sunnyside Gold Corporation was working on its own projects across the mountains near Silverton, Colorado. Sunnyside was going to backfill former Lake Emma (which had broken into the mine back in June 1978 causing an environmental mess and stopping operations) and re-contour the #1 tailings pond. This included covering it with dirt and seeding the site. The company worked closely with the State and San Juan County keeping both aware of plans and progress. Careful environmental planning and providing information paid dividends for the company and gave the industry a better public image.

Tom Hendricks in Boulder County was doing the same thing with his Cross Mine. Just being able to mine in that acutely environmentally sensitive county spoke volumes of what the industry must do today and tomorrow. As Hendricks commented, his non-mining neighbors "don't want to hear an ore-bucket or a compressor." A reporter from the *Wall Street Journal* (September 18, 1991) hit the mother lode of what mining must accomplish. "Still, being a good environmental neighbor is Mr. Hendricks' goal and his challenge." Hendricks commented, "We want to show underground mining can operate environmentally with no problem and be a good neighbor to everybody."

"A good neighbor to everybody." If the industry can achieve that, then it can operate successfully. Obviously all this translates into more expense for mining, and increased awareness of environmental matters and programs. The industry must weigh carefully public attitudes and to a lesser degree concern itself about its own history and historic preservation on the sites it is cleaning up. This was particularly shown on Red Mountain, which is a popular tourist area as well as an environmental headache.

Challenged, the industry has responded and must continue to respond to the public's concerns. The day of "rape and run" have gone with the jackass burro and free-wheeling exploitation of the previous century. The gloom sayers may claim that mining has no future; that is emphatically not so. As Mark Twain observed in 1898 when the report of his death reached the New York newspapers, "Say the report is exaggerated." It remains as true for the mining industry today as it was for the people of Israel, who a writer in "Proverbs," warned "Where there is no vision, the people perish." Catch an environmental vision and mining will survive and, perhaps, even gain more public support. The two must work hand in hand toward the common goals of both.

### 19.2.3 THE ENVIRONMENTAL FUTURE
**by L. J. MacDonnell**

Perhaps no single thing has affected the mining industry in the United States more over the last 20 years than environmental regulation. It has been a difficult and painful transition for the industry, imposing substantial new requirements with attendant increased costs and challenging long-held assumptions about the value of mineral production in relation to other uses of land. By placing additional burdens on an industry already struggling with problems of meeting competition from lower cost development in other parts of the world, environmental regulation has been seen by some as the cause of the industry's problems. Many believe that such regulation is unwarranted and that it fails to recognize the unique problems of the mining industry. On the contrary I would argue that control of the unmanaged adverse environmental effects of mining is long overdue.

Mining is a unique industry in many ways. It is unique because its location is determined almost entirely by geologic factors. Thus a valuable deposit of titanium and other heavy metals exists in the St. Lucia System – an area designated by South Africa as a wetlands of international importance under the Ramsar Convention. A valuable deposit of gold, platinum, and palladium has been found at Coronation Hill, a site considered sacred by Aborigines living in that area of Australia. Historically the decision to mine turned only on economic considerations. Today the other values of these areas weigh heavily in the decision process.

Mining is unusual also in the degree of alteration of the area where it occurs. Especially in metal mining, many tons of rock may be extracted to produce only pounds of usable material. Mining itself may only occur for a few years but the legacy of that activity in the form of its wastes is likely to be evident for much longer. The U.S. Environmental Protection Agency estimates that metal and nonfuel mining in the United States had generated over 50 billion metric tons of waste by 1985 with over one billion tons of waste being added annually. Though only 5% of these wastes are estimated to be toxic, that still amounts to about 60 million tons of material requiring special management each year.

What have been the consequences of unregulated mining? For one thing, more than 60 mining sites (most abandoned) are now in the National Priorities List for cleanup under Superfund. There are no good estimates yet of the total cost of cleaning up these areas but it is probably safe to assume that it will amount to 100s of millions of dollars. The State of Colorado has estimated that damages to natural resources resulting from unchecked pollution from the Eagle Mine near Vail exceed $50 million and that natural resources damages exceed $100 million for the Idarado Mine near Telluride. In 1988 the Colorado Department of Health reported that 1,300 miles of streams in the state have been biologically harmed by acid mine drainage from abandoned mines. It is evident that we are still paying the costs of mining that, in many cases, occurred long ago.

This unhappy legacy hangs heavily over the contemporary mining industry. Instead of being viewed as the essential source of the basic materials necessary for our economy, mining is seen as rapacious, irresponsible, and anachronistic by many people. The image of the abandoned mining sites with unmanaged wastes, unreclaimed lands, and unchecked water pollution causes some communities to resist the development of new mines even though these mines will now have to comply with very strict requirements highly protective of the environment. There is a view that mining *cannot* occur in an environmentally compatible manner. There is also a view that miners *will not* mine in an environmentally careful manner. Certainly much of the support for revision of the 1872 Mining Law comes from those who believe that mining on the public lands is inadequately regulated.

In preparation for a U.N. sponsored conference on mining and the environment in 1991, I looked at the laws in the United States, Canada and Australia and was interested to find a remarkable similarity in their approach. Four dominant elements emerged:

1. *Land areas determined to have special values deemed incompatible with mining have been specifically reserved from mineral development activity.* Most often these values are environmental but they may also be cultural or religious. The exclusion of mining from national parks and specially designated wildlife management areas is increasingly common. Moreover, processes have been established to weigh the benefits of mining against environmental losses in other important areas. Generally there is discretion to preclude mining in these areas if deemed necessary. There is also a trend toward increasing the protection of existing surface uses wherever possible.

Quite clearly, mining in these countries is no longer *automatically* considered to be the highest value use of an area.

2. *An environmental impact assessment procedure is used to evaluate the environmental effects of proposed mining activities.* Generally these assessments are not decision documents. Rather they are intended to insure full consideration of adverse environmental effects in the public decision-making process. Assessments are likely to identify environmentally protective conditions that will be included in necessary governmental approvals and may also identify more environmentally acceptable alternatives to the original proposed mining plan.

The assessment process provides a mechanism for careful consideration of ways to prevent or avoid unnecessary environmental harm associated with mining. It also may provide an opportunity for public involvement in this process. With a few notable exceptions the mining industry has not encouraged public participation in its mineral development planning. Yet such participation can provide a means of much needed public education concerning the mining industry.

3. *The pollution-generating aspects of mining activities are subjected to permitting requirements that limit the discharge of wastes according to particular performance requirements.* Effects on surface water pollution are perhaps most comprehensively controlled but groundwater is now receiving increased attention. The air quality effects of minerals processing are controlled. And, in the United States, requirements are being established for management of both hazardous and non-hazardous wastes generated by mining. Monitoring and reporting requirements are commonly a part of permit programs. Various enforcement options exist for violation of permit requirements.

Regulation of pollutants affects every industry. Mining and mineral processing simply produce greater quantities of pollutants than most industries. An important challenge for the minerals industry is to develop less polluting methods and technologies.

4. *Reclamation of the surface area is required upon cessation of mining operations.* Particular reclamation requirements vary widely but typically include revegetation and protecting surface water resources. Commonly, a bond must be posted as security for performance of the reclamation requirements.

In some cases, mined areas simply are not returnable to a usable form. At a minimum, however, the objective of reclamation is to insure that formerly mined areas are not hazardous or harmful either to people, to wildlife, or to the natural environment.

The mining and mineral processing industry in the United States has been hard hit by the costs of environmental regulation. Understandably, the industry – especially that part faced with international competition – has found it difficult to bear the burden of these costs.

There is little sentiment in the United States, at least, to provide special treatment for the mining industry. In a broad sense, the costs reflect the substantial effect that mining activities have on land, water, and air. As other countries begin to impose environmentally protective requirements on their mining activities the cost advantage presently enjoyed will be reduced.

Certainly there is a growing interest world-wide in better managing the adverse environmental effects of mining. Many international lending organizations such as the World Bank now condition loans for development activities, including mining, on meeting certain standards of environmental protection. The United Nations through its Environment Program (UNEP) and its Department of Technical Cooperation for Development (DTCD) has begun the process of developing international standards and guidelines for mining and environmental protection. Most importantly, many countries now recognize the fundamental compatibility of developing their economics in an environmentally protective and sustainable manner. The challenges in this regard for mineral development are perhaps greater than for most other kinds of development.

What is the environmental future of the mining industry? Certainly it will be radically different than its past. Some conflicts will be avoided simply by putting additional areas off limits to mineral development. But it is fair to say that decisions to mine will be carefully scrutinized for their adverse environmental consequences. There will be a general expectation that these consequences should be minimized. This further underscores the critical technical challenges facing the industry in developing minerals in a less environmentally damaging manner. This future also calls for an industry that can regain pubic confidence in its ability to perform in an acceptable manner. In part this is a matter of educating the public regarding the nature of mining and the fact that mining can be done in an environmentally more benign manner. In part this is a matter of an industry fully accepting its environmental protection responsibilities.

### 19.2.4 THE ENVIRONMENTAL ISSUES IN MINING
**by G. C. Miller**

The large amount of land disturbed by mining will continue to be a focus of new regulations in the next decade. Although significant progress has been made in recent years, the open pit methods of precious metals mining have resulted in fundamentally new problems that will receive increased attention by the public. These issues include the following:

#### 19.2.4.1 Reclamation

The single most important environmental issue in mining is the quality of reclamation. Land that is temporarily disturbed for one or two decades, but which is brought back to productive use does not constitute an irretrievable commitment of surface resources. If the public value of pre-mine and post-mine land uses are the same, criticism of mining will be muted. But the hard-rock mining industry still remains a long way away from that level of reclamation planning and reclamation success.

Particularly in arid environments, successful reclamation is technically difficult and requires individuals with the appropriate expertise. The mines that have the most successful reclamation have hired professional resource management specialists who understand soil-plant relationships and wildlife. Mines should also employ the services of landscape architects to design final configurations of waste rock dumps and other new land features. Too often, these tasks are given to mine engineers who do not have the appropriate concepts of aesthetics and land forms. Reclamation specialists need to be involved during the initial planning of a mine to ensure that reclamation can proceed concurrently with mining and to achieve cost effective and successful reclamation.

Quantitative standards for vegetation density and diversity for post-mine productive uses are necessary. Without those standards, the public will not be convinced that mines and regulatory agencies are serious about reclamation. Bond release will also be problematic and open to conflicting opinions as to what was meant when the original reclamation plan was accepted. Use of a variety of soil amendments, careful attention to seed mix, and care during the planting process all are features of reclamation. Successful revegetation has been demonstrated on even the most austere sites, and has been the result of a variety of creative and well-established procedures.

#### 19.2.4.2 Tailings Impoundments

Tailings impoundments represent a long-term public and private land management problem. Although properly sited, constructed, and closed tailing impoundments are unlikely to be acute problems during the short term, (with some exceptions) they will require permanent special land-use restrictions, consistent with the nature of the contents of the impoundments. For example, precious metals tailings will contain a variety of cyanide complexes and metals in a fine-grained high pH matrix. For the foreseeable future, if the impoundments are breached or otherwise disturbed, release of these contaminants into the environment will present not only a potential risk to the environment, but a substantial financial liability.

Tailings impoundments are substantially similar to hazardous waste sites regulated under the Resource

Conservation and Recovery Act. If the contents of the impoundments are isolated from the environment and are never released, there are few, if any problems. However, unintentional releases can never be completely precluded, and, as in RCRA sites, land use restrictions will be required.

Although many of the impoundment sites are located in remote locations, there are no assurances that these sites will continue to be remote. Park City, Utah, for example, has historically been mined and is now a ski resort. Both on public lands and private lands, restrictions as to what activities can occur on or near these sites will be required. Detailed maps of these sites will need to be maintained and those lands managed to restrict any development which will result in potential release of the contaminants in the impoundments.

#### 19.2.4.3 Pitwater

Even in some of the most arid environments in the United States, a significant percentage of pits will intercept groundwater, and require pumping during mining. When mining is discontinued, these pits will fill, ultimately to near the historic groundwater level. Some of the largest pits will have over 200,000 acre feet of water and become some of the largest volume water bodies in arid states. Because these lakes will be closed basins, the primary processes controlling the contamination in the lake will be underground flow in and out, evaporation, and dissolution of substances in the rock of the pit walls. The water quality will vary, from the very contaminated Berkeley Pit in Montana, to shallow ponds which can potentially support a fishery or recreation. Methods for assessing pit water quality and how it affects surrounding groundwater are presently not adequate for the task, and additional research is needed to predict what the water quality will be when kinetic and thermodynamic equilibrium is reached.

In addition, water quantity issues need to be considered. In Nevada, the total pit water volume will probably exceed 1 million acre feet during the next century. Coupled with the pumping deficits that are created during mining, many groundwater systems will be significantly affected over the long term.

#### 19.2.4.4 Drainage Water Quality

Water that passes over waste rock dumps, tailings impoundments or other mining disturbed land has the potential of extracting metals and other contaminants. Although most precious metals mines in the previous 10 years have been in oxide ore bodies that are reasonably well leached, many mines are now extracting ores and moving waste rock that contains greater amounts of sulfitic rock. Metals, acidity and salinity are all contaminants which can potentially degrade drainage water quality. Currently used methods to assess drainage water quality are crude, at best, and some tests for acid generating ability, in particular, need additional study.

#### 19.2.4.5 Mitigation

Even the best planned mines will generally leave at least part of the land in a condition that precludes historic uses. Pits and degraded pit water, dewatered springs, loss of scenic resources and loss of habitat are likely for many mines. On public lands these losses can and should be replaced. Examples of off-site mitigation include creation of wetlands, purchase or exchange of lands having high public values, and reclamation of historic mining disturbance. The cost of off-site mitigation is generally not substantial, but will go a long way towards convincing the public that mining is an acceptable use of public land.

The future of mining in the United States will be closely tied to public perception of the impacts of mining and the special treatment of the mining industry. Because the new open pit methods of mining are creating disturbances of a magnitude not previously known, the industry can look for continuing public pressure for reform. Central to the reform is the replacement of the Mining Law of 1872. Mining is only one of many important uses of public lands and needs to be regulated as such. The two core issues in this reform are agency discretion and reclamation. Both relate to the ultimate impact of mining on conflicting public resources, and the mining industry can expect to experience highly credible attacks until these two issues are resolved for the greatest public good. A new vision for land use is required which considers land value for as long as the pits, pit lakes and waste rock dumps exist, which for most large mines is on the order of millennia. It is my firm belief that citizens a hundred years from now will look back on current mining practices the same way that we look on historic mining practices that have created continuing chemically contaminated sites and land which no longer supports the pre-mine level of productivity. The mining industry will protect itself by aggressively seeking new ways of mining and reclamation which minimize disturbances far greater than what is presently occurring.

## 19.3 MINING WASTES AND MATERIALS

**by R. T. Dwyer**

Dealing with large volumes of waste material in an environmentally safe manner is obviously a major concern for the mining industry, regulatory agencies, and

environmental organizations. The visual impact of large unreclaimed waste disposal areas has probably done more to harm the public image of mining than any other aspect of mineral development.

For the coal mining industry, enactment of the Surface Mining Control and Reclamation Act in 1977 (SMCRA) was a major turning point. SMCRA established a comprehensive regulatory program governing nearly all aspects of surface coal mining and the surface impacts of underground coal mining. The Act is administered by the Office of Surface Mining in the Department of Interior. Most states with coal mining activity have enacted similar laws and regulations and have been delegated authority to administer the SMCRA program in their state.

SMCRA and the comparable state programs have stringent requirements for storage of overburden and coal mining and processing wastes as well as comprehensive reclamation requirements. During the past 18 years, SMCRA has undoubtedly had a significant impact on the coal industry and has resulted in improved environmental performance and reclamation practices. Furthermore, the abandoned mine land reclamation fund established by SMCRA, which receives a payment for each ton of coal mined in the United States, has enabled the states to reclaim large tracts of abandoned mine lands that otherwise would have continued as public eye-sores and areas of environmental concern. It is interesting to note that several western states where there is now considerable coal production from surface mines have started to apply some of the revenues obtained from the abandoned mined land reclamation fund toward the reclamation of abandoned hardrock mines that are creating safety hazards or environmental harm.

In contrast to the coal industry, hardrock mining at this time is not subject to a comprehensive Federal reclamation act. However, most of the states that have mineral exploration and mining have enacted laws to govern such activities and require reclamation of disturbed lands (see Chapter 4). With respect to mineral exploration and development on Federal lands, the land management agencies (the Bureau of Land Management and the Forest Service) have promulgated regulations that require filing a plan of operations for a new mine that includes reclamation of mined areas and compliance with environmental standards. Hardrock mining operators must also post a bond to assure reclamation of disturbed areas.

The Federal Solid Waste Act as amended by the Resource Conservation and Recovery Act requires EPA in consultation with the Department of Interior to conduct a detailed and comprehensive study on the adverse effects of solid wastes from surface and underground mines on the environment prior to regulating such wastes. [42 U.S.C. § 6982(f)]. In addition, EPA was directed to conduct a detailed and comprehensive study of the adverse effects on human health and the environment of the disposal and utilization of solid waste from the extraction, beneficiation, and processing of ores and minerals [42 U.S.C. § 6982(p)]. EPA is to submit both studies to the appropriate committees of the United States Senate and House of Representatives. The objective of these mining waste studies is to provide the foundation for regulations that will control waste disposal practices and mitigate adverse environmental impacts of such practices.

The provisions of the Solid Waste Act requiring these studies of mining waste prior to regulation are commonly referred to as the "Bevill Amendment" after Congressman Bevill of Alabama who sponsored this legislation. During the last few years, EPA has issued several reports to Congress with respect to mining wastes and published several regulatory determinations as to which mining wastes should be regulated as hazardous wastes. In several law suits filed against EPA by environmental groups (Environmental Defense Fund et al.) and industry (American Mining Congress et al.), the courts have generally upheld EPA's determinations regarding the application of the Bevill Amendment to mining wastes. With respect to mining and mineral processing wastes, EPA has narrowed the scope of the Bevill Amendment leaving only 20 processing wastes subject to further study and regulatory determination.

Mineral extraction and beneficiation wastes have been subject to a process of review and developing "Strawman" proposals by EPA. The initial Strawman proposals published in 1988 and 1990 were criticized by the mining industry for containing requirements similar to regulations governing hazardous wastes under RCRA. In response, EPA set up a "Policy Dialogue Committee" in early 1991 made up of representatives from the mining industry, states, environmental groups, EPA, and the Interior Department to review the Strawman proposals and examine various alternatives. The Policy Dialogue Committee has had a number of meetings but the outcome of the Committee deliberations are very uncertain.

The EPA position appears to be that a Federal program should be established requiring performance standards for the handling, storage, disposal, and reclamation of mining wastes. EPA would develop minimum standards for "regulated materials" including ore piles, concentrate, mill tailing, and heaps and dumps subject to leaching operations, that would be implemented by the states. If the state program did not meet the Federal standards, EPA would administer the program in that state.

Bills have been introduced in Congress to amend the Solid Waste Act that would authorize EPA to develop regulations and performance standards for mining materials and wastes. It is likely that legislation will pass in Congress that will give EPA authority to

develop a regulatory program for mining materials containing some of the provisions of the latest Strawman proposal. Mining and mineral processing operations can only hope that the legislation will grandfather existing ore piles, waste storage areas, and tailing impoundments and that new standards will apply to facilities constructed and used after a certain date and not retroactively.

Most mining states have statutes and regulations governing mineral operations and mined land reclamation. For example, the Colorado Mined Land Reclamation Act requires the mine owner or operator to obtain a permit from the Mined Land Reclamation Board prior to constructing and operating a mine. An application must be submitted with a plan of operations, including a description of projected air emissions, water effluent, and waste storage, as well as a reclamation plan with financial assurance guaranteeing performance. After review and a public hearing if requested, a permit can be issued with conditions that the operator use best management practices for handling and storage of waste material. Such best management practices include measures to divert storm water around waste dumps, collect and treat water that comes in contact with waste materials, collect and treat or contain seepage that may be contaminated, and cover and revegetate waste storage areas that are not presently in use.

If Federal legislation is enacted that establishes a regulatory program for mining materials and wastes, it is likely that the states will adopt similar programs in order to retain primacy and control over such program. In order to fund the program, it is likely that a permit fee will be assessed to the mine operator. Furthermore, to raise funds for reclaiming abandoned mines and waste dumps, a fee may be charged on mine production or on mining waste generated at hard rock operations. Such regulations and fees may come into effect in the late-1990s.

## 19.4 MINED LAND RECLAMATION

**by T. A. Shepherd**

In the 18th and 19th centuries, and to some extent even in the first half of the 20th century, operators of coal and metal mining facilities had no legal or social requirement to address the environmental impact of their operations and reclamation of disturbed areas. As indicated above, mineral development was promoted and generally viewed as the highest and best use of the land. The environmental impact of mining was of little concern – these were periods of economic expansion and resource exploitation that fueled the United States' economy and made this country the dominant global economic power.

The Mining Law of 1872 reflected the practices and principles developed by the miners themselves. The intent of the mining law was to promote mineral exploration and development on public lands in the West thereby opening up this area to settlement and providing fuels and minerals for the rapidly growing manufacturing industries in the United States. For the most part, the general mining law has served the industry well and achieved its objectives.

As the environmental impacts of mining and mineral processing became more of a public concern, the industry gradually became subject to regulatory controls. California enacted legislation in the 1880s to regulate hydraulic placer mining which was causing severe erosion and stream contamination. In the 1920s, Pennsylvania and other eastern states enacted laws that required coal miners to take measures that would control subsidence and to plug abandoned shafts that created safety hazards. Additional laws were enacted in mining states over the next 40 years primarily to control health and safety aspects of coal and metal mining. Regulations to address environmental impacts caused by mining started to be enacted in the 1960s.

The passage of the Surface Mining Control and Reclamation Act in 1977 started a new era for mining regulation. SMCRA marked the first comprehensive Federal legislation to regulate the environmental impacts of coal mining. The Office of Surface Mining was established in the Department of Interior and was charged with developing and enforcing comprehensive regulations governing all aspects of coal surface mining and the surface impacts of underground mining. [See Chapter 12 on Coal Mining].

Since SMCRA establishes such a comprehensive regulatory program for coal mining, the other major environmental laws such as the Clean Air Act, the Federal Water Pollution Control Act, and the Solid Waste Act, have not had as significant an impact on coal mining as these laws have had on non-coal and metal mining. Mining of industrial minerals and metals is subject to state and Federal laws controlling air emissions, water discharges and the handling, storage and disposal of solid and hazardous wastes. In addition, many mining states have enacted laws requiring mining permits that include reclamation plans and financial assurances or bonds to guarantee that environmental impacts will be properly addressed.

Mineral exploration and development on public lands also is subject to environmental regulations and land use requirements of the Federal land management agencies (primarily the Bureau of Land Management and the Forest Service). Also, mineral leases for coal and non-metal products, such as potash, phosphate, and soda ash or trona contain provisions requiring compliance with environmental laws and regulations and reclamation standards.

Notwithstanding the environmental controls required of non-coal and metal mining operations, there is

pressure from environmental groups and others on Congress to enact a comprehensive metal mining control and reclamation act similar to the coal Surface Mining Control and Reclamation Act. This pressure has in part resulted in the pending proposals to amend or in fact replace the Mining Law of 1872 with a comprehensive new mining code (see below). Given the current public awareness and concern about the environmental impacts of mining and a sense that mining is not adequately regulated, it seems likely that a Federal hard rock mining control and reclamation act will be enacted in the next few years, either as part of a new mining law or as a separate environmental control statute for the mining industry. Such a statute is likely to contain comprehensive and detailed standards for handling, storage and disposal of overburden, ore concentrate, waste material, and mill tailing as well as stringent reclamation standards, such as returning mined areas to the original contour wherever feasible and to a beneficial use at least as productive as the land use prior to mining. In addition, it is likely that such a statute will contain an abandoned mined land reclamation fund to reclaim or mitigate the environmental impacts of abandoned metal mines, said fund to be financed by a fee on mineral production or on the amount of waste generated at active mining operations. The discussion below on proposals to amend or repeal the general mining law give further indications of the type of requirements Congress is considering imposing on the hard rock mining industry.

## 19.5 REMINING OLD MINE WORKINGS AND WASTE DUMPS

**by R. B. Vrooman**

Each year, between one and two billion metric tons of mining wastes are generated in the United States. Furthermore, it is estimated that since 1910, 50 billion metric tons of mining wastes have accumulated throughout the United States. Much of this mining waste still contains valuable minerals which because of recent technological advances can now be extracted. Thus, the remining and reprocessing of mining wastes has become economically viable in many instances.

A twofold benefit is realized when mining wastes are remined and reprocessed. First, minerals that would otherwise not be recovered are recovered. Second, various environmental liabilities or concerns are alleviated in part or altogether.

Mining wastes that can be remined and reprocessed for the purpose of extracting additional mineral values include waste rock and mill tailings, both of which are typically found in large quantities at metal mining properties.

Given the size of mining waste rock piles and tailings impoundments, the potential environmental liabilities associated with them are enormous. Sixty of the approximately 1200 sites currently identified on the Environmental Protection Agency's National Priorities List under the Superfund Act are mining sites or are sites directly related to mining. Remediation costs associated with these sites are estimated to range from roughly ten million dollars to over one hundred million dollars. Remediation presently underway at the Iron Mountain Mine near Redding, California confirms these estimates. It is anticipated that the remediation will cost $72 million (1992 dollars). Likewise, cleanup of the Eagle Mine near Gilman, Colorado is anticipated to cost $30 million. Cleanup of the Idarado Mine and Pandora Millsite near Telluride, Colorado has a current price tag of $40 million.

In and of itself, mining waste is relatively inert and does not generally present a significant threat to the environment. When exposed to air and water however, those mining wastes that contain pyrites have the capacity to generate acid mine drainage or AMD (see Chapter 13). Once generated, AMD will leach other heavy metals out of the waste. AMD and the metals it contains have in many instances resulted in environmental degradation and unless contained or eliminated will almost always present a continuing threat to the environment. Containment and control of AMD and the heavy metals in mining wastes are a significant part of almost every mining waste cleanup.

There is presently no widely accepted technology available to prevent AMD production once the mine wastes are exposed to air and water. Common practice therefore dictates isolation of mining wastes from air and water to prevent AMD from developing. Isolation is accomplished by encapsulating and capping the mining wastes. In some instances, surface water diversion is also required. All of these activities require long-term maintenance commitments and do not treat the problem of AMD production at its source. Furthermore, mining wastes that have been treated in this manner retain the capacity to produce AMD indefinitely.

As noted above, because of recent technological advances, valuable minerals contained in mining wastes can now be extracted. Thus, waste rock that was previously set aside at many mines can now be processed to extract the mineral values. Similarly, mill tailings produced at many mining properties prior to the advent of modern metallurgical processing techniques can be reprocessed to extract the residual mineral content. Thus, mining companies have a unique opportunity to fund, at least in part, their environmental remediation costs and at the same time reduce the toxicity of the mining wastes they are charged with remediating. In many instances, this can result in a reduction of site closure costs and more importantly in a reduction in the long term environmental liability associated with mining wastes.

Typically, the remining and reprocessing of mining wastes can be carried out as an intermediate step in an environmental remediation project. For example, where a remediation plan calls for relocating waste rock to a centralized location and isolation by encapsulation, heap leach technology can often be included in the remediation effort. The additional costs associated with heap leaching in an overall remedial effort include the cost of the leaching operation itself and the cost for the additional time required to heap leach the waste rock prior to its final disposition. These costs are however at least partially offset by the value of the metals recovered. Similarly, when mill tailings are reprocessed, the additional processing costs are offset by the value of the metals recovered and the reduction of long term environmental liabilities associated with the tailings.

In addition to helping offset the cost of remediation and reducing long term environmental liabilities, there are several other reasons that weigh in favor of remining and reprocessing mining wastes. Other parties that are potentially responsible for part of the cost of remediating a mine site may be more willing to participate in the cost of cleanup rather than litigate where remediation costs are reduced by the value of the metals recovered. Also, the remedial work itself may provide the ability to develop remaining mineral reserves. Finally, voluntary remediation utilizing remining and reprocessing techniques can result in an enhanced corporate image which may also result in easier project approval at a later time.

The current laws and regulations governing mining waste generation, handling, transportation and disposal are discussed elsewhere within this chapter and in Chapter 3. These laws and regulations impose liability on both present and past owners and operators of properties where hazardous substances have been released or are likely to be released into the environment. This liability is strict, joint and several. Even small property acquisitions can lead to time consuming legal proceedings and asset draining liability. Those mining companies that are either present or past owners or operators of a mining property, or are for some other reason responsible for placing a hazardous substance at the mining property, are thus potentially liable for the entire cost of cleaning up the property.

Because of the all-encompassing nature of environmental cleanup liability, to a large degree, the election to remine or reprocess mining wastes will turn on whether or not a given company currently shares any potential cleanup liability at a mine site. Where a company is potentially liable for the entire cost of remediating a mining property, remining and reprocessing so as to offset part of the cleanup cost may present an economically viable alternative. On the other hand, where a company has no potential liability for any portion of the cost of cleanup, remining and reprocessing will only make sense when the net value of the minerals produced exceeds the potential environmental liability associated with the mining waste the company will assume once it elects to remine and reprocess the mining waste.

Where remining and reprocessing mining wastes presents a viable remediation alternative, it will reduce the toxicity, mobility and volume of AMD and associated heavy metals that might otherwise be generated by the mine wastes. Because of this capacity, it is anticipated that state and federal agencies will over time adopt policies to encourage the remining and reprocessing of mining wastes to facilitate cleanup. In the meantime, the technology utilized to remine and reprocess mining wastes will continue to improve and it will become an increasingly viable alternative and addition to the remediation process.

## 19.6 REVISIONS TO GENERAL MINING LAW AND REGULATIONS

**by S. D. Alfers and C. J. Harmon**

Current critics of the Mining Law of 1872 attack provisions that 1) permit miners to extract minerals from and acquire title to public lands for what is perceived to be a minimal amount of money or 2) do not provide sufficient environmental protection. Pending in Congress are several bills that would respond to this criticism by repealing the Mining Law of 1872 and the concomitant body of doctrines, rules and laws that has grown out of its interpretation by courts and agencies over its 120-year history.

The general mining law has been reformed, amended and modified to respond to changing needs and policies of the nation, from imperatives for domestic energy reserves, with the establishment of the Mineral Lands Leasing Act in 1920, to conservation and environmental protection, with the establishment of the National Forest System in 1912, the Materials Act of 1947, the Multiple Use Act of 1955 and the Federal Land Policy and Management Act of 1976. The pending bills seek to supplant the general mining law with an entirely new system of rules and administration. Before examining issues raised by the proposed legislation, a brief history of the 1872 Mining Law is in order to understand its origin, underlying policies, and evolution.

Between 1848 and 1866, mineral discoveries were made in many parts of the West. During this 18-year time period, the U.S. Congress debated mineral policy and considered and rejected a number of mining bills. Part of the reason for inaction was the inability of Congress to agree on the policy goals to be achieved.

In the meantime, the miners perceived the need for a legal system to govern relations among themselves. In

response to this need they organized mining districts, in which the miners in an area agreed to abide by a set of regulations drafted by their representatives and adopted by simple majority. Mining district rules were basic and adopted civil and common law principles. Among the rules adopted were the following: 1) claim ownership was based on priority of possession; 2) the right to hold and work property depended on actual possession and the proper marking of boundaries; 3) the right to mine existed only against other individuals; and 4) mining district rules created no rights against the state or federal government.

By the early 1860s, the inability to secure valid title to public domain mining lands was beginning to hinder development of western mineral resources. At the same time, the federal government needed revenue to prosecute the Civil War. By 1864, significant lode deposits had been discovered, but their development was more capital and labor intensive than placer mining. Miners needed greater amounts of financing to develop their claims, and financiers, in turn, needed greater security for their investments. As a result, the need for a clear system of tenure and title became increasingly important. During 1864, Congress considered various revenue-raising measures, including taxing production, seizing the mines, sanctioning free exploration and mining while retaining title to the lands in the federal government, and auctioning small tracts of mineral lands.

In 1866 the first mining law was passed by Congress. ["An Act Granting the Right of Way to Ditch and Canal Owners over the Public Lands, and for other Purposes," 14 Stat. 251 (1866)]. The Mining Law of 1866 contained provisions that were adopted from the policy of free entry by self-initiation established by the miners themselves within their various mining districts, allowing a claimant to occupy and work ground containing a lode deposit. It also provided that the claimant could obtain a patent to the mineral deposit after spending a minimum of $1,000 in labor or actual expenditures to occupy and improve a claim, according to the local miners' customs, and after paying to the government $5 per acre of patented ground.

The 1866 law was drafted primarily for the interests of the lode miners and did not adequately address the needs of the placer miners. Congress attempted to remedy that deficiency with the enactment of the Placer Act of 1870. [16 Stat. 217 (1870)]. The Mining Law of 1872 [17 Stat. 91 (1872), 30 U.S.C. § 21 *et seq.*] was enacted to correct some of the deficiencies of the two previous efforts. It defined the limits of the surface areas that could be claimed, restricted the size of individual claims, imposed the annual assessment work requirement, reduced the total amount of work necessary to support a patent, and provided for the location of millsite claims.

The Mining Law of 1872 made the standards of the early mining camps – priority, possession and diligent development – the tests of validity of a claim, and it imposed its own test, discovery, on claimants. By codifying these principles in a general mining law, Congress made a policy statement that it was proper to exploit mineral lands through the prescribed method of entry, exploration, discovery and development, and that those who take financial risks and diligently develop minerals on public lands should be rewarded.

The Mining Law of 1872 generally governed mineral activity on the public lands (except coal) until the Mineral Lands Leasing Act of 1920 [30 U.S.C. §§ 181 *et seq.*] removed fertilizer and fuel minerals from its operation and made certain nonmetalliferous minerals only leasable and not open to acquisition by claim staking. Subsequently, the Materials Act of 1947 [30 U.S.C. §§ 601-6040] and the Multiple Use Mining Act of 1955 [30 U.S.C. §§ 611 *et seq.*] removed additional mineral materials from operation of the general mining law. In addition, the 1955 statute and the rules and regulations promulgated pursuant to it by the Bureau of Land Management (BLM) or the Forest Service specify that uses of surface resources on unpatented claims are limited to uses incident to prospecting, mining, or processing operations.

As the West became more settled and its economy matured, greater and more varied demands began to be placed on the public domain. In addition, the early policy of liberal disposal of lands to encourage settlement and development began to give way to demands that the public domain be retained and made available for multiple, and often times conflicting, uses. Recreational uses of the public lands were becoming more significant, and the land management agencies were finding that the procedures available to them to review and challenge the validity of purported commercial uses of the public lands were not up to the increased demands being placed on them.

By 1964, political pressure to review the then-existing welter of federal land laws had grown sufficiently strong to prompt the creation of the Public Land Law Review Commission (PLLRC) whose task was to examine the system of federal land laws then in place and recommend necessary changes, which might include revision or repeal of old statutes and enactment of new ones. The PLLRC held numerous hearings, commissioned detailed studies of specific issues, interviewed land managers and users of the public lands, and ultimately compiled a list of recommendations published in 1970 as "One Third of the Nation's Land - A Report to the President and to the Congress by the Public Land Law Review Commission."

The PLLRC recommended a number of policy changes that would, if enacted into law, affect the mining industry in its operations on public lands. When Congress enacted the Federal Land Policy and Management Act [43 U.S.C. § 1701 *et seq.*] (FLPMA)

in 1976, it adopted the following PLLRC recommendations at the cited sections:

1. A policy of retention of federal lands was formally adopted, and the previous disposal policy was disavowed (enacted at 43 U.S.C. § 1701(a);

2. All withdrawals and classifications of public lands were to be reviewed to determine the "best use" of the lands affected (*id.*, and at 43 U.S.C. § 1712);

3. Land management agencies were instructed to promulgate extensive rules and regulations to govern their administrative procedures [*id.*, § 1701(a)(5-6)];

4. Land management agencies were instructed to formulate land use plans to obtain the greatest possible net public benefit from public lands administration [*id.*, § 1712(c)];

5. Environmental quality was to be incorporated as an objective of public land management, and policies designed to enhance and maintain high environmental quality were to be implemented [*id.*, § 1701(a)(8)];

6. It was recommended that federal environmental standards be applied to public lands (*id.*, §§ 1712, 1765);

7. PLLRC recommended that public lands users be required to conduct their activities in a manner that would minimize environmental impacts (*id.*, § 1718);

8. The Commission recommended that some public lands should continue to remain off limits to mining (*id.*, § 1714);

9. It was recommended that future disposal of public lands should be made subject to the reservation to the federal government of all mineral interest of known value (*id.*, § 1719); and

10. PLLRC recommended that mining claimants under the 1872 Mining Law be required to record their existing and future claims with the federal government, in order to clear dormant and invalid claims from the public lands and to provide federal land managers with accurate data about the number and locations of claims on public lands (*id.*, § 1744).

When it enacted FLPMA, Congress also had before it a number of PLLRC recommendations that were not incorporated in the legislation. FLPMA did not significantly amend the 1872 Mining Law. Section 1732(b) of FLPMA expressly disclaimed any intent to do so, except for the specific changes enacted in §§ 1744, 1781(f), and 1782. Instead, it imposed some additional requirements on holders of mining claims while preserving the location and entry system. In recognition of the practical needs for information of the surface management agencies, Congress sensibly adopted the recording provisions of FLPMA. However, it declined to repeal or radically alter the 1872 Mining Law, recognizing that it had served the interests of the nation and the mining industry well since its enactment.

Pending legislation would repeal the Mining Law of 1872 and eliminate the right of self-initiation, as well as severely limit rights to mine existing mining claims. The bills require that owners of claims located under the Mining Law of 1872 forfeit their claims or exchange them for new claims. The bills also limit a miner's right to bring existing claims to patent.

Not only do the bills do away with many of the material features of the Mining Law of 1872, but they also add numerous requirements under a new land-use planning system. In developing plans under FLPMA and other statutes, the Secretary of the Interior or the Secretary of Agriculture ("Secretary") is authorized to prohibit, restrict or condition certain types and classes of mineral activities that conflict with other plan objectives or management decisions of the Secretary. Among the criteria to be considered by the Secretary in determining whether or not certain lands are appropriate for the conduct of mineral activities are the location, nature and extent of mineral deposits and existing mineral activities, the development potential of mineral deposits as well as the potential cumulative environmental impacts of exploration, development and production of such deposits, an evaluation of non-mineral resources and values that may be affected by mineral activity, an evaluation of the prospects for reclaiming the mining area in accordance with new federal requirements set forth in the bills and identification of specific areas where mineral activities shall be prohibited, restricted or conditioned.

The pending bills require an approved plan of operations before any mineral activities that cause more than minimal disturbance to the environment may occur. The Secretary may approve, modify or deny a proposed plan of operations; however, a proposed plan of operations may *not* be approved unless the Secretary determines that the mineral activities proposed thereunder will be consistent with the land use plan applicable to the proposed mining area.

Provisions of the pending legislation dramatically change existing presumptions concerning the rights of a mining claimant. Currently, regulations requiring plans of operation have as their purpose the prevention of unnecessary or undue degradation of federal lands that

may result from operations authorized by the mining laws. A mining claimant now has a statutory right to go upon unappropriated and unreserved federal lands for mineral prospecting, exploration, development, extraction and uses reasonably incident thereto. Existing regulations seek to insure that any surface disturbances that occur in connection with those activities are no greater than "what would normally result when an activity is being accomplished by a prudent operator in usual, customary and proficient operations of similar character and taking into consideration the effects of operations on the resources and land uses . . ." [43 C.F.R. § 3809.0-5(k).] Rather than placing appropriate conditions on the statutorily authorized use of land for mining purposes, pending bills would give the Secretary the discretionary authority to decide whether or not use of any particular tract of land for mining purposes is appropriate in the first instance.

The bills also provide for specific federal reclamation standards. For example, surface disturbances are to be reclaimed, at a minimum, to a condition capable of supporting the same level of productive uses as existed prior to any mineral activities. The reclamation standards to be promulgated by the Secretary are to cover areas such as topsoil protection and replacement, revegetation to pre-mining production capability, reclamation of roads, permanent sealing of all tunnels and portals, protection and reclamation of surface and groundwater quality and quantity, leach pad stabilization and neutralization, safe disposal of hazardous and toxic materials and recontouring of dumps, heaps and other disturbances to minimize visual impacts and blend the mining area to natural topography.

In general, the proposed provisions of the pending legislation can be categorized into those that would impose stricter environmental requirements, either through the establishment of federal reclamation standards or the grant of broad discretionary authority to the Secretary to modify a claimant's reclamation plan, and those that would attempt to increase revenues to the federal government. The provisions of the bills are at odds with the policy statement set forth in the Mining and Minerals Policy Act of 1970, P.L. 91-631, which declared it a policy of the United States to foster and encourage private enterprise in the development of an economically stable mining industry, to develop domestic mineral resources in order to meet industrial, national security and environmental demands, and to develop sound reclamation methods to lessen the environmental impact of mining. Enactment of any of the proposed bills in their current form would sweep away 120 years of legislation, jurisprudence and regulation that have sought to balance private initiative for mineral development with national imperatives for economic development, wilderness, national parks and forests, and environmental protection.

## 19.7 FEDERAL, STATE AND LOCAL REQUIREMENTS - INTERACTION

**by M. C. Larson**

Local communities experience the most direct effect of mining and natural resource development. Communities located near a new mining operation will typically undergo a rapid growth in population, and experience a variety of associated socioeconomic impacts.

The socioeconomic impacts can be both beneficial and detrimental. Mining can create new jobs, provide a new source of tax revenues, and diversify the economy of a community. As the population increases, government services, such as fire, police, water, and waste disposal, are upgraded and expanded. Construction, retail, and service industries experience growth through greater demand. New job opportunities keep people from leaving the community.

At the same time, however, rapid growth and expansion may place a severe economic burden on the local government and the community. Local governments often experience a time lag between capital outlays for building the necessary infrastructure to support the increased population and incoming tax revenues. Even worse, a local government may find that it cannot obtain additional tax revenues to support its burgeoning population. For example, most of the workers at the Decker Coal Mine in Big Horn County, Montana, live in Sheridan, Wyoming. Sheridan had to expand government services and utilities without receiving the property and severance taxes collected from the mining operation.

The rapid influx of persons into a community can create a greater demand for goods and services, resulting in higher prices for everyone. Housing shortages often result from the inability of the local construction industry to keep up with the demand for new housing. The housing shortage is often solved by establishing mobile home parks, which rarely satisfy long-term and aesthetic needs of workers. In addition, high-paying job opportunities with the mining industry may inhibit the ability of existing businesses to obtain inexpensive labor.

In addition to the socioeconomic impacts, mineral development may be at odds with the aesthetic, environmental, and health concerns of a community. These concerns have been evidenced by the proliferation of local land use controls since the environmental awareness movement began in the 1960s. Traditionally, local communities were growth-oriented, and open to industry and its attendant economic benefits. The highest and best use of land, particularly in the western states, was the development of valuable mineral deposits. With the environmental movement, however, perceptions about the value of land began to change. Land that was viewed as worthless exclusive of its mineral deposits,

may now be considered a highly valuable asset that needs to be preserved in its natural and wild state.

Rather than looking forward to the economic boom typically attendant to mineral development as they have in the past, communities are now weighing the economic benefits against aesthetic values and quality of life issues. Many communities adopt the attitude of "Not in my backyard," (NIMBY) and oppose mineral development of any kind. Other communities will encourage mineral development in the area if they can control the way growth will occur and address the impacts that they perceive as negative.

In general, a local government can control land use through a variety of governmental powers: taxation, spending, acquisition, and planning/zoning. The taxation power is used to finance programs and services that a local government may need in order to respond to the rapid growth associated with mineral development. The acquisition/eminent domain and spending powers can be used to encourage growth in some areas and discourage it in others.

The planning and zoning power is the primary method for regulating land use within a local government's jurisdictional borders. In some circumstances, a city may be able to regulate land use outside of its territorial boundaries, particularly in matters that directly impact municipal matters, such as protection of a city's water supply or air quality. Where extraterritorial powers are applied, a mining operation may be required to satisfy a city's land use regulations in addition to any county requirements.

The planning power of a local government is usually exercised by developing a comprehensive plan that delineates future development and the way in which public services and facilities will be extended to accommodate growth. The zoning power regulates the use of property, including structural and architectural aspects, and the types of uses that are allowed. "Euclidian zoning," which is still used by many local governments, divides the land into various districts and prescribes the uses that are permitted in each district. In response to the inherent limitations of this type of zoning, there has been a gradual movement towards zoning by performance standards. In lieu of listing specific uses of land, performance zoning admits a general class of uses provided that certain performance standards relating to noise, smoke, wastes, heat, traffic, etc. are met.

Local control is the best way to deal with the adverse impacts of mining because it reflects the values of the people who will be the most directly affected by the mining operations. Furthermore, state and federal regulations do not tailor their requirements to unique, local conditions. The local terrain, climate, biologic, chemical and other physical conditions will undoubtedly affect mining operations and the way those operations in turn impact a community.

As compared to local government, the state receives less direct benefits from mineral development. This is because most of the economic benefits are absorbed by the affected communities. The primary benefits that inure to the state are tax revenues (both sales and severance taxes) and lower unemployment rates.

The state's concerns with mining are generally broader than that of local government, and tend to focus on safety and health and environmental protection. Most states have enacted laws and regulations that require mining operations to obtain construction and operating permits that impose stringent environmental impact and safety and health conditions or standards on such operations. The manner in which states protect, manage, and tax natural resources may affect their ability to compete with other states and foreign sources for energy and the rate their citizens pay for electricity.

The Federal government has a direct interest and concern where mining takes place on Federal or public lands. Where mining takes place on private land, the Federal government requires compliance with Federal (or equivalent State) environmental regulations. To a lesser degree, the Federal government's concern with mining is shaped by its regulation of interstate commerce and concern for national security.

The Federal, state, and local relationship has changed dramatically during the last 30 years. Because Federal regulations are to be applied uniformly throughout the nation, they are often ineffective or out of place at the local level. Congress has recognized that state and local governments are more responsive and may have innovative solutions to unique, local problems. The Clean Air Act, Amendments of 1990, and other significant pieces of environmental legislation enacted in the past few years have returned some functions and responsibilities to state and local government. However, while states and local governments, are being given more responsibility and authority, Federal funds to implement state and local programs is being cut. To some extent, the opportunities offered to state and local governments cannot be realized because of fiscal restraints.

There is considerable overlap and potential for conflict among the various Federal laws regulating the environment. There are laws focusing directly on the activities of the mining industry, such as the Surface Mining Control and Reclamation Act, and an entirely distinct body of law aimed at protecting the environment which is media specific. Since there is no homogeneous "umbrella" environmental protection act, a mining operation must comply with each applicable law and the framework of regulations promulgated thereunder. Compliance with one act does not ensure compliance with another act. For example, although the burning of used oil may be permitted under certain conditions pursuant to RCRA, a company must still obtain an air permit which restricts the emissions that will occur as a

result of the burning. Treatment standards under RCRA, CWA, and CERCLA can vary with respect to the same waste. In addition, some of the environmental laws are inconsistent with respect to enforcement mechanisms, and impose differing penalties. The standards and applicability of these laws to mining operations are discussed in greater detail in Chapter 3.

Conflicts between state, local and Federal laws are governed by the preemption doctrine. State or local laws will be prevented from operating if the Federal statutory scheme expressly directs that state and local law shall be preempted. When the Federal statutory scheme is silent or ambiguous, preemption will occur if Congress intended to entirely occupy the field, if the state or local law actually conflicts with Federal law, if it is impossible to comply with both state and Federal law, or if state law frustrates the purposes and objectives of Congress. State constitutional rights, state statutes, state common law claims, and municipal ordinances have all been struck down as preempted by Federal statutes. The judicial decisions in this area are inconsistent, and reflect the fact that each body of Federal law has its own particular preemption doctrine.

One of the leading cases applying the preemption doctrine in the mining context is *California Coastal Comm'n. v. Granite Rock Co.* (480 U.S. 572 (1987)). In that case, a mining company sought to enjoin the California Coastal Commission from requiring it to obtain a permit to engage in mining activities on an unpatented claim located in a national forest within the State's coastal management zone. The Ninth Circuit Court of Appeals found that the Forest Service regulations governing mining in national forests preempted the State Coastal Commission requirements, and that the power to prohibit mining for a failure to abide by environmental requirements rested with the Forest Service and not the State.

The United States Supreme Court reversed, finding that the Forest Service's environmental regulations controlling activities on unpatented mining claims did not preempt state law. Although Federal legislation preempted the application of *state land use plans* to national forests, Congress did not intend to preempt reasonable state *environmental regulation.* The Supreme Court found a clear line between land use regulations, which control particular uses of the land, and environmental regulations, which require that however the land is used, environmental harm is kept within prescribed limits.

Federal preemption of state and local laws in some cases tends to favor industry. When state or local law is preempted, industry's obligation extends only to the set of regulations promulgated by the Federal government. This can provide distinct economic benefits to the regulated industry. Furthermore, industry can make its concerns known to a single Federal agency much easier than to fifty state legislatures or numerous local governments. Conversely, preemption may impede the ability of governmental bodies to respond to citizens' needs and public values through local land use regulations.

Notwithstanding the preemption doctrine, the current trend is toward increasing control of all types of development, including mining, at the local level. More "grass roots activism" and involvement in local politics by citizens concerned with development directly affecting their lives, as well as gradual changes in values toward environmental protection and use of natural resources, is resulting in more local government land use, zoning, health and safety, and environmental regulations or ordinances governing all major development. In order to obtain the required permits and approvals for constructing and operating a mine, the operator must address the concerns of the local communities in his mine planning and engineering. As noted above, a significant community relations and education effort may be necessary before achieving community acceptance.

## 19.8 INTERNATIONAL REQUIREMENTS AND STANDARDS

**by P. Keppler**

In the last ten years, many foreign countries have enacted laws and regulations to control the environmental impact of mining similar to those adopted in the United States. As a result, most major corporations apply the same environmental controls and compliance programs at their foreign operations as they do their United States operations. Even for established facilities, if the laws of the host nation will require upgrading or retrofitting environmental controls, it is prudent to incorporate such controls as early as feasible rather than to defer the expenditure until "the last minute" when ordered to do so under a short, accelerated time-frame.

During the 1990s, the world is moving quickly toward a global economy and free trade among all nations. The European Common Market and the North American Free Trade Agreement are but two examples of the removal of trade barriers among nations and the "globalization" of the world economy. The North American Free Trade Agreement (NAFTA) among Canada, Mexico, and the United States should benefit the domestic mining industry, particularly the producers of non-ferrous metals. With the phase out of tariffs and import licenses, the domestic producers of copper, lead, and zinc and other non- ferrous metals should be able to expand exports to Canada and Mexico.

Some view NAFTA as promoting the exodus from the United States to Mexico (and eventually other South American countries) of major polluting industries, such

as mining and mineral processing, due to lax environmental laws and enforcement. In the past, a number of United States companies located manufacturing and assembly plants along the Mexican border zone in part to escape stringent environmental requirements in the United States. These *maquiladora* industries have brought Mexico the economic benefits of foreign investment without displacing domestic companies, since *maquiladoras* are generally prohibited from selling directly into the Mexican market. With the enactment of NAFTA in 1993 and the adoption of a side agreement dealing specifically with enforcement of environmental requirements, corporations can no longer locate in Mexico with the expectation of avoiding environmental controls applicable to similar facilities in the United States and Canada. NAFTA and the environmental side agreement recognize the right of each signatory country to enact and enforce its own environmental standards while setting up a process by which the regulatory agencies can compare and consult on standards and regulations in order to achieve similar levels of environmental protection in all three countries.

As noted in other chapters of this Handbook, all societies of the world are concerned with some degree of environmental protection and have enacted laws that mandate mining employ operating methods and technology to minimize adverse environmental impacts. Even in third world developing countries seeking foreign investment, mining will not be allowed without basic environmental controls and measures to protect the local ecology. International agencies such as the Inter-American Development Bank, International Monetary Fund, the World Bank, and the United Nations impose environmental norms on mineral development and other projects in foreign countries whenever such projects seek financing and government approvals.

With the heightened worldwide environmental consciousness, the mining industry should be involved in developing the environmental laws and regulations of the host country that reflect the desire for environmental protection while allowing resource development. The policies of developing countries as reflected in governing laws need to respect state participation, financing, and marketing arrangements of mining ventures and provide the companies with returns on investment that are commensurate with the risks of operating in the foreign nation. The company proposing to mine in a developing nation will request financial assistance in the form of exemption from customs fees, duties, excise and value added taxes, as well as expecting health and safety and environmental policies consistent with international practices and standards. Developing countries seeking investment by the mining industry can be expected to evaluate what the market can bear and how environmental controls can be implemented to reduce the risk premium to the investors. Policy approaches can contribute to improved environmental management practices in two ways: first, conditioning private, bilateral, and multi-national credit on environmental impact assessments and the use of best management practices; and second, promoting research and development for solutions to clean-up past mining impacts and to develop environmentally-sensitive technology.

In the past, development of environmental policy and trade policy tended to run on different tracks. With the globalization of the world's economies, this can no longer be expected. The challenge is to bridge the gap between trade policy and environmental policy. Trade policy is environmentally sensitive, and environmental programs supporting sustainable growth must not become trade barriers. In the wake of NAFTA and expanded free trade throughout the world, the mining industry will witness greater economic growth and environmental efficiency, particularly in developing countries. Ultimately, the standard of living in many third-world countries will improve due to expanded investment in mineral development in those countries.

## 19.9 ENVIRONMENTAL REQUIREMENTS AND MINING ECONOMICS

**by W. E. Martin**

Prior to passage of the National Environmental Policy Act (NEPA) in 1969, the mining sector operated in an atmosphere that required operators to have little regard for the environmental consequences of their actions. The ability of the environment to assimilate the waste generated by mining seemed almost limitless. What little concern there was for environmental issues generally focused on water quality between upstream (e.g., the mines) and downstream (e.g., agricultural uses) water users. However, once NEPA was passed the entire operating milieu for the mining industry changed. What has become known as the "NEPA process" has added significant costs and time to the development of a mining project. NEPA was only the first step in a movement that has resulted in a significant environmental compliance process that now includes numerous permits and financial bonding requirements. Evaluating and estimating the costs of environmental compliance is a step in analyzing the feasibility of developing mining properties. This section discusses the integration of the costs of environmental compliance with the traditional methodology of discounted cash flow (or net present value) analysis and considers trends in environmental compliance costs.

The key aspect of NEPA is the requirement that any "major" federal action, such as issuing a permit or lease,

consider the environmental consequences of the proposed project. Elsewhere in this volume the specifics of the NEPA process are discussed, as well as the various state and local requirements. Understanding the legal and engineering aspects of the required changes due to environmental concerns is a necessary first step to determining the economic costs of the environmental compliance process.

The focus of this section is on the costs of environmental compliance. Various approaches can be used to measure the economic costs of environmental compliance. For example, the direct costs associated with completing an environmental impact statement, filing for permits, conducting the required studies for the Endangered Species Act, etc. can be calculated and attributed to the environmental compliance process. These costs can then be expanded to include the indirect costs, such as delay of project start-up due to the NEPA and permitting process, changes in production technology, use of more expensive exploration techniques, changes in tailings disposal methods, etc. The costs will be presented based upon the various stages of a mine project. Mine projects involve four stages: exploration, development, operation, and closure/post-closure activities. The environmental compliance costs for each of these stages will be addressed separately.

### 19.9.1 EXPLORATION

The exploration phase of a mining project is generally the phase least affected by environmental regulations. The Mining Law of 1872 specifies that certain Federal lands are available for mineral exploration (and subsequent development). Only if the exploration activities disturb the land (such as building roads, etc.) will environmental compliance issues arise. However, prior to exploration activities the firm must submit a Notice-of-Intent (NOI) that specifies the proposed actions. The NOI is submitted for information purposes and does not require approval by the agency to which it is submitted, usually the Bureau of Land Management or the Forest Service. The costs associated with preparing this notice are minimal and may be treated as a sunk cost once a discovery is made and a project analysis proceeds.

The NOI is sufficient if the area disturbed by the exploration activity is minimal. However, if the area disturbed is significant then the firm is required to submit a "Plan of Operation" (POO) describing the proposed exploration activities. At this point, other requirements may be made of the firm, for example, posting a bond, conducting a Cultural Resource Survey and/or a Biological Evaluation. It is quite likely that such studies will become more common, particularly if the Mining Law of 1872 is rewritten to incorporate more environmental constraints on mining activity.

### 19.9.2 DEVELOPMENT

The development phase of a mining project is the phase most affected by the environmental compliance process. Once an ore body has been discovered and exploration has resulted in a decision to proceed with an economic analysis of the site, then the process of preparing either an environmental assessment (EA) or an environmental impact statement (EIS) must be made as specified by NEPA or comparable state law. The EIS process provides an opportunity for all interested parties to evaluate and comment on all aspects of the project. Every phase of the project must be specified in the EIS including the mining and milling process, the tailings disposal method, reclamation plans, etc. The time requirements for such a detailed analysis are quite extensive, thereby increasing the time required to place a property into production. Also, the preparation of the EIS may be only the initial step in the process, since many EISs are subsequently challenged in the court system.

Although the time requirements associated with the administration of relatively new regulations may be quite lengthy, this should be reduced as familiarity with the regulations is achieved. This does not seem to be the case for the United States environmental compliance process, however, as the time requirements are generally increasing. This is particularly true for compliance with the NEPA process. This increase can have dramatic effects on project economics by delaying production for several months or even years.

As costly as the NEPA process is, it is only one part of the total costs of the environmental compliance process. While preparing the EIS, the firm is also involved in applying for the necessary permits and approvals from the various Federal, state and local regulatory agencies and providing financial assurances (bonds, letters of credit, etc.) for environmental cleanup and reclamation. For example, to bring a mine into production in south-east Alaska, it is necessary to receive approval from the Environmental Protection Agency, the Corps of Engineers, the Fish & Wildlife Service, the Forest Service, and the Bureau of Land Management at the Federal level as well as the Department of Environmental Compliance, Department of Natural Resources, Department of Fish & Game, and Division of Governmental Coordination at the State level, plus local government. It is generally necessary for the firm to closely coordinate with the representatives of these agencies, which also requires significant time and expense. Also, an indirect cost of this multi-tiered regulatory environment is the uncertainty involved and frequently conflicting rulings from each agency. These costs need to be incorporated into the net present value analysis for a project.

The major permits required by mining operators focus

on compliance with the air, water, and solid waste legislation. Several primary permits may be required: 1) National Pollutant Discharge Elimination System (NPDES) permit under the Clean Water Act (CWA); 2) Underground Injection Control (UIC) under the Safe Drinking Water Act (SDWA); 3) Prevention of Significant Deterioration (PSD) under the Clean Air Act (CAA); and 4) a dredge and fill permit under the Clean Water Act. The costs of applying for these and many lesser permits must be incorporated into the economic analysis of the project.

As the permitting system matures, much of the overlap in the requirements by the various jurisdictions can be expected to diminish. An example of this trend is the joint application for permit that can be submitted to the United States Army Corps of Engineers and the Division of State Lands in Oregon. By filing one form, the firm is able to comply with the requirements of both the State and the Corps regarding the transport and disposal of dredged and fill material in the navigable waters and wetlands of Oregon.

### 19.9.3 OPERATIONS

By the time the operation/production phase of the project commences, the NEPA process and any necessary permitting must be completed. Therefore, most of the environmental compliance activity during this phase involves permit renewal or modification to accommodate changes in operations technology and methods over time, as well as reporting and record keeping requirements. Another related activity involves complying with new environmental legislation and regulations, such as complying with the new mining waste regulations of the Solid Waste Act once they are adopted or changes that may be required with the reauthorization of the CWA.

The operation phase of a mining project requires a high level of involvement by all personnel in the firm, from the accountant to the workers in the mine, to comply with the environmental regulations. Some of the costs of environmental compliance in the operation phase are easily identified while many others are not as easily quantifiable. For example, the firm's environmental director working on a project is easily identified and the associated costs estimated, whereas, the increased costs due to differing waste handling requirements or temporary mine closure are much less obvious.

The cost of compliance during the operation phase can be divided into two components: costs that are related to the production process and costs that are required that do not affect production per se. An example of the costs that are production related would be additional handling requirements due to hazardous wastes regulations. Examples of the second type of costs include finalizing closure and post closure plans and related changes in bonding requirements, and a permit condition that a firm continually monitor and study a species that may be potentially affected by the mining operation. This is the case with Kennecott at the Greens Creek mine in southeastern Alaska where the company is required to fund a study of the bear population on Admiralty Island.

Previous chapters in this book have discussed the legal environment affecting mining projects and the compliance requirements associated with each law. The object here is to realize that the costs associated with all aspects of the environmental compliance process must be included in the project cost analysis and not just production related costs.

### 19.9.4 CLOSURE/POST-CLOSURE

The final aspect of a mining project involves the closure of the mine and the environmental requirements associated with the closure and future monitoring activities. The primary environmental concerns at this stage of the project involve the liability associated with waste disposal that extends beyond the life of a given project. This cost and potential liability must be included in the net present value analysis of a project to get an accurate picture of the project economics. The uncertain nature of the potential liability of the firm is problematic. The firm must realize that a cost may exist but needs to 'objectively' incorporate this cost, even though there is a high degree of uncertainty as to the dollar amount, into the project analysis.

Another aspect of the post-closure commitments of a firm are the reclamation bonding required of most projects. Bonding may be required by several different agencies or jurisdictions. For example, the City and Borough of Juneau in southeastern Alaska requires bonding at the local level in addition to the Federal bonding requirements. The trend toward requiring firms to maintain responsibility for a property, even if title has been transferred and operations have ceased, is becoming more prevalent in environmental legislation.

### 19.9.5 RELATED ISSUES

One of the most important aspects of determining the cost of environmental compliance on the economic analysis of a mining project is the uncertainty associated with much of the environmental regulation. The EPA process under RCRA for regulating most mining wastes (low-level, high volume wastes) is a classic example. The Bevill Amendment to RCRA specifically excluded mining wastes from RCRA hazardous waste regulation until the EPA completed studies of the impact of these wastes on the environment. It is not clear what form the regulation will take once these wastes are regulated. Currently, the trend in the United States Congress is to rely more on market incentives, as was the case with the

acid rain provision of the 1990 Clean Air Act Amendments, as opposed to the traditional command and control approach. Several major environmental laws are currently under consideration for reauthorization and could be significantly modified.

Perhaps the revisions that will be the most significant to the mining sector will be the amendments to the Clean Water Act. These amendments could incorporate many more uses of market incentives than have been the case previously, particularly if the $SO_2$ allowance trading system under the Clean Air Act proves successful. A hypothetical example of such a system applied to a water pollutant would be as follows. The EPA determines that the cyanide content of water should not exceed a certain amount in a given watershed. Following the methodology used in the Clean Air Act, a number of allowances would be determined that would result in the desired level of cyanide concentrations in the watershed. This aspect of the regulation would be similar to the traditional command-and-control approach used previously. The market incentive aspect of the new approach results from these allowances being bought and sold in a market setting. Therefore, mining firms would be able to buy and sell allowances based upon tradeoffs between abatement costs and allowances costs.

The important aspect of this uncertainty for the firm is how to incorporate these possible changes into project analysis in a meaningful way. The objective of most environmental regulations is to internalize the costs of environmental damage and the firm must attempt to estimate these costs for use in the project analysis. This task becomes much more difficult since some of the costs involve non-market goods, or goods that have no market determined price. The task of placing a value on these goods is quite daunting.

There are basically two categories of methods for estimating the value of non-market goods. The first category of methods are the indirect approaches. The two methods most commonly used are the travel cost method (TCM) and the hedonic price method (HPM). These methods rely on the consumer revealing their value for a non-market good indirectly through other observable behavior. A direct approach may also be used to value non-market goods. This approach involves asking consumers what is their value for the good being considered. The most dominate approach in this category is the contingent valuation method (CVM). The CVM involves surveying consumers of the non-market good and asking them how much they value the good described.

The above discussion addresses the valuation of the 'use' components of a non-market good. Many non-market goods also have a 'non-use' value as well. Generally, non-use values are defined as option values and existence values. An option value is a value that a person has for a good (market or non-market) that they are willing to pay to ensure the availability of that good for future use. An existence value is the value that a person places on a good based upon the knowledge that it exists even though they do not intend to use it currently or in the future. The non-use values are generally of less concern to mine operators than the use values; however, these may become quite important in the event of a legal action under the Superfund Act.

Conducting such studies for every project considered would be quite expensive. An alternative that is becoming more feasible as more studies are being conducted is to use values from one site to infer values to another (similar) site. Although this method is somewhat new in this context, transferring available values should provide at least an order-of-magnitude estimate of relevant costs.

These types of costs are generally not considered during the project analysis phase of project development but they can help to reduce the uncertainty associated with many projects, particularly during the closure/post-closure phase when significant liability may exist. Integrating all aspects of environmental compliance costs during the initial phase of a project analysis will provide a much more complete analysis of project feasibility.

## 19.10 OTHER ISSUES

### 19.10.1 THE FEDERAL CLEAN AIR ACT AMENDMENTS

**by B. J. Beckham**

Requirements of the Federal Clean Air Act Amendments of 1990 (CAAA) are estimated to cost in excess of $25 billion per year. The implementation of the full Act may take anywhere from 20 to 25 years. There are eleven titles in the Act, seven of which will dramatically affect air emitting industries, including mining operations. Those that will have the greatest impact on industry are the non-attainment, air toxics, acid rain, permits, and enforcement titles.

There has been considerable improvement in air quality across the county for ozone, carbon monoxide, sulfur oxide and other criteria pollutants, but, even so, there are still many areas (over 100) that fail to meet the national ambient air quality standards. The CAAA Title I non-attainment provisions require air quality control areas to revise their existing air quality plans to meet national ambient air quality standards. Each area is classified depending upon the degree to which the air quality standard is exceeded. Areas with the least problematic air quality are given three years to comply with the national ambient air quality standards.

Extreme areas, such as Los Angeles for ozone, are given well over 20 years to comply with the standards.

The major control approach in the non-attainment areas is to implement reasonably available control technology or RACT. This would apply to major sources of volatile organic compounds and nitrogen oxides to address areas that cannot demonstrate compliance with the ozone standard. The more severe the problem, the tighter the major source definition, to the extent that in Los Angeles, for example, a major source is defined as emitting only 10 tons per year of NOX or volatile organic compounds.

RACT is determined on a case-by-case basis. Perhaps more important to mining operations, sources in areas designated as $PM_{10}$ non-attainment will be required to implement reasonably available control measures or RACM, which may allow for slightly more flexibility than the RACT requirements.

The states will be dependent upon EPA to provide control technology guidelines; EPA is in the process now of developing those guidelines. For new sources, offsets are required in non-attainment areas. The offset ratios change from 1.1 to 1 up to 1.5 to 1, depending upon the severity of non-attainment in a given area.

Title III applies to hazardous air pollutants. The requirements in the 1977 Clean Air Act Amendments set out a process where EPA was to establish national emission standards for hazardous air pollutants (NESHAPs). Over a period of 12 years, only seven compounds were regulated. The shift now in the 1990 legislation changes from a risk-based approach to a technology-based approach, dependent upon industry or source type. The law lists 190 substances for which EPA is required to develop maximum achievable control technology or MACT.

The first major MACT standards developed by EPA deal with hazardous organic materials emitted by the synthetic organic chemical manufacturing industry. The MACT standards for mining operations are currently not scheduled to be promulgated until the year 2000. Under the 1990 Amendments, EPA is also required to study the levels of residual risk after MACT standards have been implemented. If it is determined that there is still a substantial risk to the general population (i.e., greater than $10^{-6}$ risk level), additional risk-based standards will be developed and applied.

The definition of a major source has changed considerably for hazardous air pollutants. Annual emissions of 10 tons per year for any of the 190 hazardous air pollutants listed in the law would qualify a facility as a major source, which would trigger MACT requirements. Even if emissions are less than 10 tons per year for any one hazardous air pollutant, if in the aggregate the total exceeds 25 tons per year, that particular source would be subject to MACT as well. Furthermore, EPA has the authority to establish a lesser quantity cutoff for 47 hazardous air pollutants. In some cases, depending upon the compound, a major source could be defined down to emissions of a tenth of a ton per year, requiring the application of MACT.

Title III allows a source to delay meeting MACT for up to 6 years through an early reduction program. To qualify for this program, a source would have to demonstrate that it has reduced emissions of hazardous air pollutants by 90% since its baseline inventory in 1987 (with some exceptions). The source would then have to submit a modified permit consistent with the Title V requirements, and establish a new enforceable emission limit for the source.

Title IV applies to acid rain. The law seeks to reduce $SO_2$ emissions by 10 million tons per year by the year 2000, and nitrogen oxides emissions by 2 million tons. The goal is to be achieved in two phases. Phase I requires 111 power plants (major emitters of $SO_2$) to achieve an average emission rate of 2.5 pounds of $SO_2$ per million BTU by 1995. Phase II is to result in all power plants achieving a 1.2 pounds $SO_2$ per million BTU emission rate by 2000. Plants that achieve a rate less than 1.2 pounds per million BTU in 1995 will receive a 20% bonus in allowances to account for growth. An $SO_2$ emissions cap is effective January 1, 2000, and additional increases in $SO_2$ emissions will have to be "offset." Title IV does not require that specific technology be employed; consequently, reductions can be achieved by switching to clean burning fuels (for example, low sulphur coal). Reductions achieved can be "banked" and used for future growth, sold, or used to meet specific reduction targets.

Title V establishes the operating permit program, which is similar to the NPDES water quality program. All major sources are required to apply for operating permits. The permit program is set up to collect annual emission fees: The suggested fee under the Act is $25.00 per ton for all regulated pollutants. This fee, (which is indexed to the Consumer Price Index) is to be collected by the permitting agency to support the direct and indirect costs of operating the permit program.

EPA issued the final operating permit regulations in July 1992. State agencies will have to take the "boilerplate" requirements of EPA's regulations and obtain the necessary statutory authority and proceed with the development of permit regulations at the state level. For many major sources, permit applications will be due in late 1994 or in 1995.

Some companies will need to permit hundreds of sources. These permits are likely to have a far more comprehensive impact than previous permitting programs, even though many states currently have an operating permit program. Two provision that merit further discussion in the permit program deal with operational flexibility and establishment of a permit shield. Operational flexibility would allow a source to make minor changes in its operation without having to go through the formal permitting process. Accordingly,

it is important for sources to look at what changes have occurred historically at their particular operations and have those addressed in the permit.

Since the new operating permits are deemed to include all of the limitations in the state implementation plan and all of the requirements to demonstrate compliance with the new CAAA, if a source complies with those requirements in the permit, it is deemed to be in compliance with the law. The source obtains a shield from enforcement actions under the law if it is complying with the specific provisions of the permit.

It is important to consider the permit shield very closely since it does interface with some of the enforcement requirements. The source must ensure that the operating permit includes all of the applicable provisions and it is in full compliance. Under the new law, the enforcement agency is allowed to assess fees or penalties on site for violations, similar to a traffic ticket, of up to $5,000 per day.

The Clean Air Act Amendments of 1990 and comparable state laws will establish new and expanded permit requirements. There are some things that mining companies can do now to prepare for new regulations, particularly by obtaining an updated emission inventory, looking at ways to reduce hazardous emissions, determining what permit fees might apply, and evaluating alternative operating scenarios.

### 19.10.2 STORM WATER RUNOFF
**by P. Keppler**

Under the Federal Water Quality Act of 1987, EPA was directed to phase in regulation of storm water discharges and require permits from dischargers of storm water associated with industrial activity and from medium and large municipal separate storm sewer systems [33 U.S.C. § 1342(p)]. Pursuant to this requirement and a court entered consent decree, EPA promulgated on October 31, 1990 regulations requiring permit applications for certain industrial and municipal storm water dischargers (55 Fed. Reg. 47990, 40 C.F.R. Part 122). Industrial dischargers included mining operations where storm water is contaminated by raw materials (ore), overburden, mining wastes, or products.

As with the waste water discharge (NPDES) permit program, the new storm water permit program can be administered by the states if the state programs meet minimum Federal requirements. Many of the states where coal and metal mining occur have authority to administer the water discharge permit program and are developing regulations and accepting applications from storm water dischargers.

The Federal and state regulations provide for two types of storm water discharge permits: individual and general permits. The Federal regulations authorize similar industries to file a group application. Many coal and metal mining operations joined in group applications that were prepared and submitted through trade associations (the American Mining Congress and the National Coal Association [now the National Mining Association]) prior to the deadlines for submitting such permit applications under the new storm water rules. With the submittal of additional information, EPA accepted the group applications and most parties should be eligible for general permits covering the active mining operations in the group applications. Those states with general permit issuing authority will make the final determination as to whether mining operations in the group applications should be covered by general permits or whether some of these mines will be required to obtain individual permits.

The individual storm water discharge permit is similar to the NPDES permit for waste water discharges previously required under the CWA. The applicant for an individual permit must submit detailed information on the mining site and monitoring data on storm water discharges. The permit will contain effluent concentration limits and other conditions, including a storm water management plan.

Most mining operations should qualify for a general storm water discharge permit. Where the state has authority to issue general permits, the environmental agency develops the application requirements and the terms and conditions of the general permits. General permits may be available for several classes of industrial dischargers, including construction, light and heavy industry, industrial minerals, and coal mining. Some of these categories will cover many types of mining operations that are required to obtain storm water discharge permits.

If not a member of a group application, in order to be covered by a general permit the mine owner or operator must file a notice of intent to be covered by the general permit with EPA or the state environmental agency. The notice must provide certain basic information, including the location of the mine, a description of the operation and its discharge and other information necessary to determine if the mine is within the terms of the general permit. As in the case of an individual permit, the operation covered by general permit must develop a storm water management plan within six months of the date the general permit becomes effective and implement such plan within one year of the effective date. At the time of this writing, most states have published or are still developing the regulations for general storm water permits [some are patterned after the EPA proposed general permit rule issued on July 31, 1991 (56 Fed. Reg. 40948)]. Mining operations planning to be covered by a general permit should file a notice of intent within 180 days of the publication of general permit regulations by the state environmental agency (or EPA in those states where EPA administers the NPDES permit

program). For new or expanded mining operations, notice of intent should be filed at least 30 days prior to any construction that may result in a storm water discharge.

The storm water management plan required by the regulations must include a description of the site pollution prevention committee, a material inventory and risk identification and assessment, a preventive maintenance program, spill prevention and response procedures, and storm water management practices. In addition, chemicals subject to reporting under the Emergency Planning and Community Right-to-Know Act (SARA Title III or EPCRA) must be stored and handled in a manner that prevents the discharge of such chemicals in storm water runoff from the mining operation. The main thrust of the new storm water discharge permit regulations is to require industrial dischargers, including coal and metal mines, to develop and implement storm water management programs that will reduce or eliminate pollutants or contaminants in storm water runoff. As discussed further below under Pollution Prevention, prudent mine operators will use best management practices and investigate means of waste reduction and pollution prevention in order to stay a step ahead of mandated environmental controls and remain competitive.

The most common means for controlling storm runoff is to construct diversion ditches that carry the runoff around areas disturbed by the mining activity. Precipitation on the mine area can be collected in a catchment basin that can serve as a primary treatment system. In some areas, the water collected on site can be recycled and used in the milling process, for dust control, and for reclamation. It may also be feasible to construct a wetland and divert storm water runoff into the wetland for treatment prior to discharge. As described below, natural and constructed wetlands are being used more and more for treating acid mine drainage and other waste water from mining operations.

### 19.10.3 ENDANGERED SPECIES, WETLANDS AND ENVIRONMENTALLY SENSITIVE AREAS
**by P. Keppler**

A number of Federal and state laws have been enacted to protect areas that are considered environmentally unique or particularly sensitive, including the habitat of endangered or threatened species. These laws and implementing regulations have a significant impact on resource development, including mineral exploration and extraction, to the extent of precluding mining where it is incompatible with the area's designation or status. Three Federal laws that have restricted mineral development in the United States include the Wilderness Act, the Endangered Species Act, and Section 404 of the Clean Water Act.

Under the 1964 Wilderness Act, substantial areas of Federal lands have been set aside as wilderness where no development is allowed that will disturb the pristine character of the area. Legislation has been introduced in each Congress to designate new wilderness areas or expand existing areas. Setting aside large tracts of Federal lands as wilderness has effectively foreclosed development of natural resources in these areas in order to preserve the natural character for future generations. Similarly, national parks, wild and scenic rivers and certain wildlife refuges are "off limits" to mining operations that can adversely affect the area's status or character.

The Endangered Species Act (ESA) can have a profound impact on existing and proposed resource development and is attracting considerable attention, particularly in those areas where the ESA has been used to effectively shut down a major industry (e.g., logging and forest products in the Northwest). The controversy and resulting litigation for protecting the Northern Spotted Owl in the Pacific Northwest has joined the issue of protecting endangered species at all cost, including severe economic impacts. In some cases, Congressional action will be necessary to resolve the conflict between resource development and protection of endangered species.

Although not receiving the notoriety of the Northern Spotted Owl controversy, there have been a number of occasions where a listing or proposed listing of a threatened or endangered species and its critical habitat has severely limited or foreclosed mineral exploration and development. Section 7 of the ESA (16 U.S.C. § 1536) requires Federal agencies to use their authorities in furtherance of the purposes of the Act to carry out programs for the conservation of endangered and threatened species. Section 7(a)(2) requires each Federal agency in consultation with the Secretary of Interior (Fish and Wildlife Service) to ensure that any action authorized, funded or carried out by such agency is not likely to jeopardize any endangered or threatened species or result in adverse modification or destruction of critical habitat. This provision applies to virtually any Federal activity and includes granting of licenses, contracts, permits, leases and actions directly or indirectly modifying the environment. Thus, a mining company seeking a right-of-way or permit from a Federal agency will be subject to the review and consultation requirements of the ESA if the proposed activity may adversely impact a listed species or its habitat. If the agencies determine that the proposed project will have an adverse impact on a listed species or a critical habitat, the project will have to be modified to avoid such impact or the license, permit, or other Federal action must be denied.

Section 9 of the ESA [16 U.S.C. § 1538(a)] makes it unlawful for any person to "take" a listed species.

The term take is broadly defined to include harass, harm, pursue, hunt, trap, or capture or attempt to engage in any such conduct. Violation of the taking prohibition for listed species can result in substantial civil penalties and criminal prosecution. Courts have held that it is not necessary to prove direct causation in order for there to be a taking under the Act. In other words, an activity can be only one of several causes of harm to a listed species and still be prohibited. Therefore, a mineral development that only has minimal impact on a listed species or its habitat may be prohibited or shut down even though other activities or effects contributed to the species' decline.

When the Act comes up for reauthorization, it is anticipated that Congress will adopt several changes to the ESA to lessen the draconian impacts on economic development while still achieving the basic purpose of the Act. Representatives of the mining industry argue that the Act should be amended to allow mineral exploration and development that does not significantly harm or harass endangered and threatened species.

Section 404 of the Clean Water Act (33 U.S.C. § 1344) requires a permit from the Corps of Engineers for the discharge of dredged or fill material into navigable waters, which by definition includes wetlands. This statute and implementing regulations has generated as much controversy and has had as much impact on natural resource development and agriculture as any of the other environmental laws discussed in this volume.

Section 404(b) of the CWA directs the EPA Administrator to develop guidelines and specifications for disposal of dredged or fill material in navigable waters and wetlands. EPA can prohibit or veto a permit for the disposal of dredged or fill material if the disposal will have an unacceptable adverse effect on municipal water supplies, shellfish beds and fishery areas, wildlife or recreational areas. This dual jurisdiction by the Corps of Engineers and EPA has magnified the problems of a far reaching permit program that affects a number of activities never envisioned by the drafters when this Section was enacted as part of the Federal Water Pollution Control Act in 1972.

Section 404(g) authorizes delegation of the dredge or fill permit program to a state by EPA after consultation with the Corps of Engineers and the United States Fish and Wildlife Service. The state must submit to the EPA Administrator a full and complete description of the program and a statement from the Attorney General that the laws of the state provide adequate authority to carry out such a program. Michigan is the only state that has obtained delegation of the dredge or fill permit program during the 20 years that this provision has been in effect.

Under Section 404, a wetland is broadly defined to include any area that is periodically saturated and supports or has the ability to support wetlands type vegetation. What constitutes a wetland subject to the jurisdiction of the Corps of Engineers is one of the most controversial aspects of the Section 404 permit program. The Corps, in consultation with EPA, Fish and Wildlife Service and the Soil Conservation Service, developed a Guidance Manual in 1987 setting forth detailed criteria on what constitutes jurisdictional wetlands. The 1989 version of the Manual was criticized by industry and particularly farmers who complained that the definition of wetlands was too broad and resulted in severe restrictions on legitimate farming activity and similar development. In 1991, EPA and the Corps proposed changes to the 1989 Manual to address these concerns. The proposed changes met with an outcry from the environmental and scientific community claiming that the agencies were "selling out" to development interests and eviscerating President Bush's policy of "no net loss of wetlands." As a result of this controversy, the Congress has directed the Corps in an appropriation bill to use the 1987 Guidance Manual until such time this matter is reviewed by the National Academy of Sciences and Congress has an opportunity to review the NAS recommendations.

Both coal and metal mining are often conducted near or in wetlands areas. Obviously, the mineral resource must be mined where found and the extraction of the resource can directly or indirectly affect areas that are considered wetlands under the broad Federal definition. Even though the statute addresses "discharges of dredged or fill material," this has been interpreted by some courts as including alteration of wetlands, such as digging drainage ditches to create uplands. If a Section 404 permit is required, the Corps of Engineers will conduct an environmental assessment and if granting the permit is considered a major Federal action with significant environmental impacts, an environmental impact statement will be required under NEPA. Preparing an EIS can be an expensive and time consuming effort that can add significantly to the cost of the project.

The Section 404 regulations provide that a permit can be issued for depositing dredged or fill material in a wetland under certain conditions, including requiring the project proponent to mitigate the impacts of the project. Such mitigation measures can include constructing an equal or greater wetland area to that being affected or used. A number of mining companies have constructed wetlands for mitigation and for reclamation of mined areas, particularly surface coal mines in the mid-western United States. Furthermore, constructed wetlands are now being used for treating acid mine drainage and overflow from mineral tailing impoundments. Note that the statute does not require a permit for constructing a wetland unless this requires filling an existing wetland area. However, once a wetland is created, placing dredged or fill material into that wetland requires a Section 404 permit from the U. S. Army Corps of Engineers.

Section 401 of the CWA (33 U.S.C. § 1341)

requires the applicant for a dredge or fill permit to obtain certification from the state that the discharge of the material into wetlands will comply with state standards and regulations. The state can establish procedures for public notice and hearings in connection with granting such certification. Accordingly, the applicant for a Section 404 permit will need to review applicable state standards and satisfy the environmental agency that the discharge of dredged or fill material into a wetland area will not violate any water quality requirement in such state or that the applicant will implement acceptable mitigation measures that will offset such adverse impacts. The state agency can require that the Section 404 permit contain conditions and standards that are considered necessary to meet state requirements and such conditions and standards shall be incorporated into the Federal permit.

The Corps of Engineers has issued regulations for nationwide or general permits for activities that have little or minimal impacts on the nation's waters and wetlands (33 CFR Part 330). The regulations provide general permits for certain types of activities, including discharges of dredged or fill material to wetlands, without having to go through the process of obtaining an individual permit. Several nationwide permits are relevant to coal and metal mining, specifically permit #18 (minor discharges of dredged or fill material that does not exceed 25 cubic yards or cause a loss of more than 1/10th acre of wetlands), permit #21 (disturbance associated with surface coal mining activities authorized by OSM or a state with an approved program), and permit #26 (discharges of dredged or fill material into headwaters and isolated waters that do not cause the loss of more than 10 acres of waters or wetlands). The nationwide permits covering the discharges of dredged or fill material into wetlands that cause the loss of either more than 1/10th acre (permit #18) or 1 acre (permit #26) require notification of the District Engineer, such notification to provide certain information, including a delineation of the affected wetlands. If the District Engineer determines that the proposed activity will have more than minimal impacts, he can require the proponent to file an application and obtain an individual permit before authorizing the project to proceed.

All of the Corps' nationwide permits are subject to general conditions and the Section 404 permits are subject to special conditions that if violated will result in voiding the permit and can lead to enforcement action to prohibit the activity and to obtain restoration of the disturbed area as well as payment of fines. Although the nationwide permit program has assisted in reducing the number of permits required for activities having limited impacts on the nation's waters and wetlands, many mining activities are not covered by nationwide permits and thus are required to obtain individual Section 404 permits. In the future, it is doubtful that the nationwide permit program will be significantly expanded and as a result, most mineral exploration and development affecting wetlands will trigger the requirement for an individual Section 404 permit.

### 19.10.4 ENVIRONMENTAL AUDITS
**by P. Keppler**

Performing periodic environmental compliance audits is becoming a common practice in the mining industry. Most companies with large mining operations conduct audits of such operations every one to two years. Environmental audits are a key element of an environmental management program.

The objective or goal of an environmental audit should be well defined and understood by management. An audit can be used to determine compliance with applicable regulations, to evaluate performance of the facility, to verify that the operation meets company policy which may go beyond strict compliance, or the audit may identify means for pollution prevention and waste reduction. A comprehensive environmental audit may achieve several or all of these objectives.

The fundamental purpose for conducting an environmental audit is to identify potential problem areas where the operation may not be in full compliance with all applicable regulations or standards. An audit can serve as an early warning of practices or procedures that may result in violations which in turn can result in significant penalties or shut down of the facility.

The keys to an effective environmental audit program are full support of top management, adequate resources to conduct the audits and prepare reports, and timely follow-up on the audit findings. If top management is not committed to environmental audits and an environmental compliance program, the environmental performance of the organization will suffer and compliance with regulations and permits can not be assured. An effective audit program requires commitment of resources, either in-house legal and technical personnel or outside contractors. A comprehensive audit of a large mining operation can involve several man-weeks of effort. However, the real costs of an audit program generally are incurred in the follow-up necessary to correct matters that were uncovered and identified during the audit. If some environmental matters have been neglected for a period of time, major capital and operating expense may be necessary to satisfy current requirements and avoid noncompliance.

Environmental audits should be performed by persons not directly involved with or responsible for performance of the facility being audited. The audit must be an objective, thorough assessment of the operation that provides information and recommendations to management that can be acted upon. It is critical that the company act on the audit findings and recommendations

in a timely manner. Failure to address problems identified in the audit report may lead to violations and enforcement actions seeking criminal penalties and imprisonment of responsible officials for knowing or intentional violations.

Government agencies have adopted policies encouraging self-evaluation audits. In July 1986, EPA published its original environmental auditing policy statement encouraging the use of environmental audits to help achieve and maintain compliance with environmental laws and regulations (51 Fed. Reg. 25004). On July 1, 1991, the United States Department of Justice issued a statement providing in part: "It is the policy of the Department of Justice to encourage self-auditing, self-policing and voluntary disclosure of environmental violations by the regulated community by indicating that these activities are viewed as mitigating factors in the Department's exercise of criminal environmental enforcement discretion." On December 22, 1995, EPA issued its final policy to "enhance protection of human health and the environment by encouraging regulated entities to voluntarily discover, and disclose and correct violations of environmental requirements." (60 Fed.Reg. 66706.) Incentives for conducting audits and reporting violations include substantially reducing civil penalties and not recommending cases for criminal prosecution. A number of conditions have to be met (e.g., voluntary discovery, prompt disclosure, correction and remediation, preventing recurrence, etc.) in order to avoid penalties and criminal enforcement.

A number of states have recently enacted laws providing a self-evaluation privilege and immunity from penalties for companies performing voluntary audits and promptly reporting violations and correction the non-compliance. For example, in 1994 the Colorado Legislature enacted the Self-Evaluation Privilege and Voluntary Disclosure Law that creates an environmental audit privilege for information obtained through a voluntary audit and provides immunity from civil and certain criminal penalties if the violations are reported promptly to the Colorado Department of Public Health and Environment and the non-compliance is corrected as soon as practicable (§§ 13-25-126.5, 13-90-107, and 25-1-114.5, C.R.S.). The Colorado law and other, similar state statutes go beyond the EPA audit policy in terms of evidentiary privilege and immunity from penalties and, as a result, some tensions have developed between the states and EPA on enforcement authority and delegation of environmental programs to the states. It is expected that these differences in policies will be satisfactorily resolved so that the states with self-evaluation privilege laws will retain delegation of major programs and industries will continue to have the benefit of the self-evaluation privilege and immunity from penalties when voluntarily conducting audits and reporting and correcting violations. Obtaining voluntary compliance with environmental laws is obviously the mutually desired goal and can best be achieved through cooperation and trust.

Financial institutions and investors as a matter of course now request information on a company's environmental compliance status and performance. Accurate information must be provided on environmental matters before the company can obtain significant financing through loans or issuing stock. Information obtained through recent environmental audits is essential for satisfying these requests.

The practice of conducting periodic environmental compliance audits will become commonplace for most mining companies. Even small companies with one or two operations are likely to conduct some type of self-evaluation or audit to confirm compliance with applicable requirements. It is anticipated that audits will become more comprehensive and be used for identifying means for pollution prevention and source reduction in the mining and mineral processing industries.

### 19.10.5 POLLUTION PREVENTION
**by P. Keppler**

"Pollution prevention" and "source reduction" are the benchmarks for environmental control in the 1990s. The Pollution Prevention Act of 1990 (42 U.S.C. §§ 13101-13109) was enacted by Congress to address the growing concern over treatment of pollution and waste disposal. In the Act, Congress declares that it is the national policy that pollution should be prevented or reduced at the source whenever feasible and pollution that cannot be prevented should be recycled or treated in an environmentally safe manner. Waste disposal or release into the environment should be employed only as a last resort. A number of states have enacted similar pollution prevention laws.

The Pollution Prevention Act emphasizes "source reduction," which is defined as a practice that reduces the amount of any hazardous pollutant entering any waste stream or otherwise released into the environment prior to recycling, treatment, or disposal, and reduces the hazards to public health and the environment. Source reduction includes modification of equipment or technology or processes or procedures, reformulation or design of products, substitution of raw materials, and improvements in housekeeping, maintenance, employee training and inventory control.

Because of the nature of mineral extraction and processing, pollution prevention and source reduction may be somewhat limited. However, the industry will need to examine innovative methods for improving minerals recovery and for reducing the use of hazardous chemicals and reagents in mineral extraction and beneficiation. Preparing a material balance and a

comprehensive audit of operations may identify source reduction and pollution prevention opportunities. For example, it may be possible to make equipment modifications or changes in milling reagents that reduce the hazardous constituents of mineral tailings. It may also be possible to increase recycling of additives and reagents used in certain metals recovery and milling processes.

Mining is an energy intensive industry. Large coal and metal mines and mineral processing facilities consume considerable amounts of electric power. By reducing power consumption and conserving energy, the mining industry can assist in achieving greater source reduction in the electric utility industry and thereby aid in achieving the goals of the Pollution Prevention Act.

Through market forces that are creating greater demand for recycled and secondary materials, the mining industry is having to more closely examine secondary materials recovery in all sectors, from reprocessing mineral tailings to recycling appliances and automobiles. Consumers in developed countries are demanding not only more "green" products, but also products that are made from recycled materials and can in turn be recycled after their useful life. Although there will always be a need for a certain amount of virgin material, the industry will need to develop more economical minerals recovery technology using secondary feed materials.

The goals of pollution prevention, source reduction, and recycling reflect a new paradigm in environmental policy – that is to devise a system of sustainable industry practices that can be implemented without posing undue environmental risks now or in the future. The new paradigm for environmental protection will influence decisions about materials (including minerals) society uses, the technologies for manufacturing goods, and the responsibilities of governments and industry to protect the global environment. For the minerals industry, the move toward sustainable industry will result in increased full life cycle analysis – determining the risks of minerals from extraction through processing, manufacture and use, distribution, and consumer application to final disposal or reuse.

It is evident that the mining industry is faced with major challenges in protecting the environment and addressing public concerns while at the same time producing the basic raw materials needed for sustaining and advancing our society. The United States mining industry must be willing to meet these challenges and remain competitive in the global market if it is to survive. If the past is prologue to the future, the industry will adapt and continue to be a viable player in the international minerals market.

## Chapter 20

# DIRECTORY OF STATE REGULATORY AGENCIES

### ALABAMA

**(Coal)**

Alabama Surface Mining Commission
1811 Second Avenue, 2nd Floor
P.O. Box 2390
Jasper, Alabama 35502-2390

**Tele: 205-221-4130**
**Fax: 205-221-5077**

**(Non-Coal)**

State Programs Division
Alabama Department of Industrial Relations
649 Monroe Street
Montgomery, Alabama 36130

**Tele: 334-242-8265**
**Fax: 334-242-8403**

### ALASKA

Division of Mining and Water Management
Alaska Department of Natural Resources
3601 C Street, Suite 800
Anchorage, Alaska 99503-5935

**Tele: 907-762-8630**
**Fax: 907-563-1853**

### ARIZONA

Office of State Mine Inspector
1700 West Washington
Suite 400
Phoenix, Arizona 85007-2805

**Tele: 602-542-5971**
**Fax: 602-542-5335**

### ARKANSAS

Department of Pollution Control and Ecology
P.O. Box 8913
8001 National Drive
Little Rock, Arkansas 72219-8913

**Tele: 501-682-0809**
**Fax: 56501-682-0880**

### CALIFORNIA

Office of Mine Reclamation
California Department of Conservation
801 K St., MS-09-06
Sacramento, CA 95814-3529

**Tele: 916-323-8565**

### COLORADO

Division of Minerals and Geology
Colorado Department of Natural Resources
1313 Sherman Street, Room 215
Denver, CO 80203

**Tele: 303-866-3567**
**Fax: 303-832-8106**

### CONNECTICUT

Environmental Protection Departmant
65 Capitol Ave.
Hartford, CT 06006

### DELAWARE

Department of Natural Resources and
Environmental Control
89 Kings Highway
P.O. Box 1401
Dover, DE 19903

**Tele: 302-736-4506**

### FLORIDA

Department of Environmental Protection
Resource Management Division
2051 E. Dirac Drive
Tallahassee, FL 32310-3760

**Tele: 904-488-3177**

### GEORGIA

Land Reclamation and Sedimentation
Control Program
Department of Natural Resources
4244 International Parkway, Suite 104
Atlanta, Georgia 30354

**Tele: 404-362-2537**

### IDAHO

Bureau of Minerals
Department of Lands
1215 W. State Street
Boise, Idaho 83720

**Tele: 208-334-0247**
**Fax: 208-334-2339**

### ILLINOIS

Office of Mines and Minerals
Department of Natural Resources
524 South Second Street
Springfield, Illinois 62701-1787

**Tele: 217-782-6791**
**Fax: 217-524-4819**

### INDIANA

Department of Natural Resources
402 W. Washington Street Room W256
Indianapolis, Indiana 46204

**Tele: 317-232-4020**
**Fax: 317-233-6811**

### IOWA

Department of Agriculture & Land Stewardship
Division of Soil Conservation
Wallace State Office Building
Des Moines, Iowa 50319

**Tele: 515-281-6147**
**Fax: 515-281-6170**

### KANSAS

Surface Section
Department of Health & Environment
P. O. Box 1418
Pittsburg, Kansas 66762-1418

**Tele: 316-231-8615**
**Fax: 316-231-0753**

### KENTUCKY

Natural Resources and Environmental
Protection Cabinet
5th Floor, Capital Plaza
Frankfort, Kentucky 40601

**Tele: 502-564-3350**
**Fax: 502-564-3354**

### LOUISIANA

Department of Natural Resources
Office of Conservation
Injection and Mining Division
P.O. Box 94725
Baton Rouge, Louisiana 70804-4275

**Tele: 504-342-5528**
**Fax: 504-342-3094**

### MAINE

Department of Environmental Protection
Division of Site Location
State House Station 17
August, ME 04333-0017

**Tele: 207-287-7688**

## MARYLAND

Department of Natural Resources
Water Resouces Administration
Tawes State Office Building
580 Taylor Avenue
Annapolis, Maryland 21401-2351

**Tele: 301-974-2788**

## MICHIGAN

Geological Survey Division
Department of Natural Resources
P.O. Box 30256
Lansing, Michigan 48909

**Tele: 517-334-6923**

## MINNESOTA

Pollution Control Agency
Environmental Analysis Office
520 Lafayette Road
St. Paul, MN 55155

**Tele: 612-296-7794**

## MISSISSIPPI

Department of Environmental Quality
Office of Geology
2380 Highway 80 West
P.O. Box 20307
Jackson, Mississippi 39289-1307

**Tele: 601-961-5500**
**Fax: 601-961-5521**

## MISSOURI

Land Reclamation Program
Department of Natural Resources
Jefferson State Office Building
P.O. Box 176
Jefferson City, Missouri 65102

**Tele: 573-751-4041**
**Fax: 573-751-0534**

## MONTANA

**(Coal)**

Reclamation Division
Department of Environmental Quality
P.O. Box 200901
Helena, Montana 59620-0901

**Tele: 406-444-4982**
**Fax: 406-444-1923**

**(Non-Coal)**

Montana Department of State Lands
Hard Rock Bureau
P.O. Box 202301
1625 Eleventh Ave.
Helena, MT 59620-2301

**Tele: 406-444-4988**

## NEBRASKA

Environmental Control Department
State Office Building
P.O. Box 98922
Lincoln, NE 68509-8922

**Tele: 402-471-2186**

## NEVADA

Nevada Division of Minerals
400 W. King St., Suite 106
Carson City, NV 89710

**Tele: 702-687-5050**

## NEW HAMPSHIRE

Environmental Services Department
6 Hazen Dr.
Concord, NH 03301

**Tele: 603-271-3503**

## NEW JERSEY

Environmental Protection Department
401 E. State St.
Trenton, NJ 08625-0402

**Tele: 609-292-3131**

**NEW MEXICO**

Mining and Minerals Division
Energy, Minerals and Natural Resources Department
2040 South Pacheco Street
Santa Fe, New Mexico 87505

**Tele: 505-827-5974**
**Fax: 505-827-7195**

**NEW YORK**

Department of Environmental Conservation
Division of Mineral Resources
50 Wolf Road, Room 202
Albany, NY 12233-6500

**Tele: 518-457-0100**

**NORTH CAROLINA**

Department of Environment,
Health and Natural Resources
Division of Land Resources
P.O. Box 27687
Raleigh, NC 27611-7687

**Tele: 919-733-3833**

**NORTH DAKOTA**

Reclamation Division
North Dakota Public Service Commission
Capitol Building
Bismarck, North Dakota 58505

**Tele: 701-328-4108**
**Fax: 701-328-2410**

**OHIO**

Division of Reclamation
Department of Natural Resources
1855 Fountain Square Bldg. H
Columbus, Ohio 43224

**Tele: 614-265-6675**

**OKLAHOMA**

Oklahoma Department of Mines
4040 N. Lincoln Blvd., Suite 107
Oklahoma City, Oklahoma 73105

**Tele: 405-521-3859**
**Fax: 405-427-9646**

**OREGON**

Mined Land Reclamation
Department of Geology and Mineral Industries
1536 Queen Avenue, S.E.
Albany, Oregon 97321-6687

**Tele: 541-967-2039**
**Fax: 541-967-2075**

**PENNSYLVANIA**

Department of Environmental Resources
P.O. Box 2063
Harrisburg, Pennsylvania 17105-2063

**Tele: 717-787-2814**

**RHODE ISLAND**

Department of Environmental Management
9 Hayes Street
Providence, Rhode Island 02906

**Tele: 401-277-2771**

**SOUTH CAROLINA**

Department of Health & Environmental Control
Division of Mining and Solid Waste Permitting
2600 Bull St.
Columbia, SC 29201

**Tele: 803-896-4263**

**SOUTH DAKOTA**

Division of Environmental Services
Department of Environment and Natural Resources
Joe Foss Building, 523 E. Capitol
Pierre, South Dakota 57501-3181

**Tele: 605-773-3153**
**Fax: 605-773-6035**

## TENNESSEE

Department of Environment and Conservation
Bureau of Environment
L and C Tower, 21st Floor
401 Church Street
Nashville, TN 37243-1530

**Tele: 423-532-0220**

## TEXAS

Surface Mining and Reclamation Division
Railroad Commission of Texas
P.O. Drawer 12967 Capitol Station
Austin, Texas 78711-2967

**Tele: 512-463-6900**
**Fax: 512-463-6709**

## UTAH

Department of Natural Resources
Utah Division of Oil, Gas and Mining
3 Triad Center Suite 350
355 West North Temple
Salt Lake City, Utah 84180-1230

**Tele: 801-538-5340**
**Fax: 801-359-3940**

## VIRGINIA

Department of Mines, Minerals and Energy
9th Street Office Building, 8th floor
202 N. 9th Street
Richmond, Virginia 23219

**Tele: 804-692-3202**
**Fax: 804-692-3237**

## WASHINGTON

Division of Geology and Earth Resources
Department of Natural Resources
P.O. Box 47007
1111 Washington St., S.E.
Olympia, Washington 98504-7007

**Tele: 360-902-1440**
**Fax: 360-902-1785**

## WEST VIRGINIA

West Virginia Division of Environmental Protection
10 McJunkin Road
Nitro, West Virginia 25143

**Tele: 304-759-0515**
**Fax: 304-759-0526**

## WISCONSIN

Natural Resources Department
P.O. Box 7921
Madison, WI 53707

**Tele: 608-266-2621**

## WYOMING

Department of Environmental Quality
Herschler Bldg - 4th Floor West
122 West 25th Street
Cheyenne, Wyoming 82002

**Tele: 307-777-7938**
**Fax: 307-777-5973**

# Chapter 21
# GLOSSARY

*(A list of acronyms follows this Glossary)*

## A

**Abatement:** Measures taken to reduce the degree or intensity of, or eliminating, pollution.

**Acceptable Daily Intake** (ADI): An estimate of the largest amount of a substance to which a person can be exposed on daily basis that is not anticipated to result in adverse effects.

**Acid Deposition:** A complex chemical and atmospheric phenomenon that occurs when emissions of sulfur and nitrogen compounds and other substances are transformed by chemical processes in the atmosphere, often far from the original sources, and then deposited on earth in either a wet or dry form. The wet forms, popularly called "acid rain," can fall as rain, snow, or fog. The dry forms are acidic gases or particulates.

**Acid Rain:** (See Acid Deposition.)

**Action Levels:** Regulatory levels recommended by EPA for enforcement by FDA and USDA when pesticide residues occur in food or feed commodities for reasons other than the direct application of the pesticide. As opposed to "tolerances" that are established for residues occurring as a direct result of proper usage, action levels are set for inadvertent residues resulting from previous legal use or accidental contamination; in the Superfund program, the existence of a contaminant concentration in the environment high enough to warrant action or trigger a response under SARA and the National Oil and Hazardous Substances Contingency Plan. The term can be used similarly in other regulatory programs. (See Tolerances.)

**Activated Carbon:** A highly adsorbent form of carbon used to remove odors and toxic substances from liquid or gaseous emissions. In waste treatment it is used to remove dissolved organic matter from waste water. It is also used in motor vehicle evaporative control systems.

**Administrative Procedure Act:** A law that spells out procedures and requirements related to the promulgation of regulations.

**Advanced Waste Water Treatment:** Any treatment of sewage that goes beyond the secondary or biological water treatment stage and includes the removal of nutrients such as phosphorus and nitrogen and a high percentage of suspended solids. (See Primary Waste Treatment.)

**Aeration:** The process that promotes biological degradation of organic water. The process may be passive (as when waste is exposed to air) or active (as when a mixing or bubbling device introduces the air).

**Aeration Tank:** A chamber used to inject air into water.

**Aerobic:** Life or processes that require, or are not destroyed by, the presence of oxygen. The presence of free oxygen. (See Anaerobic.)

**Aerobic Treatment:** Process by which microbes decompose complex organic compounds in the presence of oxygen and use the liberated energy for reproduction and growth. Types of aerobic processes include extended aeration, trickling filtration, and rotating biological contractors.

**Agglomeration:** The process by which precipitation particles grow larger by collision or contact with cloud particles or other precipitation particles.

**Agglutination:** The process of uniting solid particles coated with a thin layer of adhesive material or of arresting solid particles by impact on a surface coated with an adhesive.

**Air Pollutant:** Any substance in air that could, if in high enough concentration, harm man, other animals, vegetation, or material. Pollutants may include almost any natural or artificial composition of matter capable of

being airborne. They may be in the form of solid particles, liquid droplets, gases, or in combinations of these forms. Generally, they fall into two main groups: 1) those emitted directly from identifiable sources; and 2) those produced in the air by interactions between two or more primary pollutants, or by reaction with normal atmospheric constituents, with or without photoactivation. Exclusive of pollen, fog, and dust, which are of natural origin, about 100 contaminants have been identified and fall into these categories: solids, sulfur compounds, volatile organic chemicals, nitrogen compounds, oxygen compounds, halogen compounds, radioactive compounds, and odors.

**Air Pollution:** The presence of contaminant or pollutant substances in the air that do not disperse properly and interfere with human health or welfare, or produce other harmful environmental effects.

**Air Quality Standards:** The level of pollutants prescribed by regulations that may not be exceeded during a specified time in a defined area.

**Airborne Particulates:** Total suspended particulate matter found in the atmosphere as solid particles or liquid droplets. The chemical composition of particulates varies widely, depending on location and time of year. Airborne particulates include windblown dust, emissions from industrial processes, smoke from the burning of wood and coal, and the exhaust of motor vehicles.

**Alpha Particle:** A positively charged particle composed of 2 neutrons and 2 protons released by some atoms undergoing radioactive decay. The particle is identical to the nucleus of a helium atom.

**Ambient Air:** Any unconfined portion of the atmosphere; open air, surrounding air.

**Anaerobic:** A life process that occurs in, or is not destroyed by, the absence of oxygen.

**Aquifer:** An underground geological formation, or group of formations, containing usable amounts of groundwater that can supply wells and springs.

**AOC** (Area of contamination): A continuous (significant) extent of contamination at a Superfund site. For the purposes of ARARs, is used as the equivalent of a RCRA land-based unit to determine whether disposal occurs.

**Area Source:** Any small source of nonnatural air pollution that is released over a relatively small area but which cannot be classified as a point source. Such sources may include vehicles and other small fuel combustion engines.

**ARARS** (Applicable or Relevant and Appropriate Requirements): Those cleanup standards, standards of control, and other substantive environmental protection requirements, criteria, or limitations promulgated under Federal or State law that specifically address a hazardous substance, pollutant, contaminant, remedial action, location, or other circumstance at a CERCLA site, or that address problems or situations sufficiently similar to those encountered at the CERCLA site that their use is well-suited to the particular site.

**Ash:** The mineral content of a product remaining after complete combustion.

**Atmosphere:** A standard unit of pressure representing the pressure exerted by an 29.92 inch column of mercury at sea level at 45° latitude and equal to 1000 grams per square centimeter; the whole mass of air surrounding the earth, composed largely of oxygen and nitrogen.

**Attainment Area:** An area considered to have air quality as good as or better than the national ambient air quality standards as defined in the Clean Air Act. An area may be an attainment area for one pollutant and a non-attainment area for others.

# B

**Backfill (ing):** The process of filling and/or the material used to fill a mine opening; in general, the material placed "back" to refill an excavation; waste sand or rock used to support the roof after removal of ore from a stope.

**Background Level:** In air pollution control, the concentration of air pollutants in a definite area during a fixed time prior to the starting up or on the stoppage of a source of emission under control. In toxic substances monitoring, the average presence in the environment, originally referring to naturally occurring phenomena.

**BACT** (Best Available Control Technology): An emission limitation based on the maximum degree of emission reduction that (considering energy, environmental, and economic impacts and other costs) is achievable through application of production processes and available methods, systems, and techniques. In no event does BACT permit emissions in excess of those allowed under any applicable Clean Air Act provision. Use of the BACT concept is allowable on a case by case basis for major new or modified emissions sources in attainment areas and applies to each regulated pollutant.

**Baghouse Filter:** Large fabric bag, usually made of glass fibers, used to eliminate intermediate and large (greater the 20 microns in diameter) particles. This device operates in a way similar to the bag of an electric vacuum cleaner, passing the air and smaller particulate matter, while entrapping the larger particles.

**Bench:** The horizontal step or floor along which coal, ore, stone or overburden is worked or quarried.

**Best Practical Technology** (BPT): The degree of treatment to be applied to all industrial wastes by July 1, 1977, based generally on the average pollution control performance achieved by the best existing plants.

**Beta Particle:** An elementary particle emitted by radioactive decay that may cause skin burns. It is halted by a thin sheet of paper.

**Bevill Amendment:** Part of RCRA legislation that classifies certain wastes non-hazardous unless EPA finds otherwise. Wastes included are: flyash, bottom ash, mineral ore wastes, and cement kiln dust. Typically high volume / low toxicity materials.

**Biodegradation:** Metabolic process by which high-energy organics are converted to low energy organics, $CO_2$, and $H_2O$.

**Bioassay:** Using living organisms to measure the effect of a substance, factor, or condition by comparing before-and after-data. Term is often used to mean cancer bioassays.

**Biological Treatment:** A treatment technology that uses bacteria to consume waste. This treatment breaks down organic materials.

**Biotechnology:** Techniques that use living organisms or parts of organisms to produce a variety of products (from medicines to industrial enzymes) to improve plants or animals or to develop microorganisms for specific uses such as removing toxics from bodies of water, or as pesticides.

**Biotransformation:** The enzymatic transformation of a foreign compound into a different one. The new compound may be more or less toxic than the old one.

**Bottom Ash:** The non-airborne combustion residue from burning pulverized coal in a boiler. The material falls to the bottom of the boiler and is removed mechanically.

**Black Lung:** A disease of the lungs caused by habitual inhalation of coal dust.

# C

**CA** (Cooperative Agreement): A Federal assistance agreement with the States and/or their political subdivisions to transfer Federal funds and/or responsibilities. Cooperative agreements are required for State-lead, fund-financed Superfund actions.

**Cap:** A layer of clay, or other highly impermeable material, installed over the top of a closed landfill to prevent entry of rainwater and minimize production of leachate.

**Capture Efficiency**: The fraction of all organic vapors generated by a process that are all directed to an abatement or recovery device.

**Carcinogen:** Any substance that can cause or contribute to the production of cancer.

**Cells:** In solid waste disposal, holes where waste is dumped, compacted, and covered with layers of dirt on a daily basis; the smallest structural part of living matter capable of functioning as an independent unit.

**CERCLA** (Comprehensive Environmental Response, Compensation, and Liability Act): A Federal law passed in 1980 and modified in 1986 by the Superfund Amendments and Reauthorization Act (SARA). The Acts created a special tax that goes into a Trust Fund, commonly known as Superfund to investigate and clean up abandoned or uncontrolled hazardous waste sites. Under the program, EPA can either: 1) Pay for site cleanup when parties responsible for the contamination cannot be located or are unwilling or unable to perform the work; or 2) Take legal action to force parties responsible for site contamination to clean up the site or pay the Federal government for the cost of cleanup.

**CERCLIS** (Comprehensive Environmental Response, Compensation, and Liability Information System): EPA's comprehensive data base and management system that inventories and tracks releases addressed or needing to be addressed by the Superfund program.

**CFCs** (Chlorofluorocarbons): A family of inert, nontoxic, and easily liquefied chemicals used in refrigeration, air conditioning, packaging, insulation, or as solvents and aerosol propellants. Because CFCs are not destroyed in the lower atmosphere, they drift into the upper atmosphere where their chlorine components destroy ozone.

**CFR** (Code of Federal Regulation): All Federal regulations in force are published annually in codified

form in the Code of Federal Regulations.

**Characteristic:** Any one of the four categories used in defining hazardous waste: ignitability, corrosivity, reactivity, and toxicity.

**Chemical Treatment:** Any one of a variety of technologies that use chemicals or a variety of chemical processes to treat waste.

**Chemicals of Potential Concern:** Chemicals that are potentially site-related and whose data are of sufficient quality for use in the quantitative risk assessment.

**Chlorination:** The application of chlorine to drinking water, sewage, or industrial waste to disinfect or to oxidize undesirable compounds.

**Cleanup:** Actions taken to deal with release or threat of release of a hazardous substance that could affect humans and/or the environment. The term "cleanup" is sometimes used interchangeably with the terms remedial action, removal action, response action, or corrective action.

**Coagulation:** A clumping of particles in waste water to settle out impurities. It is often induced by chemicals such as lime, alum, and iron salts.

**Comminution:** Mechanical shredding or pulverizing of wastes. Used in both solid waste management and wastewater treatment.

**Confined Aquifer:** An aquifer in which ground water is confined under pressure that is significantly greater than atmospheric pressure.

**Consent Decree:** A legal document, approved by a judge, that formalizes an agreement reached between EPA and potentially responsible for parties (PRPs) through which PRPs will conduct all or part of a cleanup action at a Superfund site, cease or correct actions or processes that are polluting the environment, or otherwise comply with regulations where the PRP's failure to comply caused EPA to initiate regulatory enforcement actions. The consent decree describes the action PRPs will take and may be subject to a public comment period.

**Contaminant:** Any physical, chemical, biological, or radiological substance or matter that has an adverse effect on air, water, or soil.

**Contingency Plan:** A document setting out an organized, planned, and coordinated course of action to be followed in case of a fire, explosion, or other accident that releases toxic chemicals, hazardous wastes, or radioactive materials that threaten human health or the environment.

**Corrosion:** The dissolving and wearing away of metal caused by a chemical reaction such as between water and the pipes that the water contacts, chemicals touching a metal surface, or contact between two metals.

**Corrosive:** A chemical agent that reacts with the surface of a material causing it to deteriorate or wear away.

**Cost-Effective Alternative:** The cleanup alternative selected for a site on the National Priorities List (NPL) based on protectiveness, technical feasibility, permanence, reliability and cost. The alternative is not required to be the least expensive.

**Cost Recovery:** A legal process by which potentially responsible parties who contributed to contamination at a Superfund site can be required to reimburse the Trust Fund for money spent during any cleanup actions by the federal government.

**Critical Habitat:** That part of habitat essential to the survival of a species.

**CWA** (Clean Water Act): A statute under which EPA promulgates Water Quality Criteria and administers the National Pollutant Discharge Elimination System (NPDES) permit program, as well as regulates discharges to or dredging of wetlands.

**Cut:** An excavation, usually with one dimension significantly longer than the other.

# D

**Degradation:** Chemical or biological transformation of a complex compound into a number of simple ones.

**Deliquescent:** The ability to absorb water from the air.

**Digester:** In wastewater treatment, a closed tank. In solid waste conversion, a unit in which bacterial action is induced and accelerated in order to break down organic matter and establish the proper carbon to nitrogen ratio.

**Digestion:** The biochemical decomposition of organic matter, resulting in partial gasification, liquefaction, and mineralization of pollutants.

**Dike:** A low wall that can act as a barrier to prevent a

spill from spreading.

**Dioxin:** Any of a family of compounds known chemically as dibenzo-p-dioxinx. Concern about them arises from their potential toxicity and contaminants in commercial products. Tests on laboratory animals indicate that it is one of the more toxic man-mad chemicals known.

**Direct Discharger:** A municipal or industrial facility that introduces pollution through a defined conveyance or system; a point source.

**Direct Haulage:** Hauling soil directly to a regrade site.

**Disposal:** Final placement or destruction of toxic, radioactive, or other wastes, surplus or banned pesticides or other chemicals, polluted soils, and drums containing hazardous materials from removal actions or accidental releases. Disposal may be accomplished through use of approved secure landfills, surface impoundments, land farming, deep well injection, ocean dumping, or incineration.

**DO** (Dissolved Oxygen): The oxygen freely available in water. Dissolved oxygen is vital to fish and other aquatic life and for the prevention of odors. Traditionally, the level of dissolved oxygen has been acceptable as the single most important indicator of a water body's ability to support desirable aquatic life. Secondary and advanced waste treatment are generally designed to protect DO in waste-receiving waters.

**Dissolved Solids:** Disintegrated organic and inorganic material contained in water. Excessive amounts make water unfit to drink or use in industrial processes.

**Dose:** The amount of a substance penetrating the exchange boundaries of an organism after contact. Dose is calculated from the intake and the absorption efficiency, and it usually is expressed as mass of a substance absorbed into the body per unit of time. Also, in radiology, the quantity of energy or radiation absorbed.

**Dose-response Evaluation:** The process of quantitatively evaluating the toxicity information and characterizing the relationship between the dose of the contaminant administered or received and the incidence of adverse health effects in the exposed population. From the quantitative dose-response relationship, toxicity values are derived that are used in the risk characterization step to estimate the likelihood of adverse effects occurring in humans at different exposure levels.

**Dredging:** Removal of mud from the bottom of water bodies using a scooping machine. This disturbs the ecosystem and causes silting that can kill aquatic life. Dredging of contaminated mud can expose aquatic life to heavy metals and other toxics.

# E

**EA** (Endangerment Assessment): A study conducted as a supplement to a remedial investigation to determine the nature and extent of contamination at a Superfund site and the risks posed to public health and/or the environment. EPA or State agencies conduct the study when legal action is pending to require potentially responsible parties to perform or pay for the site cleanup.

**Ecosphere:** The "bio-bubble" that contains life on earth, in surface waters, and in the air.

**Ecosystem:** The interacting system of a biological community and its nonliving environmental surroundings.

**EDD** (Enforcement Decision Document): A document that provides an explanation to the public of EPA's selection of the cleanup alternative at enforcement sites on the National Priorities List. Similar to a Record of Decision.

**Effluent:** Wastewater, treated or untreated, that flows out of a treatment plant, sewer, or industrial outfall. Generally refers to wastes discharged into surface waters.

**Effluent Limitation:** Restrictions established by a State or EPA on quantities, rates, and concentrations in wastewater discharges.

**Emission Standard:** The maximum amount of air polluting discharge legally allowed from a single source, mobile or stationary.

**Emission Trading:** EPA policy that allows a plant complex with several facilities to decrease pollution from some facilities while increasing it from others, so long as total results are equal to or better than previous limits. Facilities where this is done are treated as if they exist in a bubble in which total emissions are averaged out.Complexes that reduce emissions substantially may "bank" their "credits" or sell them to other industries.

**Endangered Species:** Animals, birds, fish, plants, or other living organisms threatened with extinction by man-made or natural changes in their environment. Requirements for declaring a species endangered are contained in the Endangered Species Act.

**Endangerment Assessment:** A study conducted to determine the nature and extent of contamination at a site on the National Priorities List and the risk posed to public health or the environment. EPA or the state conducts the study when a legal action is to be taken to direct potentially responsible parties to clean up a site or pay for the cleanup. An endangered assessment supplements a remedial investigation.

**Enrichment:** The addition of nutrients (e.g., nitrogen, phosphorus, carbon compounds) from sewage effluent or agricultural runoff to surface water. This process greatly increases the growth potential for algae and aquatic plants.

**Environment:** The sum of all external conditions affecting the life, development and survival of an organism.

**Environmental Assessment:** A written environmental analysis that is prepared pursuant to the National Environmental Policy Act to determine whether a federal action would significantly affect the environment and thus require preparation of a more detailed environmental impact statement.

**Environmental Audit:** An independent assessment of the current status of a party's compliance with applicable environmental requirements; an independent evaluation of a party's environmental compliance policies, practices, and controls.

**Environmental Impact Statement:** A document required of federal agencies by the National Environmental Policy Act for major projects or legislative proposals significantly affecting the environment. A tool for decision making, it describes the positive and negative effects of the undertaking and lists alternative actions.

**Environmental Response Team:** EPA experts located in Edison, NJ, and Cincinnati, OH who can provide around-the-clock technical assistance to EPA regional offices and states during all types of emergencies involving hazardous waste sites and spills of hazardous substances.

**EPA:** The U.S. Environmental Protection Agency, established in 1970 by Presidential Executive Order, bringing together parts of various government agencies involved with the control of pollution.

**Epidemiology:** The study of diseases as they affect population, including the distribution of disease, or other health-related states and events in human populations, the factors that influence this distribution, and the application of this study to control health problems.

**Erosion:** The wearing away of land surface by air or water. Erosion occurs naturally from weather or runoff but can be intensified by land-clearing practices related to farming, residential or industrial development, road building, or timber-cutting.

**Estuary:** Regions of interaction between rivers and near shore ocean waters, where tidal action and river flow create a mixing of fresh and salt water. These areas may include bays, mouths of rivers, salt marshes, and lagoons. These brackish water ecosystems shelter and feed marine life, birds, and wildlife.

**Evaporation Ponds:** Areas where sewage sludge is dumped and allowed to dry out.

**Exposure Route:** The way a chemical or physical agent comes in contact with an organism (i.e., by ingestion, inhalation, or dermal contact).

**Extremely Hazardous Substances:** Any of the chemicals identified by the EPA on the basis of toxicity, and listed under SARA Title III. This list is subject to periodic revision.

# F

**Filtration:** A treatment process, under the control of qualified operators, for removing solid (particulate) matter form water by passing the water through porous media such as sand or a man-made filter. The process is often used to remove particles that contain pathogenic organisms.

**Floc:** A clump of solids formed in sewage by biological or chemical action.

**Flocculation:** The process by which clumps of solids in water or sewage are made to increase in size by biological or chemical action so that they can be separated from the water.

**Flue Gas:** The air coming out of a chimney after combustion in the burner it is venting. It can include nitrogen oxides, carbon oxides, water vapor, sulfur oxides, particles and many chemical pollutants.

**Flume:** A natural or man-made channel that diverts water.

**Fly Ash:** Noncombustible residual particles from the combustion process, carried by flue gas. Consists mainly of various oxides and silicates. Major sources are pulverized coal burning boilers.

**FONSI** (Finding of No Significant Impact): A document prepared by a federal agency that presents the reason why a proposed action would not have a significant impact on the environment and thus would not require preparation of an Environmental Impact Statement. A FONSI is based on the results of an environmental assessment.

**Food Chain:** A sequence of organisms, each of which uses the next, lower member of the sequence as a food source.

**Formulation:** The substance or mixture of substances that is comprised of all active and inert ingredients in a pesticide.

**Free Liquids:** Liquids that readily separate from the solid portion of a waste under ambient temperature and pressure.

**Fresh Water:** Water that generally contains less than 1,000 milligrams per liter of dissolved solids.

**FS** (Feasibility Study): A study undertaken by the lead agency to develop and evaluate options for remedial action. The feasibility study emphasizes data analysis, implementability of alternatives, and cost analyses, as well as compliance with mandates to protect human health and the environment and attain regulatory standards of other laws. The FS is generally performed concurrently and in an interactive fashion with the remedial investigation, using data gathered during the remedial investigation.

**Fume:** Tiny particles trapped in vapor in a gas stream.

# G

**Gamma Radiation:** Gamma rays are true rays of energy in contrast to alpha and beta radiation. The properties are similar to x-rays and other electromagnetic waves. They are the most penetrating waves of radiant nuclear energy but can be blocked by dense materials such as lead.

**Gasification:** Conversion of solid material such as coal into gas for use as a fuel.

**Gene:** A length of DNA that directs the synthesis of a protein.

**Gross Alpha Particle Activity:** Total activity due to emission of alpha particles. Used as the screening measurement for radioactivity generally due to naturally-occurring radionuclides. Activity is commonly measured in picocuries.

**Ground Cover:** Plants grown to keep soil from eroding.

# H

**Habitat:** The place where a population lives and its surroundings, both living and nonliving.

**Half-life:** The time required for a pollutant to lose half its effect on the environment. For example, the half-life of DDT in the environment is fifteen years, of radium, 1,580 years; the time required for half of the atoms of a radioactive element to undergo decay; the time required for the elimination of one half a total dose from the body.

**Hazardous Substance:** Section 101(14) of CERCLA, as amended, defines "hazardous substance" chiefly by reference to other environmental statutes, such as the Solid Waste Disposal Act, Federal Water Pollution Control Act, Clean Air Act, and Toxic Substances Control Act. The term excludes petroleum, crude oil or any fraction thereof, natural gas, natural gas liquids, or synthetic gas usable for fuel.

**Hazardous Waste:** By-products of society that can pose a substantial or potential hazard to human health or the environment when improperly managed. Possesses at least one of four characteristics (ignitability, corrosivity, reactivity, or toxicity), or appears on special EPA lists.

**Hazard Analysis:** The procedures involved in: identifying potential sources of release of hazardous materials from fixed facilities or transportation accidents; determining the vulnerability of a geographical area to a release of hazardous materials; and comparing hazards to determine which present greater or lesser risks to a community.

**Heavy Metals:** Metallic elements with high atomic weights or high density (> 5g/cm3), toxic for the most part. They can damage living things at low concentrations and tend to accumulate in the food chain. Examples include mercury, chromium, cadmium, arsenic, and lead.

**Highwall Reduction:** Lowering the angle of a highwall by means of excavation or blasting.

**Holding Pond:** A pond or reservoir, usually made of earth, built to store polluted runoff.

**Hydraulic Stowing:** The filling of mine voids with granular material or waste transported to the deposition site as a water slurry by a pipeline.

**Hydrocarbons:** Chemical compounds that consist entirely of carbon and hydrogen.

**Hydrology:** The science of dealing with the properties, distribution, and circulation of water.

# I

**Incineration:** Burning of certain types of solid, liquid or gaseous materials; a treatment technology involving destruction of waste by controlled burning at high temperatures, e.g., burning sludge to remove the water and reduce the remaining residues to a safe, non-burnable ash that can be disposed of safely on land, in some waters or in underground locations.

**Incinerator:** A furnace for burning wastes under controlled conditions.

**Inflow:** Entry of extraneous rain water into a sewer system from sources other than infiltration, such as basement drains, manholes, storm drains, and street washing.

**Influent:** Water, wastewater, or other liquid flowing into a reservoir, basin, or treatment plant.

**Injection Zone:** A geological formation, group of formations, or part of a formation receiving fluids through a well.

**Inorganic Chemicals:** Chemical substances of mineral origin, not of basically carbon structure.

**Interstate Waters:** Waters that flow across or form part of state or international boundaries.

**Ion Exchange Treatment:** A common water softening method often found on a large scale at water purification plants that removes some organics and radium by adding calcium oxide or calcium hydroxide to increase the pH to a level where the metals will precipitate out.

**Isotope:** A variation of an element that has the same atomic number but a different weight because of its neutrons. Various isotopes of the same element may have different radioactive behaviors.

# L

**Landscape Character:** The arrangement of a particular landscape as formed by the variety and intensity of the landscape features and the four basic elements of form, line, color, and texture. These factors give the area a distinctive quality that distinguishes it from its immediate surroundings.

**Leachate Collection System:** A system that gathers leachate and pumps it to the surface for treatment.

**Leaching:** The process by which soluble constituents are dissolved and carried down through the soil by a percolating fluid.

**Limestone Scrubbing:** Process in which sulfur gases moving towards a smokestack are passed through a limestone and water solution to remove sulfur before it reaches the atmosphere.

**List:** Shorthand term for EPA list of violating facilities or lists of firms debarred from obtaining government contracts because they violated certain sections of the Clean Air or Clean Water Acts. The list is maintained by the Office of Enforcement and Compliance Monitoring.

**LLRW** (Low Level Radioactive Waste): Wastes less hazardous than most of those generated by a nuclear reactor. Usually generated by hospitals, research laboratories, and certain industries. The Department of Energy, Nuclear Regulatory Commission, and EPA share responsibilities for managing them.

**LOAEL** (Lowest Observed Adverse Effect Level): In dose-response experiments, the experimental exposure level representing the lowest level tested at which adverse effects were demonstrated.

**LOC** (Level of Concern): The concentration in air of an extremely hazardous substance above which there may be serious immediate health effects to anyone exposed to it for short periods of time.

**Lowest Achievable Emission Rate:** Under the Clean Air Act, this is the rate of emissions that reflects 1) the most stringent emission limitation that is contained in the implementation plan of any state for such source unless the owner or operator of the proposed source demonstrates such limitations are not achievable; or 2) the most stringent emissions limitation achieved in practice, whichever is more stringent. Application of this

term does not permit a proposed new or modified source to emit pollutants in excess of new source standards.

# M

**Major Stationary Sources:** Term used to determine the applicability of Prevention of Significant Deterioration and new source regulations. In a non-attainment area, any stationary pollutant source that has a potential to emit more than 100 tons per year is considered a major stationary source. In PSD areas the cutoff level may be either 100 or 250 tons, depending upon the type of source.

**Marsh:** A type of wetland that does not accumulate appreciable peat deposits and is dominated by herbaceous vegetation. Marshes may be either fresh or saltwater and tidal or non-tidal.

**MCL** (Maximum Contaminant Level): The maximum permissible level of a contaminant in water delivered to any user of a public water system. MCLs are enforceable standards.

**Media:** Specific environments – air, water, soil – that are the subject of regulatory concern and activities.

**Mine Waste:** Barren or subeconomic material in a mine.

**Monitoring:** Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, animals, and other living things.

**Monitoring Wells:** Wells drilled at a hazardous waste management facility or Superfund site to collect groundwater samples for the purpose of physical, chemical, or biological analysis to determine the amounts, types, and distribution of contaminants in the ground water beneath the site.

# N

**NPL** (National Priorities List): EPA's list of the most serious uncontrolled or abandoned hazardous waste sites identified for possible long-term remedial response.

**NRT** (National Response Team): Representatives of thirteen federal agencies that, as a team, coordinate federal responses to nationally significant incidents of pollution and provide advice and technical assistance to the responding agency(ies) before and during a response action.

**Neutralization:** The chemical process in which the acidic or basic characteristics of a fluid are changed to those of water. This usually is accomplished by adding other bases or acids until the concentration of hydrogen and hydroxyl ions in the solution are approximately equal.

**Nonpoint Source:** Pollution sources that are diffuse and do not have a single point of origin or are not introduced into a receiving stream from a specific outlet. The pollutants are generally carried off the land by stormwater runoff. The commonly used categories for nonpoint sources are: agriculture, forestry, urban, mining, construction, dams and channels, land disposal, and saltwater intrusion.

**Nutrient:** Any substance assimilated by living things that promotes growth. The term is generally applied to nitrogen and phosphorus in wastewater, but is also applied to other essential and trace elements.

# O

**Operable Unit:** Term for each of a number of separate activities undertaken as part of a Superfund site cleanup. A typical operable unit would be removing drums and tanks from the surface of a site.

**Organic:** Referring to or derived from living organisms; in chemistry, any compound containing carbon.

**Original Contour:** Pre-mining topography.

**Overburden:** The rock and soil cleared away before mining.

**Oxidation:** The addition of oxygen that breaks down organic waste or chemicals such as cyanides, phenols, and organic sulfur compounds in sewage by bacterial and chemical means; oxygen combining with other elements; the process in chemistry whereby electrons are removed from a molecule.

# P

**PA** (Preliminary Assessment): The process of collecting and reviewing available information about a known or

suspected hazardous waste site or release. EPA or States use this information to determine if the site requires further study. If further study is needed, a Site Inspection (SI) is undertaken.

**Passive Treatment:** Improving water quality using techniques that, after an initial investment, engineering and construction, little or no care or maintenance is required.

**Pay Zone:** The portion of a deposit that carries the profitable material.

**PCBs:** A group of toxic, persistent chemicals (polychlorinated biphenyls) used in transformers and capacitors for insulating purposed and in gas pipeline systems as a lubricant.

**Percolation:** The movement of water downward and radially through the subsurface soil layers, usually continuing downward to the ground water.

**Permeability:** The rate at which liquids pass through soil or other materials in a specified direction. Usually described as a rate of penetration at a defined pressure.

**Permit:** An authorization, license, or equivalent control document issued by EPA or an approved state agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.

**Physical and Chemical Treatment:** Processes generally used in large-scale wastewater treatment facilities. Physical processes may involve air-stripping or filtration. Chemical treatment includes coagulation, chlorination, or ozone addition. The term can also refer to treatment processes, treatment of toxic materials in surface waters and ground waters, oil spills, and some methods of dealing with hazardous materials in the ground.

**Plume:** A visible or measurable discharge of a contaminant from a given point of origin. Can be visible or thermal in water, or visible in the air as, for example, a plume of smoke; the area of measurable and potentially harmful radiation leaking from a damaged reactor.

**Pneumatic Stowing:** A system of filling mined cavities in which the crushed rock is carried through a pipeline by compressed air and discharged at high velocity into the space to be packed, the intense projection ensuring a high density of packed material.

**Point Source:** A stationary location or fixed facility from which pollutants are discharged or emitted. Also, any single identifiable source of pollution, e.g., a pipe, ditch, ship, ore pit, factory smokestack.

**Pollutant:** Generally, any substance introduced into the environment that adversely affects the usefulness of a resource.

**Pollution:** Generally, the presence of matter or energy whose nature, location or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, and radiological integrity of water.

**Potable Water:** Water that is safe for drinking and cooking.

**Precipitate:** A solid that separates from a solution because of some chemical or physical change.

**Precipitation:** Removal of solids from liquid waste so that the hazardous solid portion can be disposed of safely; removal of particles from airborne emissions.

**Precipitators:** Air pollution control devices that collect particles from an emission.

**Pre-stripping:** Removal of a portion of overburden ahead of another process.

**Pretreatment:** Processes used to reduce, eliminate, or alter the nature of wastewater pollutants from non-domestic sources before they are discharged into publicly owned treatment works.

**Primary Waste Treatment:** First steps in wastewater treatment; screens and sedimentation tanks are used to remove most material that floats or will settle. Primary treatment results in the removal of about 30% of carbonaceous biochemical oxygen demand from domestic sewage.

**PRP** (Potentially Responsible Party): Any individual or company (such as an owner, operator, transporter, or generator) potentially responsible for, or contributing to, the contamination problems at a Superfund site. Whenever possible, EPA requires PRPs, through administrative and legal actions, to clean up sites contaminated by hazardous substances.

**PSI** (Pollutant Standard Index): Measure of adverse health effects of air pollution levels in major cities.

# Q

**Quality Assurance/Quality Control:** A system of procedures, checks, audits, and corrective actions to ensure that all EPA research design and performance, environmental monitoring and sampling, and other technical and reporting activities are of the highest achievable quality.

# R

**RA** (Remedial Action): The actual construction or implementation phase that follows the remedial design of the selected cleanup alternative at a site on the National Priorities List (NPL).

**RAD** (Radiation Absorbed Dose): A unit of absorbed dose of radiation. One RAD of absorbed dose is equal to .01 joules per kilogram.

**Radiation:** Any form of energy propagated as rays, waves, or streams of energetic particles. The term is frequently used in relation to the emission of rays from the nucleus of an atom.

**Radionuclide:** Radioactive element characterized according to its atomic number that can be man-made or naturally occurring. Radioisotopes can have a long life as soil or water pollutants, and are believed to have potentially mutagenic effects on the human body.

**RCRA** (Resource Conservation and Recovery Act of 1976): A Federal law that established a structure to track and regulate hazardous wastes from the time of generation to disposal. The law requires safe and secure procedures to be used in treating, transporting, storing, and disposing of hazardous substances. RCRA is designed to prevent new, uncontrolled hazardous waste sites. The law also regulates the disposal of solid waste that may not be considered hazardous.

**Recharge:** The process by which water is added to a zone, usually by percolation from the soil surface, e.g., the recharge of an aquifer.

**Recharge Area:** A land area in which water reaches to the zone of saturation from surface infiltration, e.g., an area where rainwater soaks through the earth to reach an aquifer.

**Releveling:** Making a structure that has deflected or tilted, because of subsidence, level again by using jacks or other such devices.

**Remote** (or blind) Backfilling: Backfilling in a mine area or site where access by personnel is not feasible.

**Response Action:** A CERCLA-authorized action at a Superfund site involving either a short-term removal action or a long-term remedial response that may include, but is not limited to, the following activities: removing hazardous materials from a site to an EPA approved, licensed hazardous waste facility for treatment, containment, or destruction; containing the waste safely on-site to eliminate further problems; destroying or treating the waste on-site using incineration or other technologies; and identifying and removing the source of groundwater contamination and halting further movement of the contaminants.

**Risk Assessment:** An evaluation performed as part of the remedial investigation to assess conditions at a Superfund site and determine the baseline risks posed to public health and/or the environment.

**Risk Communication:** The exchange of information about health or environmental risks between risk assessors, risk managers, the general public, news media, interest groups, etc.

**Risk Management:** The process of evaluating alternative regulatory and non-regulatory responses to risk and selecting among them. The selection process necessarily requires the consideration of legal, economic and social factors.

**RMCL** (Recommended Maximum Contaminant Level): The maximum level of a contaminant in drinking water at which no known or anticipated adverse effect on human health would occur, and which includes an adequate margin of safety. Recommended levels are nonenforceable health goals.

**Rock Sculpturing:** Configuring rock cuts to produce staggered benches and planting pockets that mimic natural terrain and accent natural fracture lines in the rock.

**ROD** (Record of Decision): A legal document that explains which cleanup alternative(s) will be used to cleanup Superfund remedial sites. The Record of Decision is based on information and technical analysis generated during the remedial investigation/feasibility study (RI/FS) and consideration of public comments and community concerns.

**RP** (Responsible Party): A party that admits to or that EPA or the DOJ prove was responsible for contamination at a Superfund site.

**Run-Off:** That part of precipitation, snow melt, or irrigation water that runs off the land into streams or other surface-water. It can carry pollutants from the air and land into receiving waters.

**RUSLE:** Revised Universal Soil Loss Equation.

# S

**Saturated Zone:** A subsurface area in which all pores and cracks are filled with water under pressure equal to or greater than that of the atmosphere.

**Scrubber:** An air pollution device that uses a spray of water or reactant or a dry process to trap pollutants in emissions.

**Security Cover:** Habitat that provides security for wildlife.

**Sedimentation:** Gravitational settling of solid particles in a liquid system; the separation of suspended particles in an aqueous waste stream.

**Site Inspection:** The collection of information from a Superfund site to determine the extent and severity of hazards posed by the site. It follows and is more extensive than a preliminary assessment. The purpose is to gather information necessary to score the site, using the Hazard Ranking System, and to determine if the site presents an immediate threat that requires prompt removal action.

**Slurry:** A watery mixture of insoluble matter that results from some pollution control techniques.

**SMCRA** (Surface Mining Control and Reclamation Act of 1977): An act that regulates the environmental effects of coal mining.

**SMOA** (Superfund Memorandum of Agreement): A voluntary, non-binding agreement executed by an EPA Regional Administrator and the head of a State agency establishing the nature and extent of EPA and State interaction during the pre-remedial, remedial, and enforcement response process.

**Soil Salvage:** Saving soil for later use in reclamation.

**Solid Waste:** Non-liquid, nonsoluble material ranging from municipal garbage to industrial wastes that contain complex, and sometimes hazardous, substances. Solid wastes include sewage sludge, agricultural refuse, demolition wastes, and mining residues. Technically, solid waste also refers to liquids and gases in containers.

**Sorption:** The action of soaking up or attracting substances. A process used in many pollution control systems.

**Spoil:** The overburden that has been removed in gaining access to coal or other ores.

**Subsidence:** The lowering of strata, including the surface, due to underground excavations; surface caving, distortion or fissuring due to effects of collapse of deep workings; a sinking down of a part of the earth's crust.

**Superfund:** The common name used for the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also referred to as the Trust Fund.

**Surfactant:** A surface-active agent used in detergents to cause lathering.

**Swamp:** A type of wetland that is dominated by woody vegetation and does not accumulate appreciable peat deposits. Swamps may be fresh or salt water and tidal or nontidal.

# T

**Tailings:** Residue of raw materials or waste separated out during the processing of crops or mineral ores.

**Tertiary Treatment:** Advanced cleaning of wastewater that goes beyond secondary or biological stage. It removes nutrients such as phosphorus and nitrogen and most BOD and suspended solids.

**Thermal Pollution:** Discharge of heated water from industrial processes that can affect the life processes of aquatic organisms.

**Tolerances:** The permissible residue levels for pesticides in raw agricultural produce and processed foods. Whenever a pesticide is registered for use on a food or a feed crop, a tolerance must be established. EPA establishes the tolerance levels, which are enforced by the Food and Drug Administration and the Department of Agriculture.

**Total Exposure Point:** A point of potential exposure to substances from more than one exposure pathway.

**Toxic:** Harmful to living organisms.

**TSS** (Total Suspended Solids): A measure of the suspended solids in wastewater, effluent, or water bodies, determined by using tests for "total suspended nonfilterable solids."

**Trust Fund:** A fund set up under CERCLA to help pay for cleanup of hazardous waste sites and for legal action to force those responsible for the sites to clean them up.

**Turbidimeter:** A device that measures the amount of suspended solids in a liquid.

**Turbidity:** Haziness in air caused by the presence of particles and pollutants; a similar cloudy condition in water due to suspended silt or organic matter.

# U

**UCC** (Ultra Clean Coal): Coal that has been washed, ground into fine particles, then chemically treated to remove sulfur, ash, silicone, and other substances; usually briquetted and coated with a sealant made from coal.

# V

**Vapor:** The gaseous phase of substances that are liquid or solid at atmospheric temperature and pressure, e.g., steam.

**Visual Arc: The** angle an object occupies in a viewer's eye.

**Visual Contrast Elements:** The principal elements considered in completing a visual contrast rating.

Color: The property of reflecting light of a particular intensity and wavelength to which the eye is sensitive. Color is the major visual property of surfaces.

Chroma: The degree of color saturation or brilliance, determined by the mixture of light rays. It is the degree of grayness in a color, ranging from pure (high chroma) to dull (low chroma).

Hue: The aspect of color that we know by particular names, e.g., red, blue, orange, and which forms the visual spectrum. A given hue or color tint is caused by a particular wavelength.

Value: The degree of lightness or darkness, caused by the intensity of light being reflected, ranging from black to white.

Form: The mass or shape of an object or of objects which appear unified.

Line: The path, real or imagined, that the eye follows when perceiving abrupt differences in form, color, or texture.

Scale: The proportionate size relationship between an object and the surroundings in which it is placed.

Space: The spatial qualities of a landscape are determined by the three-dimensional arrangement of objects and voids.

Texture: The aggregation of small forms or color mixtures into a continuous surface pattern so that the aggregated parts do not appear as discrete objects in the composition of a scene.

**Visual Contrast Rating:** A systematic process developed by the Bureau of Land Management to analyze potential visual impacts of proposed objects and activities.

**Visual Impact:** Changes to visual quality of the landscape caused by an activity. The degree of visual impact is dependent upon the amount of visual contrast created between the activity and the existing landscape character.

**Visual Remediation:** Management alternatives and/or practices that return existing adverse visual impacts through modification or elimination to a desirable visual (scenic) quality.

**Volatile Organic Compound** (VOC): Any organic compound that participates in atmospheric photochemical reactions except for those designated by the EPA as having negligible photochemical reactivity.

# W

**Waste:** Unwanted materials left over from a manufacturing process; refuse from places of human or animal habitation.

**Wastewater:** The spent or used water from individual

homes, a community, a farm, or an industry that contains dissolved or suspended matter.

**Water Pollution:** The presence in water of enough harmful or objectionable material to damage the water's quality.

**Water Quality Standards:** State-adopted and EPA-approved ambient standards for water bodies. The standards cover the use of the water body and the water quality criteria that must be met to protect the designated use or uses.

**Water Solubility:** The maximum concentration of a chemical compound that can result when it is dissolved in water. If a substance is water soluble it can readily disperse through the environment.

**Watershed:** The land area that drains into a stream.

**Wetlands:** An area that is regularly saturated by surface or ground water and subsequently is characterized by a prevalence of vegetation that is adapted for life in saturated soil conditions. Examples include: swamps, bogs, fens, marshes, and estuaries.

**WL** (Working Level): A unit of measure for documenting exposure to radon decay products. One working level is equal to approximately 200 picocuries per liter.

**WLM** (Working Level Month): A unit of measure used to determine cumulative exposure to radon.

## ACRONYMS

| | |
|---|---|
| A&C | Abatement and Control |
| A&R | Air and Radiation |
| AA | Accountable Area |
| AA | Adverse Action |
| AA | Attainment Area |
| A&C | Abatement and Control |
| ACO | Administrative Consent Order |
| ADI | Acceptable Daily Intake |
| AL | Acceptable Level |
| ANWR | Arctic National Wildlife Refuge |
| AOC | Area of Contamination |
| AOC | Administrative Order on Consent (RCRA) |
| APA | Administrative Procedure Act |
| ARARS | Applicable or Relevant and Appropriate Requirements |
| ARCS | Alternative Remedial Contracts Strategy |
| AST | Aboveground Storage Tank |
| ATS | Action Tracking System |
| BACT | Best Available Control Technology |
| BPT | Best Practical (Control) Technology |
| BLM | Bureau of Land Management |
| BMR | Baseline Monitoring Report |
| BTU | British Thermal Unit |
| CA | Cooperative Agreement |
| CAA | Clean Air Act |
| CAAA | Clean Air Act Amendments |
| CAR | Corrective Action Report |
| CBA | Cost Benefit Analysis |
| CCP | Composite Correction Plan (CWA) |
| CD | Consent Decree |
| CERCLA | Comprehensive Environmental Response, Compensation, and Liability Act |
| CERCLIS | Comprehensive Environmental Response, Compensation, and Liability Information System |
| CFCs | Chlorofuorocarbons |
| CFR | Code of Federal Regulations |
| CGL | Comprehensive General Liability |
| CIP | Carbon in pulp |
| CIS | Chemical Information System |
| CO | Consent Order |
| CWA | Clean Water Act |
| DHS | Designated Hazardous Substances |
| DI | Diagnostic Inspection (CWA) |
| DL | Detection Limit |
| DMR | Discharge Monitoring Report (CWA) |
| DNAPL | Dense Non-Aqueous Phase Liquid |
| DO | Dissolved Oxygen |
| DOI | Department of the Interior |
| DOJ | Department of Justice |
| DQO | Data Quality Objectives |
| EA | Endangerment Assessment |
| EA | Environmental Assessment |
| EA | Environmental Action |
| EAP | Environmental Action Plan |
| EDD | Enforcement Decision Document |
| EIA | Economic Impact Assessment |
| EIS | Environmental Impact Statement |
| EIS | Emissions Inventory System |
| EP | Environmental Profile |
| EPA | Environmental Protection Agency |
| ERD | Emergency Response Division |
| ESA | Endangered Species Act |
| FERC | Federal Energy Regulatory Commission |
| FIP | Federal Implementation Plan |
| FONSI | Finding of No Significant Impact |
| FLPMA | Federal Land Policy and Management Act |
| FNSI | Finding of No Significant Impact |
| FR | Federal Register |
| FS | Feasibility Study |

| | |
|---|---|
| FS | Forest Service |
| FWS | Fish and Wildlife Service |
| GACT | Generally Available Control Technology |
| GW | Groundwater |
| GWPS | Groundwater Protection Standard |
| HAP | Hazardous Air Pollutant |
| HSWA | Hazardous and Solid Waste Amendments (RCRA, 1984) |
| HW | Hazardous Waste |
| IAG | Interagency Agreement |
| LLRW | Low Level Radioactive Waste |
| LOAEL | Lowest Observed Adverse Effect Level |
| LOC | Level of Concern |
| LTRA | Long Term Response Actions |
| MCL | Maximum Contaminant Level |
| MOU | Memorandum of Understanding |
| MSHA | Mine Safety and Health Administration |
| NAA | Nonattainment Area(s) |
| NAAQS | National Ambient Air Quality Standards |
| NCP | National Contingency Plan (CERCLA) |
| NCP | Noncompliance Penalties (CAA) |
| NCR | Noncompliance Report (CWA) |
| NEPA | National Environmental Policy Act of 1969 |
| NIMBY | Not In My Back Yard |
| NOAEL | No Observable Adverse Effects Level |
| NOD | Notice of Deficiency (RCRA) |
| NOI | Notice of Intent |
| NPL | National Priorities List |
| NRT | National Response Team |
| NSPS | New Performance Standards |
| NSR | New Source Review (CAA) |
| O&M | Operation and Maintenance |
| OSM | Office of Surface Mining |
| OU | Operable Unit |
| OWP | Office of Wetlands Protection |
| PA | Preliminary Assessment |
| PAI | Performance Audit Inspection (CWA) |
| PAT | Permit Assistance Team (RCRA) |
| PCS | Permit Compliance System (CWA) |
| PSI | Pollutant Standards Index |
| PSM | Point Source Modeling |
| PRP | Potentially Responsible Party |
| QA/QC | Quality Assurance/Quality Control |
| RA | Remedial Action |
| RAD | Radiation Absorbed Dose |
| RAMP | Rural Abandoned Mine Program |
| RCMS | Removal Cost Management System |
| RCRA | Resource Conservation and Recovery Act of 1976 |
| RI | Remedial Investigation |
| RIA | Regulatory Impact Analysis |
| RIP | RCRA Implementation Plan |
| RMCL | Recommended Maximum Contaminant Level |
| ROD | Record of Decision |
| RP | Responsible Party |
| RUSLE | Revised Universal Soil Loss Equation |
| RQs | Reportable Quantities |
| RUSLE | Revised Universal Soil Loss Equation |
| RWQCB | Regional Water Quality Control Board |
| SAP | Sampling and Analysis Plan |
| SARA | Superfund Amendments and Reauthorization Act |
| SCAP | Superfund Comprehensive Accomplishments Plan (CERCLA) |
| SEA | State/EPA Agreement |
| SERA | Superfund Emergency Response Actions |
| SF | Superfund |
| SI | Site Investigation (CERCLA) |
| SITE | Superfund Innovative Technology Evaluation |
| SMCRA | Surface Mining Control and Reclamation Act |
| SMOA | Superfund Memorandum of Agreement |
| SOW | Statement of Work |
| SSC | Superfund State Contract |
| TAGs | Technical Assistance Grants |
| TSDF | Treatment, Storage, & Disposal Facility (RCRA) |
| TSS | Total Suspended Solids |
| UCC | Ultra Clean Coal |
| UMTRCA | Uranium Mill Tailings Radiation Control Act |
| USEPA | United States Environmental Protection Agency |
| USLE | Universal Soil Loss Equation |
| VOC | Volatile Organic Compound |
| WAP | Waste Analysis Plan (RCRA) |
| WL | Working Level |
| WLM | Working Level Month |
| WSRA | Wild and Scenic Rivers Act |

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