RESPONSIBLE MINING

Case Studies in Managing Social & Environmental Risks in the Developed World






Edited by Michelle E. Jarvie-Eggart

SME

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PUBLISHED BY THE
SOCIETY FOR MINING, METALLURGY & EXPLORATION

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(303) 948-4200 / (800) 763-3132
www.smenet.org

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Electronic edition published 2015.

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ISBN: 978-0-87335-373-1
Ebook: 978-0-87335-374-8

Library of Congress Cataloging-in-Publication Data
Responsible mining : case studies in managing social and environmental risks in the developed world / edited by Michelle E. Jarvie-Eggart.
pages cm
Includes bibliographical references and index.
ISBN 978-0-87335-373-1 (print) -- ISBN 978-0-87335-374-8 (ebook)
1. Mineral industries--Environmental aspects--Case studies. 2. Mineral industries--Social aspects--Case studies. I. Jarvie-Eggart, Michelle E., editor. II. Society for Mining, Metallurgy, and Exploration (U.S.)
TD195.M5R487 2015
622.028'6--dc23
2014042370

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Contents

Preface ..... **v**

Part I **Managing Social, Economic, and Environmental Risks** **1**

Chapter 1 The International Council on Mining and Metals: Sustainable Development Framework **13**

Chapter 2 The Global Reporting Initiative: Sustainability Reporting for the Mining and Metals Sector **39**

Chapter 3 Managing Business Sustainability in the Australian Mining Industry **63**

Chapter 4 The Mining Association of Canada's Towards Sustainable Mining Program **85**

Part II **Stakeholder Engagement and Participation** **111**

Chapter 5 Indigenous Engagement in a Vocational Educational Training Program in Australia **115**

Chapter 6 Building Trust **151**

Chapter 7 Evaluating the Science of Environmental Assessments with Aboriginal Groups **231**

Part III **Biodiversity and Conservation Management** **259**

Chapter 8 Joint Land Management Project in the Northern Yilgarn, Western Australia **263**

Chapter 9 Spider Conservation and Mining **277**

Chapter 10 Biodiversity Management and Mining in the San Bernardino Mountains **289**

Part IV **Climate Changes, Energy, and Greenhouse Gas Management** **317**

Chapter 11 Climate Change for Mine Planning **321**

Chapter 12 Molycorp's Project Phoenix—Water and Reagent Recycling with Clean Power **347**

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Chapter 13 Geothermal Energy Recovery from Closed Underground Mines 371

Chapter 14 Optimal Mine Site Energy Supply 389

Part V Mine Water Management 431

Chapter 15 Responsible Mine Water Management: Water and Mass Balance Modeling, and Creative Mine Water Management Solutions 433

Chapter 16 Mine Water Treatment Techniques and the Application of Vacuum Membrane Distillation 461

Chapter 17 Integrating Pit Lakes into Water Basin Planning: The Meirama Brown Coal Mine 489

Part VI Tailings and Waste Rock 519

Chapter 18 Responsible Tailings Disposal at Minnesota Taconite Mines 521

Chapter 19 Responsible Management of Acid Mine Wastes: Geochemical and Microbiological Resources 553

Part VII Reclamation, Closure, and Land-Use Planning 577

Chapter 20 Global Implications and Challenges of Evolving Mine Closure Requirements in Western Australia 583

Chapter 21 Identifying Natural and Novel Ecosystem Goals for Rehabilitation of Postmining Landscapes 609

Chapter 22 After the Gold Rush: Developing Closure Criteria for a Mined Landscape 639

Chapter 23 Best Practices for Forest Restoration When Reclaiming Surface Coal Mines 663

Chapter 24 Responsible Land and Resource Management in Northeastern Minnesota 705

Chapter 25 Adaptive Environmental Management Plans and Practices 725

Part VIII Crisis Management 753

Chapter 26 Mine Disaster Crisis Management from the Operational and Legal Perspectives 755

Index 779

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Preface

This book presents common themes and best practices for managing social, economic, and environmental risks and impacts at mines in the developed world. Although the term *sustainability* is often applied to efforts to address social, economic, and environmental risks and impacts, many struggle with its application to the extraction of nonrenewable resources. Obviously, a finite amount of mineral deposits exist on Earth, so we cannot mine *forever*. For this reason, the term *responsible mining* is chosen as the title of this book. Responsible mining means planning, operating, and closing mines in a manner that manages specific social, economic, and environmental risks and impacts (or sustainability) at a given operation. Although these issues are unique for each operation, several organizations have evolved to help operators understand common industry-wide risks and impacts and to better manage them at individual mine sites.

The book is divided into the following sections:

- Part I: Managing Social, Economic, and Environmental Risks
- Part II: Stakeholder Engagement and Participation
- Part III: Biodiversity and Conservation Management
- Part IV: Climate Change, Energy, and Greenhouse Gas Management
- Part V: Mine Water Management
- Part VI: Tailings and Waste Rock
- Part VII: Reclamation, Closure, and Land-Use Planning
- Part VIII: Crisis Management

Part I describes various organizations and programs dedicated to the management and reporting of social, economic, and environmental impacts. The chapters summarize the efforts of the following major mining associations and nongovernmental organizations to further responsible mining practices.

- The International Council on Mining and Metals (ICMM) Sustainable Development Framework establishes 10 principles to guide members in addressing the social, economic, and environmental impacts of mining. The ICMM is a mining association. Members include various mining associations from around the world. Membership is voluntary, but all members must commit to the 10 principles of the Sustainable Development Framework and integrate them within their business practices. The ICMM has issued position

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statements on topics such as climate change, partnerships for development, transparency in minerals reporting, mercury risk management, Indigenous peoples, and protected areas. The ICMM has also established work programs on social and economic development, climate change and the environment, health and safety, and materials stewardship, providing various toolkits to assist its members in addressing these issues. ICMM members are also required to use the Global Reporting Initiative's reporting guidelines on its social, economic, and environmental impacts, and provide third-party assurance for sustainability reporting.

- The Global Reporting Initiative's (GRI's) sustainability reporting guidelines are used worldwide by organizations issuing sustainability reports. GRI is a nonprofit organization that encourages governing bodies to manage their social, economic, and environmental impacts, and transparently report their performance in these areas. GRI has created special sector-specific sustainability reporting guidelines for mining and metals companies.
- The Minerals Council of Australia's (MCA's) Enduring Value Framework aligns itself with ICMM's Sustainable Development Framework. Water scarcity is a particular problem in Australia, and the MCA has developed a water accounting framework to help its members accurately track and manage water use at its operations.
- The Mining Association of Canada's (MAC's) Towards Sustainable Mining program includes protocols on crisis management, energy and greenhouse gas (GHG) management, tailings management, biodiversity and conservation management, safety and health, and Aboriginal and community outreach, as well as a framework on mine closure. Each of the formal protocols requires procedures, management systems, and annual reporting on implementation progress. Of all the national associations addressing social and environmental risks and impacts in mining, MAC has the most prescriptive requirements for its members' activities. Notably, in the United States, the National Mining Association has a position statement on sustainable development but does not have formal programs or requirements for members to address sustainability at their operations.

Parts II through VII present case studies describing best practices organized around common themes in responsible mining identified by the above-mentioned organizations, with a few exceptions: human rights and safety. The focus of this text is on mining in the *developed* world. Although human rights is a significant concern for the industry, the issue tends to be more significant for operations in the *developing* world. Human rights considerations generally address adherence with the United Nations' Universal Declaration of Human Rights in 1948 (www.un.org/en/documents/udhr/). The declaration asserts for all people the right to life, liberty, and security of person; freedom of peaceful assembly and association;

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equal pay; the right to form unions; and the right to rest and reasonable imitation of working hours, among others. The declaration also prohibits slavery and arbitrary arrest. Within the developed world, these rights are generally protected by labor laws and enforced by governments. As such, concerns about child or slave labor, or rights to assemble as workers, are not as significant a concern as they are for mining workers in the developing world. Because the focal point of this book is on the developed world, efforts to address human and workers' rights are not included in this text, although companies may make significant efforts to address them.

Stakeholder engagement and participation is covered in Part II. Stakeholders can comprise a wide group of individuals, including those external and internal to a mining company. MAC prefers the term *communities of interest*, which it broadly defines as anyone who believes they are affected by the actions and decisions of a mining operation. This can include local communities, suppliers, investors, nongovernmental organizations, native populations, and so forth. The chapters in this section use varying terms to describe native populations. In the United States, the term *Native American* is often used; those in Canada may use *First Nations*, *Indigenous peoples*, and/or *Aboriginal peoples*; and those in Australia use *Aboriginal*. No effort has been made to force standardization of the term among the submissions from around the globe. The authors of the various chapters use the term that is appropriate to the cultural context about which they are writing. Part II includes case studies on employment programs for Aboriginal peoples in Australia, First Nations and traditional knowledge for technical information review in Canada, and community environmental monitoring and scoring of mining operation performance in the United States. Together, these examples highlight the proactive activities mining companies have taken to involve stakeholders in mine development, operation, and monitoring.

Part III presents case studies on biodiversity and conservation management. Activities of the organizations highlighted in Part I show agreement on the importance of managing biodiversity impacts at mining operations. Although mining companies have been replanting disturbed areas for awhile, recent focus has shifted to "biodiversity management." This is an emerging discipline, with ongoing debate over exactly what this term means and how to measure it. Biodiversity can be measured by quantifying individual plant and animal populations, by surveying the area of habitat provided for specific species, or, at a much higher level, by assessing ecosystem function. To help enlighten how biodiversity can be constructively managed, Part III highlights several case studies of actual efforts within the United States and Australia for managing biodiversity at the mine and regional level.

The issue of climate change has several ramifications for mining operations. Today's mining companies must consider their own contributions to GHG emission and the operational risks the physical impacts of climate change may pose to mining operations. Part IV includes a chapter explaining how climate change can

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present risks to mining operations that should be considered in mine planning, a case study on the overall benefits gained by implementing energy-saving projects, and a case study on the innovative extension of the useful life of an underground mine to provide energy and facility-specific energy optimization. Although many energy management activities are driven by cost-savings issues rather than concern for GHG emissions, the environmental benefits of consuming less energy are realized nevertheless.

Mine Water Management (Part V) is one of the most critical global environmental issues of the twenty-first century and one of the most important resources for a mining operation. Mining, mineral processing, and tailings disposal require significant volumes of water. In the context of climate change, an increase in droughts and more storm and flooding events can be expected, indicating the importance of proactive water management at mining operations. Freshwater resources are anticipated to become more scarce, and our global population growth will demand more freshwater for drinking and irrigation. Mining operations face increasing pressure to conserve and reuse water in novel ways, and to work with local communities to ensure that the water needs of all are met. As standards for water treatment become more stringent, mines must treat water effluents to greater final quality. Part V includes case studies of water management at mining operations and mine water treatment techniques, and a unique case study on the utilization of pit water to augment a community water supply in Spain. This section is by no means exhaustive, and SME has dedicated entire books to the subject of water in mining. The reader may also refer to the following SME publications: *Basics of Metal Mining Influenced Water* (2008), *Mitigation of Metal Mining Influenced Water* (2009), and *Water in Mineral Processing* (2012).

Tailings and waste rock disposal is one of the significant environmental issues for mines, especially those with acid generation potential. Part VI includes a chapter highlighting factors to consider in tailings disposal, from design through reclamation, using the example of taconite facilities in the Great Lakes region of the United States. It also includes a chapter addressing the responsible management of acid mine wastes, including methods for reducing acid generation and case studies from several mines in Canada and Australia. The realm of tailings management is much greater than can be covered in this text. For further reading, see the following SME books: *Challenges in Fine Coal Processing, Dewatering, and Disposal* (2012) and *Underwater Tailing Placement at Island Copper Mine* (2002).

Reclamation and closure for modern mines is much more regulated than it has been in the past. Reclamation planning requirements vary widely among countries, and debate exists as to whether original ecosystems can be fully restored. Part VII includes a chapter that suggests a hierarchy for postmining land uses which begins with efforts to reinstate "natural" ecosystems as similar as possible to the original ecosystem and ends with developing alternative land uses. This section also includes

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a reclamation case study from an Australian mine highlighting the important measures of success for ecosystems, as well as case studies from forest reclamation in the Appalachian coal region of the United States, and land and resource management in the Minnesota Iron Range. Adaptive environmental management plans are also discussed in this section, with a chapter explaining the iterative process for making decisions when significant uncertainty exists.

Although safety is one of the most significant issues for mines, like workers' rights, it is highly regulated within the developed world. With emerging computer technology that makes real-time tracking of behavior a possibility, a whole text could be dedicated to new and innovative technologies at managing worker safety. Additionally, because of the litigation that can arise after a mining accident, many companies are reluctant to share their best practices and case studies with lessons learned post-event. For these reasons, submissions for this book were not received to adequately cover the topic of safety. The final chapter in Part VIII, however, does address crisis management planning and provides a good example of typical plan requirements. For more information on health and safety, the reader is referred to the following texts: *Mine Health and Safety Management*, published by SME in 2001, and *Race Against Time: Building a Culture of Mine Safety*, published by Moody International in 2008.

Together, the topics included in this book provide a broad overview of the issues that must be addressed when managing social, economic, and environmental risks and impacts at mines in the developed world. It is my hope that these examples inspire readers to become more responsible miners and managers of mining operations.

ACKNOWLEDGMENTS

Many companies contributed case studies to this text. Particular recognition and appreciation goes to the following corporations and individuals:

- Barr Engineering, for supporting me in developing and editing this book, and for contributing case studies on taconite tailings management and water management
- Paul West and Rob Howard of Cliffs Natural Resources, for wonderful examples of biodiversity management in Australia
- Sandra Daff, specialist in indigenous relations at Pacific Aluminium, and Klaus Helms, general manager of the Gumatj Corporation, for their contributions to the case study on Aboriginal employment programs in the Northern Territory of Australia
- Mary B. Korpi, director external relations, Newmont USA Limited, for contributions to the chapter on mine disaster crisis management

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- Roberto González-Philippon, mine manager at Lignitos de Meirama, and Alvaro Fernández-García, coordinator of reclamation activities at the Meirama mine, for contributions to the case study on integrating pit lakes into water basin planning
- Scott Honan, director of health, environment, safety and sustainability at Molycorp, Inc., for contributions to the case study on Project Phoenix
- Simon Nish, vice president of sustainability at BG Canada, and Chantae Lessard of Lundin Mining, for case studies on the Eagle mine

A thank-you for assistance in soliciting authors and early editing efforts goes to Helen Muga, assistant professor in civil engineering at the University of Mount Union. Mansour Edraki, senior research fellow at the Centre for Mined Land Rehabilitation in the Sustainable Minerals Institute of The University of Queensland in Brisbane, Australia, is also thanked for editing assistance. Special thanks are extended to Jane Olivier and SME's editorial and production staff for guiding the development of the text. Huge thanks are given to Melisa Pollak, environmental specialist at Barr Engineering, who managed to keep the project on task and provided editing assistance with eloquence and grace. Finally, the largest thank-you goes to my wonderful husband, Brian Eggart, for drawing me into the mining industry in the first place and always encouraging me in all of life's endeavors.

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PART I

MANAGING SOCIAL, ECONOMIC, AND ENVIRONMENTAL RISKS

Michelle E. Jarvie-Eggart

As the concept of sustainability has become the focus of international environmental efforts, the mining industry and its critics have grappled with mining's role in sustainable development. While the debate is not over, the conversation has been fruitful. Efforts have advanced the understanding of mining practices designed to protect the environment, contribute to local communities, and build value into the postclosure landscape.

Early efforts to address sustainable development began with the United Nations (UN), and spread into the business world, including mining. At the end of the 20th century, mining companies began to address the social (including health and safety), economic, and environmental impacts and risks associated with their operations. In 2002, the International Council on Mining and Metals (ICMM) made the first attempt to standardize sustainability efforts within corporate programs. The Minerals Council of Australia's framework for sustainable development was developed in 2005 in response to ICMM's sustainable development principles. The Mining Association of Canada launched its own program in 2004 based on its 1998–2002 research on the Canadian public's concerns about sustainability with regard to the mining industry.

Sustainability in mining is now generally understood as the thoughtful management of social, economic, and environmental impacts. This introduction to Part I reviews the evolution of sustainability concepts and definitions, presents the business case for sustainability, and describes how the concept has diffused into the mining industry.

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INTERNATIONAL EFFORTS TO DEFINE SUSTAINABILITY

The idea of sustainability traces its roots to the environmental movement of the 1970s, when many industrialized countries began to regulate and limit environmental emissions. As public awareness grew about the toll that industrialization had taken on the environment in developed countries, concern emerged about how to protect human health and the environment during the global process of industrialization. In 1972, the nations of the world came together to address humanity's environmental impact at the UN Conference on the Human Environment in Stockholm. The conference proclaimed the interdependent imperatives of environmental protection, economic development, and social justice. The foundations for the idea of sustainability are evident in the declaration of "solemn responsibility to protect and improve the environment for present and future generations" (UN 1972). The year 1972 also saw the first modern usage of the term *sustainable*, when the Club of Rome issued its famous report *Limits to Growth*, saying "We are searching for … a world system that is sustainable without sudden and uncontrolled collapse, and capable of satisfying the basic material requirements of all of its people" (Meadows et al. 1972).

By 1980, the concept of *sustainable development* had entered the international conversation. The International Union for Conservation of Nature and Natural Resources (IUCN) published the *World Conservation Strategy*, with advice and financial assistance from the United Nations and collaboration from the World Wildlife Federation. The *World Conservation Strategy* asserted that humans must come to terms with the realities of resource limitation and carrying capacities of ecosystems, and account for the needs of future generations (IUCN 1980).

The strategy asserted that "development and conservation are equally necessary for our survival and for the discharge of our responsibilities for the generations to come." The strategy laid out priorities for national and international actions focused on the biological environment, which included maintaining essential ecological processes and life support systems, preserving genetic diversity, and ensuring the sustainable utilization of species and ecosystems. The strategy ended with a call for action "toward sustainable development."

Perhaps the most famous definition of sustainability came in 1987, in a report titled *Our Common Future*, issued by the UN World Commission on Environment and Development (WCED), chaired by the prime minister of Norway, Gro Harlem Brundtland. The Brundtland Commission defined sustainable development as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs." This definition of sustainable development implies that sustainable activities are those that can occur indefinitely throughout future time.

The international community began to take steps to implement sustainable development with the UN Conference on Environment and Development in 1992

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in Rio de Janeiro. Commonly called the Earth Summit, this international gathering adopted Agenda 21: Programme of Action for Sustainable Development. Agenda 21 acknowledged the social, economic, and environmental factors in sustainable development and promoted protection of the atmosphere, soil, water, and biological diversity. Agenda 21 called for broader stakeholder involvement in sustainable development, including stronger roles for women, Indigenous peoples, nongovernmental organizations (NGOs), governments, workers, businesses, farmers, and the science and technical community. In short, it recognized the need for the involvement of everyone to solve the question of how to develop sustainably. The conference also resulted in agreements related to biological diversity and climate change.

Ten years after the Earth Summit, the World Summit on Sustainable Development was held in Johannesburg, South Africa, in 2002. The "Johannesburg Declaration" stated that the attending nations would "assume a collective responsibility to advance and strengthen the interdependent and mutually reinforcing pillars of sustainable development—economic development, social development, and environmental protection—at the local, national, regional, and global levels (UN 2002a). To advance these goals, the 2002 summit issued the "Plan of Implementation of the World Summit on Sustainable Development" (UN 2002b).

For the mining industry, one of the most significant aspects of the Johannesburg Plan of Implementation is paragraph 46, which lays out principles for "enhancing the contribution of mining, minerals and metals to sustainable development" (UN 2002b). Paragraph 46 calls for actions to

- "Address the environmental, economic, health and social impacts and benefits of mining, minerals and metals throughout their life cycle, including workers' health and safety, and … to promote transparency and accountability for sustainable mining and minerals development";
- "Enhance the participation of stakeholders, including local and indigenous communities and women, to play an active role in minerals, metals and mining development throughout the life cycles of mining operations, including after closure for rehabilitation purposes…"; and
- "Foster sustainable mining practices through the provision of financial, technical and capacity-building support to developing countries and countries with economies in transition for the mining and processing of minerals, including small-scale mining, and, where possible and appropriate, improve value-added processing, upgrade scientific and technological information and reclaim and rehabilitate degraded sites" (UN 2002b).

Twenty years after the Earth Summit, the United Nations returned to Rio de Janeiro for the 2012 UN Conference on Sustainable Development (commonly referred to as Rio+20). Rio+20 focused on building green economies and

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coordinating international sustainable development activities. The outcome was a nonbinding document titled "The Future We Want" (UN 2012). Two sections of this document specifically address the mining industry: paragraphs 227 and 228.

Paragraph 227 acknowledges the importance of mining and calls for government regulation of sustainable mining development. It states "…mining activities should maximize social and economic benefits, as well as effectively address negative environmental and social impacts. In this regard, we recognize that governments need strong capacities to develop, manage and regulate their mining industries, in the interest of sustainable development" (UN 2012).

Paragraph 228 elaborates on the need for effective governance of mining, recognizes the role of businesses, and calls for greater transparency. It affirms "…the importance of strong and effective legal and regulatory frameworks, policies and practices for the mining sector that deliver economic and social benefits and include effective safeguards that reduce social and environmental impacts, as well as conserve biodiversity and ecosystems, including during post-mining closure," and then "call(s) upon governments and businesses to promote the continuous improvement of accountability and transparency…" (UN 2012).

SUSTAINABILITY AS A BUSINESS CONCEPT

The business world traditionally concerned itself only with the economic bottom line. The environmental movement of the 1960s led to the creation of regulatory bodies charged with protecting the environment in developed countries, such as Environment Canada in 1971 and the U.S. Environmental Protection Agency in 1970. These regulators created environmental rules that required businesses to mitigate their environmental impacts, but little consideration was provided for social impacts of businesses.

Sustainability as a business concept was introduced through the work of John Elkington, who coined the phrase "triple bottom line" (TBL) to refer to a new means of business accounting that considers social, economic, and environmental impacts and risks when making business decisions. In 1998, Elkington's book *Cannibals with Forks: The Triple Bottom Line of 21st Century Business* advised the business world to adopt the TBL approach as a means to consider social and environmental impacts within business decisions. Since then, this trifecta of society, the economy, and the environment has often been referred to as the "three pillars" of sustainability. For truly sustainable development to occur, social, environmental, and economic impacts must all be considered. From a business standpoint, sustainability can be viewed as including social and environmental risk management in financial risk considerations. Risk management does not assume that all risks can be identified or even quantified. Rather, risk management seeks to recognize significant foreseeable risks or impacts, identify those that are feasibly controllable, select those impacts and risks a company and its stakeholders want controlled,

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quantify the cost of these programs, and then make strategic business decisions about which social and environmental risks and impacts to address through sustainability programs. In the context of extractives, sustainability efforts become an exercise in reducing and managing potential social, economic, and environmental impacts and their associated risks.

Social, economic, and environmental risks and impacts of mining operations are widely varied and site specific. Each mining operation must analyze the risks and impacts to the company and its external stakeholders. Some general examples are provided here to assist the reader, but this is by no means a comprehensive list.

Possible economic risks and impacts of mining projects include the following:

- Financial risks to the operation, such as the price of the commodity or fuels
- High-paying jobs for the community
- Economic impacts to associated businesses serving the mine in a community
- Loss of economic value of land for other uses, such as ecotourism or farming during the life of mine
- Increased tax revenues gained by local governments, as applied to the ore extraction, land leasing, or local sales

Examples of social risks and impacts when developing a mine include the following:

- Increased disease risk to a community due to the influx of workers from outside an area
- Improved medical care due to nursing or medical staff provided for workers and the community
- Increased opportunities for education in workers' training programs
- Improvement in local government services (schools, parks, drinking water, etc.) due to an increase in funds from tax revenue
- Improved local infrastructure (roads, electricity, etc.) during life of mine and responsibility for those assets postmining
- Impacts to local cultures that may have fishing, hunting, gathering, religious, or recreational ties to land impacted by mine developments

Within mining projects, environmental risks and impacts may include the following:

- Biodiversity impacts caused by land disturbance
- Postclosure land reclamation
- Water quality impacts to groundwater and surface water
- Water quantity impacts to groundwater and surface water
- Fugitive air emissions, such as dust from haul roads
- Point-source air emissions from processing plants

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DIFFUSION OF SUSTAINABILITY CONCEPTS INTO THE MINING INDUSTRY

The wide range of social, economic, and environmental risks and impacts previously listed illustrate the challenges for the mining industry in addressing sustainability issues. As the UN efforts to implement sustainable development objectives have progressed, the mining industry has responded, exploring how mining practices could be modified to better manage social and environmental impacts.

When considering the Brundtland definition of *sustainable development* as that which "meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987), it may seem difficult to apply the term *sustainability* to mining. The extraction of nonrenewable resources obviously leaves less of the resource for future generations. Of course some mined materials (such as metals) can be recycled and reused, and the industry is promoting and developing new recycling methods to maintain the amount of metal available for manufacturing in the future. But even when recyclable metals are reused, their underground reserves are limited. Other mined materials (such as coal and bituminous oil sands) are consumed in their use, leaving less for future generations. Despite the fact that the Brundtland definition of sustainability does not strictly fit extractive industries, the mining industry recognized the need for efforts to address the social, economic, and environmental risks and impacts of developing nonrenewable resources. Over time, various industry programs began to define the unique sustainability objectives for mining.

As the international dialogue about sustainable development gained prominence, the mining industry began to organize to respond to criticisms and support development of more socially and environmentally responsible practices. Following the first UN Conference on Environment and Development in 1992, nine of the largest metals and mining companies formed the Global Mining Initiative (GMI) to address mining's role in sustainable development.

The GMI has been credited with the original use of the term *sustainable mining* in 1998 (Whitmore 2006). The phrase *sustainable mining* has been criticized as an oxymoron (Kirsch 2010), but use of the term *sustainable* in extractives is not meant to invoke the Brundtland definition of sustainability. Clearly, extractive industries leave fewer nonrenewable resources for future generations by their very nature. The term *sustainability* applied to extractive industries utilizes Elkington's TBL concept of accounting for social, economic, and environmental impacts and risks. Sustainable mining implies that companies can identify and rank the most relevant social, economic, and environmental risks and plan strategies to manage potential impacts. However, some prefer to use other terms, such as *responsible mining* or *corporate social responsibility*, to avoid implication of the Brundtland definition.

To deepen understanding of the social and environmental risks and impacts of mining, in 2000 the GMI created the Mining, Minerals and Sustainable

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Development (MMSD) project. MMSD was designed as a broad based multi-stakeholder process, with regional partnerships to research and consult with stakeholders on mining and sustainable development within North and South America, South Africa, and Australia. Their efforts included work in 20 countries and included 23 global workshops. The results of the MMSD process highlighted some challenges for the mining sector, including viability of the industry; control, use, and management of land; local and national economic development; local communities; environmental impacts such as large-quantity wastes, acid drainage, and closure; mineral use rates and recycling; artisanal and small-scale mining; and lack of governance structures in developing countries. The MMSD report, which was presented at the 2002 Johannesburg World Summit on Sustainable Development, called for four actions (IIED 2002):

1. Greater industry action to understand sustainable development issues through further research
2. The creation of sustainability policies and management systems within companies, which might be required by governments or encouraged by NGOs
3. Building capacity for effective actions, with recommendations at the community, national, and global levels
4. Cooperation among those interested in sustainable development in the mining sector, which leads to the development of protocols for sustainable mine development, perhaps though the International Council on Mining and Metals (ICCM)

The ICMM was formed in 2001 by the GMI with the intent of improving sustainable development performance within the mining industry. It is a voluntary industry organization with members that include national and regional mining associations and major mining and metals companies. The ICMM created the Sustainable Development Framework (SDF) based on the results of the MMSD project. All members are required to implement the ICMM's SDF.

The SDF includes 10 principles and seven supporting position statements that ICMM members are required to integrate into their corporate policies as commitments regarding their sustainable development practices. The 10 guiding principles were adopted in 2003 as the foundation of the SDF:

1. Ethical business practices and corporate governance
2. Consideration of sustainable development in decisions
3. Respect for human rights and cultures
4. Risk management
5. Health and safety
6. Environmental performance
7. Biodiversity conservation and land-use planning
8. Responsible product life cycle, including re-use and recycling

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9. Contributions to social, economic, and institutional development in communities
10. Transparent engagement, communication, and externally verified reporting with stakeholders (ICMM 2003a)

Over the years, several position statements have been released by the ICMM to clarify the commitments members make in the 10 principles. The ICMM released guidance on mining and protected areas to address environmental performance, biodiversity, and land-use planning (ICMM 2003b). The position statement on mining and Indigenous peoples provides further information on respecting human rights and cultures (ICMM 2008). Mercury risk management guidance addresses risk management, environmental performance, and responsible product life-cycle considerations (ICMM 2009a). The position statement on transparency in mineral reserves pertains to ethical business practices and corporate governance (ICMM 2009b). Guidance on partnerships for development further addresses contributions to social, economic, and institutional development in communities (ICMM 2010). A brief on climate change policy and design principles is meant to assist companies with risk management and environmental performance (ICMM 2011). Together, these position statements further expound on the original 10 guiding principles. More details on the ICMM SDF are presented in Chapter 1.

Demonstrating their commitment to transparent public reporting, the ICMM worked with the Global Reporting Initiative (GRI) to develop sustainability reporting practices for the metals and mining sector. The GRI is a nonprofit organization that has developed global standardized sustainability reporting protocols across industries. In 2005, ICMM members committed to using the GRI's protocols for public reporting on sustainability performance.

The GRI reporting framework was developed with input from stakeholders representing civil society, business, mediating institutions, academia, labor, public agencies, and intergovernmental organizations. The reporting guidelines are regularly revised and include public comment periods. Standard disclosure information in each GRI report includes information describing a company and its governance structure. The guidelines include a series of indicators developed to assist companies in self-reporting on the broader topics of social (labor practices and decent work, product responsibility, and human rights), economic, and environmental performance. Within each broader topic, several indicators exist that a company can choose to report to the public. These indicators are meant to provide information for comparing performance across companies or operations. The mining and metals sector–specific guidance includes indicators that were developed uniquely for the mining industry. Using the GRI reporting format, a company selects which and how many of the indicators they will report. They are not required to report on all the GRI indicators. Thus, the information provided by one company may not be provided by another. The GRI reporting system does promote transparency

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in reporting; however, scores indicate the amount of information a company is reporting to the public but not how well they are actually performing with regard to each indicator. GRI scores do not provide an overall ranking for company or facility performance to compare across the industry. Additional detail about the GRI's reporting framework is included in Chapter 2.

National mining industry organizations in Australia and Canada have played an important role in efforts to integrate sustainability concepts into mining industry practices. The Minerals Council of Australia (MCA) requires all of its members to issue sustainability reports, using GRI or a self-developed framework, through its Enduring Value Framework (EVF) to address sustainable development. The MCA is an industry association with the self-proclaimed objective "to advocate public policy and operational practice for a world-class industry that is safe, profitable, innovative, environmentally and socially responsible, attuned to community needs and expectations" (MCA 2013). MCA's Environmental and Social Policy Committee was established to serve members addressing environmental, social, and wealth creation issues as a part of its approach to sustainable development. MCA's efforts with regard to sustainable development focus on two goals:

1. "An Australian minerals industry enhancing value for stakeholders and the broader community through sustainable practices; and
2. Commitment by the Australian minerals industry to sustainable development through wealth creation, environmental leadership and socially responsible development, which is acknowledged by key stakeholders and decision-makers" (MCA 2013).

MCA's framework for sustainable development, Enduring Value, was developed in 2005 in response to ICMM's 2003 sustainable development principles (MCA 2005). The EVF builds on the Australian Minerals Industry Code for Environmental Management developed in 1996. All MCA members must sign a pledge of commitment to the principles and elements of the EVF, though it is open to more than just MCA members. The EVF applies to exploration, mining, and processing activities of signatories. In essence, the EVF requires

- Progressive implementation of the ICMM principles and elements;
- Public reporting of site-level performance, on a minimum annual basis, with reporting metrics self-selected from the GRI, the GRI Mining and Metals Sector Supplement, or self-developed; and
- Assessment of the systems used to manage key operational risks (using either internal or external assessment, as appropriate) (MCA 2005).

To support their efforts for sustainable mineral development, MCA has also issued a Memorandum of Understanding with the Australian government on Indigenous Employment and Enterprise Development and policy statements on biodiversity offsets, land stewardship, and water. Due to the significant water

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concerns in arid Australia, the MCA also has a water accounting framework to standardize water accounting across member companies. These efforts of the MCA are discussed in further detail in Chapter 3.

MCA members are not alone in sustainability reporting within the mining industry. Most publicly traded mining companies issue some sort of sustainability report or information online. These are often referred to as corporate social responsibility (CSR) reports and may or may not follow GRI reporting guidelines. A 2006 study of the top 10 mining companies' CSR reporting revealed such a wide range of sophistication of reporting and metrics used that the reporting results could not be applied to compare performance among companies (Jenkins and Yakovleva 2006). In essence, the industry still lacks a global metric to rank mining companies by performance on sustainability. However, within Canada, one program is ranking mining companies on sustainability performance, the Mining Association of Canada's (MAC's) Towards Sustainable Mining (TSM) program.

MAC's efforts to address sustainability began with the 1993 Whitehorse Mining Initiative (WMI), an effort to provide a national roundtable for environmental groups, labor groups, Aboriginal groups, miners, and regulators. The WMI effort was criticized for lack of any monitoring, verification, or reporting on performance by the companies (Fitzpatrick et al. 2011). Having learned from its past, before developing the TSM program, MAC researched the public concerns of sustainability with regard to the mining industry by meeting with community leaders across Canada from 1998 to 2002. Based on this work, MAC developed the TSM program, which launched in 2004, with four original protocols covering tailings management, energy and greenhouse gas emissions, crisis management planning, and external outreach. A community of interest advisory panel, composed of industry representatives and external stakeholders, reviews the program for implementation and progress. TSM was created as a dynamic program with the intent that new protocols could be added when needed and established protocols could be revised as necessary. In 2010, protocols were added for biodiversity and health/safety, and the external outreach protocol was revised to specifically include Aboriginal and community of interest engagement.

The TSM program is mandatory for MAC members to implement at Canadian operations, and it is encouraged to be implemented at operations worldwide. TSM requires specific systems to be developed under each protocol and assigns a letter grade based on meeting MAC standards and performance. The TSM program is discussed in greater detail in Chapter 4.

The following four chapters explore the efforts to address the social and environmental risks within mining by the ICMM, GRI, MCA, and MAC in greater depth.

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CHAPTER 1

The International Council on Mining and Metals: Sustainable Development Framework

Nadine Czoschke, Shiela Ugargol Keefe, and Michelle E. Jarvie-Eggart

INTRODUCTION

Since its inception in 2001, the International Council on Mining and Metals (ICMM) has worked to define sustainable development in the context of mining. Through its membership of international mining companies and mining associations throughout the world, ICMM has worked to establish a global consensus on the most significant issues to the industry. ICMM has established a Sustainable Development Framework (SDF), the foundation of which is its "10 Principles for Sustainable Development" to which all members must commit and integrate within their business practices. To support the 10 principles, ICMM has issued position statements clarifying member commitments on topics such as climate change, partnerships for development, transparency in minerals reporting, mercury risk management, Indigenous peoples, and protected areas. ICMM has also established work programs on social and economic development, climate change and the environment, health and safety, and materials stewardship. ICMM has published position statements and produced toolkits to assist their members in addressing these issues. ICMM members are also required to use the Global Reporting Initiative's guidelines to report on their social, economic, and environmental impacts, and provide third-party assurance for sustainability reporting.

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HISTORY OF ICMM

In late 1991, 30 prominent international mining and minerals companies created the International Council on Metals and the Environment (ICME) with the purpose of giving the mining industry "an international voice on environmental matters" (Hodge 2011). Working through the World Business Council for Sustainable Development, the ICME initiated the Global Mining Initiative (GMI) in 1999. One purpose of the GMI was to prepare the mining sector for the World Summit on Sustainable Development. The GMI resulted in the development of the Mining, Minerals and Sustainable Development (MMSD) project, meant to "undertake a global review that could lead to the identification of how mining and minerals can best contribute to the global transition to sustainable development" (Hodge 2011).

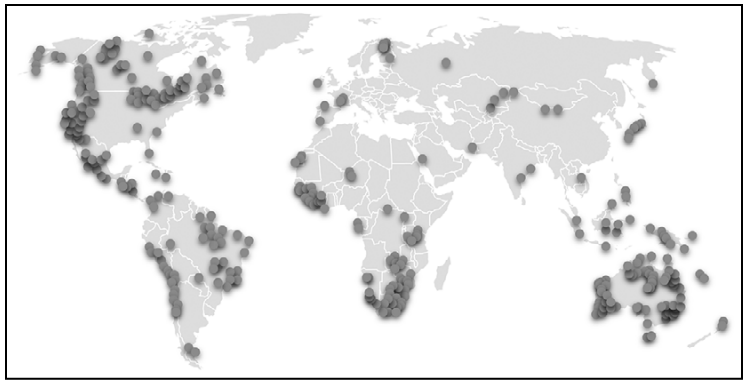
The MMSD project released the *Breaking New Ground* report in 2002 (IIED 2002). However, before this report was released, the participants of this project saw the need to form the ICMM. To make this happen, in 2001, the ICME board agreed to broaden the ICME mandate and transform into the ICMM with a secretariat based in London.

The ICMM was formed "to represent the world's leading companies in the mining and metals industry and to advance their commitment to sustainable development" (ICMM 2013b). The ICMM provides members a platform to work together to further the sustainable development contributions of the mining sector and the minerals and metals industry. This mission is carried out through members' commitments to sustainability principles as well as via projects and work programs (ICMM 2013a). The purpose of the ICMM was to "represent the world's leading companies in the mining and metals industry to advance their commitment to sustainable development" (ICMM 2013b). In 2003, the ICMM council adopted the 10 guiding principles that formed the first element of ICMM's SDF.

ICMM MEMBERSHIP AND GOVERNANCE

The ICMM is composed of corporate members and member associations. The ICMM unites members from more than 20 of the world's leading mining and metals companies, including Anglo American, Barrick, BHP Billiton, Freeport-McMoRan Copper and Gold, Newmont, Rio Tinto, and Teck, among others (ICMM 2013k). ICMM companies are responsible for about 50% of the world's copper and platinum group metals, and about 40% of the world's iron ore, nickel, and gold (ICMM 2013k). In addition to mining companies, the ICMM also has mining and minerals associations as members. Currently, more than 30 member associations belong to the ICMM, located worldwide (ICMM 2013m), including the Minerals Council of Australia, the Mining Association of Canada, and the National Mining Association (in the United States).

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Figure 1.1 Map of ICMM operations

ICMM members operate at about 800 sites in more than 60 countries around the world (Figure 1.1). The sites include prefeasibility exploration, mines under construction, operating mines, temporarily closed mines, refineries, and smelters (ICMM 2013k). The dots on the map in Figure 1.1 may represent multiple operations in a concentrated area.

The ICMM is governed by a council composed of the CEOs of all member companies. The council meets twice each year and formulates policy, determines priorities, and sets the strategic direction of the ICMM. Member engagement and communications, however, are primarily through the Principal Liaisons Committee. This committee is composed of nominated representatives from all member companies and meets four times each year. The Principal Liaisons Committee is responsible for the budget and implementation of ICMM programs. The Associations Co-ordination Group supports the Principal Liaisons Committee and the council with input regarding common strategic issues. Program committees support the work programs and projects, which are the vehicle through which ICMM members and working groups communicate and participate in the organization. Figure 1.2 shows a simplified organizational chart of ICMM. The ICMM also has a staff of specialists that represents the views and interests of members. This staff works with member companies to promote good practices in sustainable development and serves as the primary point of contact for stakeholders in the international community.

The ICMM's efforts surrounding sustainability are consolidated in its Sustainable Development Framework (SDF). The SDF has three main components: 10 Principles for Sustainable Development (supported by position statements and work programs), sustainability reporting following Global Reporting Initiative (GRI) requirements, and the ICMM assurance procedure (Fonseca 2010).

Although membership in the ICMM is voluntary, all ICMM members are required to implement the SDF as follows (ICMM 2013l):

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Figure 1.2 ICMM organizational chart

1. Integrate the 10 sustainable development principles and supporting positions into their corporate policy.
2. Report on progress with implementing the principles and position statements in annual sustainable development reports in accordance with the GRI guidelines, including the GRI *Mining and Metals Sector Supplement* (GRI 2013b).
3. Provide third-party assurance of their sustainability performance from an independent auditor. The auditor must review and assess the quality of the ICMM member's reports, systems, and processes as compared to ICMM's assurance procedure.

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All ICMM member companies must show they are meeting their membership requirements in an annual public report. The ICMM has conducted a yearly assessment of member companies since 2010 to see if they are meeting their commitments. If a company is not meeting its commitments, ICMM will work with the member company to help make changes in the future. If there are continuing problems, the ICMM Council of CEOs reviews the company's membership. The council can suspend or expel a member company with the support of a 75% majority of council members. If the ICMM receives a complaint about a member company, ICMM immediately refers the complaint to the company involved. Although ICMM does not provide a forum for conflict resolution, it does encourage that matters of concern be resolved.

ICMM PRINCIPLES FOR SUSTAINABLE DEVELOPMENT

The concept of sustainable development as it relates to mining practices has become more defined due in part to ICMM efforts in developing its SDF. The 10 Principles for Sustainable Development and corresponding objectives are described as follows (ICMM 2013c):

- **Principle 1:** Implement and maintain ethical business practices and sound systems of corporate governance.
- **Principle 2:** Integrate sustainable development considerations within the corporate decision-making process.
- **Principle 3:** Uphold fundamental human rights and respect cultures, customs, and values in dealings with employees and others who are affected by our activities.
- **Principle 4:** Implement risk management strategies based on valid data and sound science.
- **Principle 5:** Seek continual improvement of our health and safety performance.
- **Principle 6:** Seek continual improvement of our environmental performance.
- **Principle 7:** Contribute to the conservation of biodiversity and integrated approaches to land-use planning.
- **Principle 8:** Facilitate and encourage responsible product design, use, re-use, recycling, and disposal.
- **Principle 9:** Contribute to the social, economic, and institutional development in the communities in which we operate.
- **Principle 10:** Implement effective and transparent engagement, communication, and independently verified reporting requirements with our stakeholders.

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ICMM POSITION STATEMENTS

In addition to the 10 principles, the ICMM has produced position statements to clarify how the ICMM principles relate to specific sustainability issues, including protected areas, minerals revenue reporting, mercury risk management, partnerships for development, climate change, and Indigenous peoples (ICMM 2013d). Each ICMM position statement is described in the following paragraphs.

The "Mining and Protected Areas Position Statement" was released in 2003 and complements Principles 6 and 7. In this statement, member companies commit to respect legally designated protected areas, not explore or mine in World Heritage properties, work with the International Union for Conservation of Nature and Natural Resources (IUCN) to strengthen their system of protected area categorization, work to develop better tools for integrating biodiversity and protected areas into land-use planning, and develop best practice guidance on biodiversity conservation (ICMM 2003).

The "Transparency of Mineral Revenues Position Statement" was released in 2009 and complements Principle 1. As part of this statement, member companies commit to endorsing the Extractive Industries Transparency Initiative (EITI), which provides a global standard for disclosing the payments made by mining companies to governments, such as taxes and royalties, under the oversight of national multi-stakeholder groups. It is an effort to promote transparency and government accountability in resource-rich countries. In addition, as part of the commitment to the EITI, member companies commit to submitting an international-level self-assessment to the EITI, along with independently audited material financial payments information (ICMM 2009b).

The "Mercury Risk Management Position Statement" was also released in 2009 and complements Principles 4, 6, and 8. In this document, member companies commit to "not open any mines designed to produce mercury as the primary product," use materials stewardship to promote responsible management of mercury produced or in products, minimize point-source air emissions of mercury through the use of "cost effective best available technology," report significant point-source mercury air emissions, participate in government-led partnerships to transfer to low- to no-mercury technologies into artisanal and small-scale mining (where appropriate), encourage the development of science on mercury in the environment, and "work on an integrated multi-stakeholder strategy through ICMM to reduce and eventually cease supplying mercury into the global market once policy and economically viable long-term technological solutions for the retirement of mercury are developed" (ICMM 2009c).

The "Mining: Partnerships for Development Position Statement" was released in 2010 and complements Principle 9. In this document, ICMM member companies commit "to actively support or help develop partnerships with other stakeholder groups with the aim of enhancing the social and economic contribution of mining through development partnerships" (ICMM 2010b). For major projects, this

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includes developing "an understanding of the social and economic contribution of the project, including an analysis of the barriers that might weaken this contribution" and working with stakeholder groups to ensure "the project's full potential socio-economic contribution is realized" (ICMM 2010b).

Principles for Climate Change and Policy Design was released in 2011 and complements Principles 4 and 6. In this document, ICMM members accept their responsibility to reduce GHG emissions (ICMM 2011).

The "Indigenous Peoples and Mining Position Statement" of 2013 complements Principle 3. In this document, member companies commit to the following:

- Engage with potentially impacted Indigenous peoples to ensure that the development of mining and metals projects fosters respect for the rights, interests, aspirations, culture, and natural resource–based livelihoods of Indigenous peoples. Design projects to avoid, minimize, or compensate for adverse impacts. Ensure sustainable benefits and opportunities for Indigenous peoples through the development of mining and metals projects.
- Understand and respect the rights, interests, and perspectives of Indigenous peoples regarding a project and its potential impacts, using participatory and inclusive social and environmental impact assessments or other social baseline analyses.
- Agree on appropriate engagement and consultation processes with potentially impacted Indigenous peoples and relevant government authorities as early as possible during project planning, using methods consistent with Indigenous peoples' decision-making processes.
- Work to obtain the consent of Indigenous communities for new projects (and changes to existing projects) that are located on lands traditionally owned by or under customary use of Indigenous peoples and are likely to have significant adverse impacts on Indigenous peoples.
- Collaborate with the responsible authorities to achieve outcomes consistent with the commitments in the "Indigenous Peoples and Mining Position Statement," in situations where government is responsible for managing Indigenous peoples' interests in a way that limits company involvement.
- Companies and potentially impacted Indigenous communities should agree on reasonable tests or avenues of recourse to be applied where differences of opinion arise (ICMM 2013o).

ICMM PROJECTS AND WORK PROGRAMS

ICMM focuses its work efforts in four major program areas: social and economic development, environment and climate change, health and safety, and materials stewardship. Most work programs involve collaborative engagements and have related projects. The work programs may also develop best practice documents, guidelines, and toolkits to be used by members and other organizations. Work

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programs and projects do not define commitments or requirements of members but generally provide support materials and information to members and/or the greater mining community.

SOCIAL AND ECONOMIC DEVELOPMENT WORK PROGRAM

The social and economic development work program focuses on human rights and Indigenous peoples. This work program aims to create positive social and economic outcomes from mineral resource development in host communities. ICMM members commit to seeking partnerships that strengthen the mining sector's contribution to six priority areas as related to mining: poverty reduction, revenue management, regional development planning, local content, social investment, and dispute resolution (ICMM 2013f.) The projects associated with the social and economic development work program include the following topics:

- Human Rights
- Indigenous Peoples
- Mining: Partnerships for Development
- Community Development
- Resource Endowment Initiative
- Minerals Taxation
- Artisanal and Small-Scale Mining

Human Rights

ICMM addresses human rights as part of sustainable development through Principle 3, which is to "uphold fundamental human rights and respect cultures, customs, and values in dealing with employees and others who are affected by our activities." The topic of human rights as an element of social responsibility for the extractives industry has gained prominence, in part due to the efforts of Professor John Ruggie. In 2005, Ruggie was appointed to the position of United Nations Special Representative of the Secretary-General (UNSRSG) with a mandate to bring clarity to the issue of human rights, transnational corporations, and other business enterprises (ICMM 2014a). Ruggie's work lead to widespread acceptance of the idea that companies have a responsibility to protect human rights. During Ruggie's tenure, the United Nations produced *Guiding Principles on Business and Human Rights: Implementing the United Nations "Protect, Respect and Remedy" Framework* (UN 2011). This document examines three crucial concepts put forth by Ruggie between 2005 and 2008: the state's duty to protect human rights, the corporate responsibility to protect human rights, and access to remedy. Initial work by the ICMM focused on engaging debate around the respective roles of governments and businesses in regard to human rights.

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The ICMM has made three submissions to the UNSRSG since Ruggie's first appointment. The first, published in 2009, *Human Rights in the Mining and Metals Industry: Overview, Management Approach and Issues*, provides an overview of the main challenges and dilemmas facing companies in the mining and metals industry (ICMM 2014a). The ICMM also participated as an observer during the development of the Voluntary Principles on Security and Human Rights (VPs). The VPs were developed through dialogue between the governments of the United States and the United Kingdom, extractive and energy sector companies, and non-governmental organizations with a common interest in human rights and social responsibility (VPSHR 2014). Many core concepts of the VPs are embodied in ICMM Principle 3.

Indigenous Peoples

Mining often occurs in areas that are home to Indigenous communities. Relationships between mining and metals operations and the local communities in which they operate are often complex, particularly in areas with Indigenous peoples. Indigenous peoples may have characteristics that set them apart from the broader community and which can leave them socially and economically marginalized. The ICMM urges members to take positive steps when operations are located on or near land belonging to Indigenous groups to respect the rights of Indigenous peoples and institute programs that benefit affected Indigenous communities. In 2005, the ICMM published *Mining and Indigenous Peoples Issues Review*. This report documented how differently ICMM members and Indigenous people view their mutual issues. The report found that for many Indigenous people, their concerns are founded on troubled relationships with national governments and whether their rights will be upheld by law, specifically with regard to land rights and free prior and informed consent (ICMM 2005b). In November 2005 and January 2008, ICMM and IUCN hosted two roundtable conferences regarding Indigenous people's issues to further the process of building constructive relationships between mining companies and Indigenous peoples.

Mining: Partnerships for Development

The goal of this global initiative is to improve mining's contribution to poverty reduction and development through multi-stakeholder partnerships, with member commitments to seek partnership across six priority areas:

1. Poverty reduction
2. Revenue management
3. Regional development planning
4. Local content
5. Social investment
6. Dispute resolution

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The ICMM has identified 41 economies that have either historically or more recently relied on mining. Many of these economies are in developing countries that have high poverty levels.

Among other resources, the ICMM has developed *Mining: Partnerships for Development*, a toolkit that provides "methodologies for evaluating the positive and negative economic and social effects of mining at the local, regional, and national levels in mining countries" (ICMM 2013j), and has primarily been used in developing countries.

Community Development

The ICMM defines *community development* as "the process of increasing the strength and effectiveness of communities, improving people's quality of life and enabling people to participate in decision making to achieve greater long-term control over their lives" (ICMM 2012b). Community development can be supported by contributing local assets such as social, economic, and environmental capital, which can aid poverty reduction and sustainable development at the community level. Mining projects can be positive for communities and provide employment and infrastructure that can support community development in areas such as education and healthcare programs. The aim of the ICMM community development project is to ensure that programs are designed to deliver what the local community wants and needs and provides benefits to the community long after closure of the mine.

The ICMM developed the *Community Development Toolkit* in 2005 and updated it in 2012 (ICMM 2012b), in partnership with the World Bank, with funding support from the Energy Sector Management Assistance Programme. The toolkit is designed to help ICMM members build good relationships with communities and create a lasting, positive impact. It is intended to help groups move beyond the donor/recipient model of community relations and establish community development programs that strengthen local capacities and are mutually beneficial to the mining company and the community. Implementing the toolkit depends on significant stakeholder participation to develop a strategic approach that is aligned with the community's long-term goals. The ultimate goal is to work in partnership with communities and existing organizations to provide the lasting local benefits desired by the community.

Resource Endowment Initiative

The Resource Endowment Initiative (REI) was a three-phase study on the economic and social impacts of mining through comparative research across 33 countries, with a focus on the developing world. In 2004, Phase 1 developed the *Resource Endowment Toolkit* to assess the local, regional, and national socioeconomic impacts of mining, to provide a systematic approach to documenting impacts of mining

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projects (ICMM 2008d). Phase I of the REI also performed a literature review and comparative analysis of 33 countries with a high dependence on minerals to identify the key factors that can contribute to the successful transformation of mineral endowment into development that is truly sustainable. A multi-stakeholder workshop was held to critique the initial findings of Phase I.

In 2005, Phase 2 tested the *Resource Endowment Toolkit* in Peru and Ghana where mining was believed to contribute to economic and social improvements. Feedback on the results of Phase 2 was collected at a multi-stakeholder workshop. From 2006 to 2010, Phase 3 involved workshops and pilot studies in Peru, Ghana, and Tanzania to disseminate the initiative's findings and recommendations (ICMM 2014b). One of the primary findings of the REI was that multi-stakeholder partnerships can be a powerful way to overcome development challenges and enhance the positive impacts of mining.

Minerals Taxation

The ICMM's work around minerals taxation is an extension of previous work in the REI. In 2009, the ICMM published *Minerals Taxation Regimes: A Review of Challenges in their Design and Application* with the assistance of an independent advisory group of tax experts from the public and private sectors. As a result of this report, the ICMM formed a tax network to meet regularly and discuss mineral taxation issues and promote policies regarding minerals taxation. In 2012, ICMM members consulted with the International Monetary Fund during their development of a paper on natural resource taxation (ICMM 2014c).

Artisanal and Small-Scale Mining

Artisanal and small-scale mining (ASM) is a form of subsistence mining most often encountered in the developing world. ASM may take place near active or developing corporate mines. It often creates unique local issues due to poor environmental, health, and safety practices; security issues; illegal mineral trade; and child and forced labor. Under Principle 9, ICMM members commit to the social, economic, and institutional development of communities. When ASM is a part of local communities, the economic and safety needs of the artisanal miners must be considered. In 2009, ICMM partnered with Communities and Small-Scale Mining and the International Finance Corporation (IFC) to develop methods for working with ASM operators. They issued the report *Working Together: How Large-Scale Mining Can Engage with Artisanal and Small-Scale Miners* (as cited in ICMM 2014d). Although this report might still be used by mining companies for developing or operating projects, ASM is not an active project of the ICMM (ICMM 2014d).

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ENVIRONMENT AND CLIMATE CHANGE WORK PROGRAM

ICMM members commit to work toward a low-carbon economy (ICMM 2013g). Three focus areas have been identified as being of importance to the mining and metals industries: national climate policies and competitiveness; land use and adaptation to climate change impacts; and measurement, reporting, and verification of GHG emissions. To improve their environmental and climate change performance, ICMM members agree to

- Develop strategies to reduce GHG emissions and implement emission reduction opportunities,
- Use natural resources efficiently,
- Support research and development of industry-appropriate low-GHG emission technologies, and
- Measure progress and report results.

The 2013 ICMM report *Adapting to a Changing Climate: Implications for the Mining and Metals Industry* outlines how the mining and minerals industry is affected by climate change and what options the sector has to adapt to these impacts (ICMM and IUCN 2013).

In addition to commitments regarding climate change, ICMM members make commitments to protect global cultural resources. In 2003, ICMM members committed to not exploring or mining World Heritage Properties. However, a good portion of the environment and climate change work program focuses on three project areas: water, mine closure and legacy, and biodiversity.

Water

Water is a basic human necessity and continues to be an international concern. Population growth, economic development, and climate change are key factors that impact the availability of water. Addressing the fact that almost 900 million people worldwide do not have access to clean water, in July of 2010, the United Nations stated that safe and clean drinking water and sanitation is a basic human right essential to the full enjoyment of life and all other human rights UN 2010). Water issues are specifically relevant to the mining industry because

- Water scarcity, pollution, and competition issues are growing in importance in many regions around the world; and
- The issues around water can present a real business risk to the success of mining operations (ICMM 2013i).

The ICMM has identified water accounting as a priority (ICMM 2013i) and is exploring common tools to understand the water balance at mining sites and to help operations communicate more effectively about water. To achieve these goals, the ICMM published a document in 2012 titled *Water Management in Mining:*

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A Selection of Case Studies to illustrate good practices in water resource management (ICMM 2012c).

Mine Closure and Legacy

The planning and execution of a mine closure may have long-lasting effects on a mining company's reputation and social license to operate. The ICMM has two focus areas regarding mine closure: financial assurance and better planning for closure. In 2005a, the ICMM published a guidance report titled *Financial Assurance for Mine Closure and Reclamation*, recommending actions by operators and governments to improve standards of practice.

As a result of earlier studies indicating the need for consistent implementation of good practices surrounding closure, in 2008 the ICMM developed the *Planning for Integrated Mine Closure: Toolkit* to assist those who manage and implement mine closure (ICMM 2008b). The toolkit includes 13 tools, some of which have been developed as stand-alone tools by other ICMM projects, covering topics such as stakeholder engagement, community development, risk/opportunity assessment, knowledge mapping, goal setting, cost risk assessment, change management, and biodiversity management.

Biodiversity

Biodiversity encompasses the variety of life in terrestrial, aquatic, and other environments. It is considered important to human life on Earth and may be of special importance to people who lead a subsistence lifestyle or have cultural or historical values associated with the biodiversity in natural environmental systems. The ICMM council recognized in 2003 that biodiversity conservation and enhancement was an important issue for metals and minerals mining companies, for not only moral but also business reasons. Through Principle 7 in the ICMM Sustainable Development Framework, ICMM members make the commitment to "contribute to conservation of biodiversity and integrated approaches to land use planning." Mining companies need access to land. Maintaining the intangible social license to operate from the communities in which they work may depend on biodiversity conservation policies. Additionally, access to capital may be influenced by a company's biodiversity management policies because many international banks are signatories of the Equator Principles, which include a Biodiversity Performance Standard (Equator Principles Association 2013).

In 2006, the ICMM, in collaboration with the IUCN, developed a guide titled *Good Practice Guidance for Mining and Biodiversity (GPG)*. The GPG has identified ways in which every stage of a mining project may impact biodiversity and suggests methods and tools for management, mitigation, and/or rehabilitation for each of these stages (ICMM 2006a). Biodiversity is covered in GPG through the use of stakeholder engagement, environmental management systems, mitigation

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and rehabilitation tools, and environmental and social assessment at any stage in a project's life cycle, exploration through closure.

The environmental and social impact assessment (ESIA) may be used as a tool to integrate biodiversity issues into project planning and decision making. In many developed countries, an ESIA or similar assessment is a regulatory requirement. ICMM guidance in the GPG recommends that biodiversity considerations be included in each component of an ESIA (ICMM 2006a). The exploration and feasibility stages of a mining project require the most input via the ESIA process.

Tools used for rehabilitation, mitigation, and enhancement of biodiversity resources are suggested by the GPG. Avoidance of impacts through changes in location or design is the preferred method. Minimizing impacts through decisions and actions, such as water treatment or access road rerouting, is also an option. Mitigation of impacts through rehabilitation is a less desirable option, and compensation through offsets is a final option when all other options have been considered (ICMM 2006a).

In 2013, the ICMM developed a discussion paper on biodiversity offsets in collaboration with the IUCN (ICMM 2013r). The ICMM and IUCN have also partnered to produce two volumes of case studies regarding biodiversity conservation in mining projects around the world to illustrate approaches, processes, tools, and scientific knowledge used by some companies in their biodiversity conservation efforts (ICMM and IUCN 2004a; ICMM 2010a.)

HEALTH AND SAFETY WORK PROGRAM

The health and safety work program is concerned with assessing and managing risks and hazards to human health and safety of employees in mining and minerals companies and people in host communities. This work program encourages collaborative actions and transparent information sharing to improve the health and safety performance of member companies (ICMM 2013h.) Projects associated with this work program are as follows:

- Flight Safety
- Leading Indicators
- Preventing Fatalities
- HIV/AIDS, Tuberculosis, and Malaria
- Health Impact Assessment
- Occupational Exposure Limits for Metals
- Health and Safety Conference
- Emergency Response

Flight Safety

Because of the remote locations of many mining operations, mining companies often rely heavily on the use of chartered aircraft to move workers to and from

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operations. The ICMM encourages the use of the Basic Aviation Risk Standard (BARS) as a common safety audit standard for aviation among its members. BARS was developed by the Flight Safety Foundation in conjunction with a number of extractive industry companies, including several ICMM members, for improving aviation safety in the extractive industries. BARS can be used to review existing flight safety requirements or for the development of new ones within a company (ICMM 2014e).

Leading Indicators

Many health and safety performance indicators are based on post-incident statistics or accident reports. Since these provide an indicator of safety after an incident has occurred, they are called lagging indicators. Leading indicators are those that can be monitored to indicate safety performance before an incident or accident takes place. Leading indicators are desirable because they allow a company to take proactive steps to manage safety to avoid incidents and accidents. However, appropriate leading indicators may vary between commodities and companies. The ICMM has a long-term goal of developing a suite of core leading indicators for use by metals and mining companies. An initial workshop on the subject was held by the ICMM in March 2011 (ICMM 2014f).

Preventing Fatalities

The ICMM's goal is zero fatalities at its members' operations, including employees and contractors. In 2009, the ICMM published *Leadership Matters: Eliminating Fatalities* to assist senior leaders in increasing workplace safety through established processes and personal actions (ICMM 2009d). In 2010, the ICMM followed this document with *Leadership Matters: Managing Fatal Risk Guidance*, written for operation-level managers and including self-diagnostics to assist in identifying gaps in safety management systems (ICMM 2010c). Future work will examine the causes of fatalities at mining and metals operations to provide guidance on how they can be avoided.

HIV/AIDS, Tuberculosis, and Malaria

For ICMM member operations in the developing world, there can be significant workforce exposure to HIV/AIDS, tuberculosis, and malaria. In 2008, the ICMM published *Good Practice Guidance on HIV/AIDS, Tuberculosis and Malaria* to provide disease management information for company managers (ICMM 2008a).

Health Impact Assessment

Health Impact Assessments (HIAs) are used to help identify the potential effects of a mining or metals project on the heath of a local population, so that any effects can be managed. They are generally recognized as a part of the overall impact assessment process required by the World Bank and the IFC. As such, HIAs are

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increasingly integrated into the project screening and development process. The ICMM encourages the integration of heath assessments with ESIAs. In 2010, the ICMM developed *Good Practice Guidance on Health Impact Assessment*, explaining the HIA process, providing a template for a rapid health impact analysis, and supplying information on managing and following up on community health and well-being impacts (ICMM 2010d).

Occupational Exposure Limits for Metals

National governments often set exposure limits for common substances, but the limits vary around the world. Multi-national mining and metals companies may experience workforce confusion over appropriate standards, especially those who may work in different countries. The ICMM promotes systematic methods of evaluating data, as well as standardized ways to assess the risks of exposures and resultant health effects. In 2005, the ICMM and the Institute of Environment and Health held an international workshop for regulatory scientists, academics, and industry representatives, which led to the report, *Towards a Harmonized Approach to Setting Occupational Exposure Limits* in 2006 (ICMM 2006b). Then in 2007, the ICMM established a database of agents and materials of concern for the minerals sector, called the REACH Metals Gateway (ICMM 2007).

Health and Safety Conference

In 2006, the ICMM held its first Health and Safety Conference in Johannesburg, South Africa. This conference was followed by a second one in 2012 in Santiago, Chile, with the intent of sharing lessons learned from successes and challenges. In 2013, the ICMM published a report of the 2012 conference, including messages from chief executives, discussion and debate points, and key messages from each session (ICMM 2013p).

The ICMM has also been working with IPIECA (the global oil and gas industry association for environmental and social issues) and the International Association of Oil and Gas Producers on the subject of fatigue management. These organizations held a workshop on the topic in Johannesburg, South Africa, in 2011, and another in Perth, Australia, in 2012. These workshops discussed the development and implementation of Fatigue Management System, technological developments in fatigue management, and the practical implementation of tools for fatigue management for extractive industries. Summary reports from both of these workshops have also been issued (ICMM 2012d, 2013q).

Emergency Response

It is essential that companies and the communities in which they operate are prepared to respond effectively to an emergency. With the support of the United Nations Environment Programme (UNEP), the ICMM published a 2005 report

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titled *Good Practice in Emergency Preparedness and Response* (Emery 2005). This report is designed to help companies work with communities and local authorities in preparing for possible emergencies, and suggests a number of practice measures to help prevent emergencies and to deal with problems efficiently and effectively. The goal of this project is that ICMM members and host communities will be better prepared in the unlikely event of an accident, and that communities and regulators have a greater appreciation of the company's emergency preparedness and foresight.

MATERIAL STEWARDSHIP WORK PROGRAM

The triple-bottom-line approach to managing the mining sector's social, economic, and environmental impacts is usually referred to as *materials stewardship*. For the mining industry, materials stewardship includes both process stewardship and product stewardship. *Process stewardship* involves designing the activities to explore, extract, and refine metals and minerals using methods that minimize environmental impacts and health and safety risks. *Product stewardship* includes activities that reduce or minimize the environmental, health, and safety risks of the use of minerals and metals; and enabling of the reuse, recovery, and recycling of these metals and minerals.

The materials stewardship work program emphasizes appropriate extraction of metals and minerals as well as minimization of the impacts of materials used in the supply chain. The materials stewardship work program currently has two projects: chemicals management, and sustainable consumption and production.

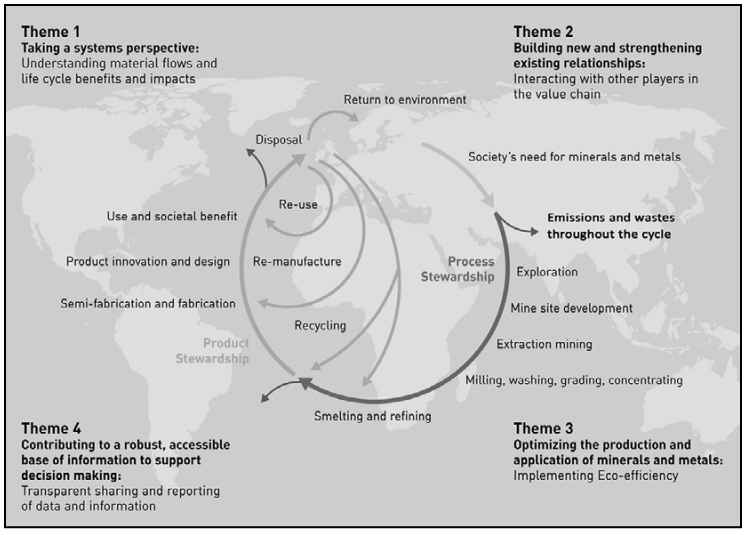
Chemicals Management

The ICMM addresses materials stewardship by advocating a strategic approach based on the UN's Strategic Approach to International Chemicals Management (SAICM). The goal of SAICM is for all chemicals, including metals and minerals, to be produced and used such that adverse environmental and health impacts are minimized (ICMM 2009a). In 2012, the ICMM released *Minerals and Metals Management 2020: A Chemicals Management Progress Report*, summarizing goals for 2020 and progress on helping members meet those goals. This progress includes publication of the Metals Environmental Risk Assessment Guidance (MERAG) and Health Risk Assessment Guidance for Metals (HERAG); a partnership with the UNEP/SETAC (Society of Environmental Toxicology and Chemistry) Life Cycle Initiative to improve life-cycle impact assessment for metals; mercury stewardship efforts; and the ICMM Health and Safety Conferences (ICMM 2012a).

Sustainable Consumption and Production

The ICMM describes the concept of materials stewardship as related to the minerals and metals life cycle using four themes: taking a systems perspective, building and

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Figure 1.3 Mining life cycle and themes of materials stewardship in mining

strengthening existing relationships, optimizing minerals and metals production, and contributing to a base of information to support decisions (see Figure 1.3). In addition, the ICMM has identified 23 priority actions in response to these themes (ICMM 2009a).

ICMM activities have addressed most, but not all, of these priority actions to varying degrees. These action items have been addressed at an organizational level through guidance publications, partnerships, creation of toolkits and models, participation and organization of workshops and conferences, and research sponsorship (ICMM 2012a). Notable publications include the MERAG and HERAG.

REPORTING AND ASSURANCE OF ICMM MEMBERS

ICMM members must report on their progress in implementing the 10 Principles for Sustainable Development using the Global Reporting Initiative (GRI) reporting framework. The GRI reporting framework provides protocols and guidelines regarding how to report against specific indicators, including social, economic, and environmental aspects related to sustainable development. In 2004, the ICMM participated in a joint working group with the GRI to develop the *Mining and Metals Sector Supplement* (MMSS) to the GRI Guidelines (GRI 2013b). The MMSS guidelines standardize the content of sustainability reporting across the globe for metals and mining companies. In 2005, ICMM corporate members committed to report nonfinancial information in accordance with the GRI reporting framework. The following year, the ICMM approved a pilot procedure for third-party assurance on members' sustainability reports.

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ICMM members are required to create their sustainable development report using the guidelines in the MMSS for the self-declared application level A or A+ (ICMM 2013e). By declaring an application level, a member company indicates the extent to which the elements of the GRI reporting framework were used in preparing the sustainable development report. An A is the highest level of application of the GRI reporting standards and an A+ indicates that the application level has been externally assured (GRI 2013a). This letter only reflects report content completeness; it does not indicate the member's sustainability performance. For example, a company may have significant fines for environmental violations yet may report at the A+ level based on report content completeness, as long as those fines have been fully disclosed in the report.

Sustainability reporting has been criticized for its voluntary nature, allowing companies to self-determine the information they disclose. Arguments have been made that external assurance is essential for increasing public trust in sustainability reporting (Fonseca 2010). When the ICMM's SDF was established, it originally did not require external assurance of progress reports. As a result, it was criticized for "not providing any information as to how company performance would be independently verified and results reported to the public" (Sethi 2005). In response to these concerns, the ICMM developed an assurance procedure, based on the GRI reporting guidelines, the AccountAbility 1000 Assurance Standard (AA1000AS) and the International Standard on Assurance Engagements (ISAE) 3000 (ICMM 2008c).

Since 2008, ICMM members have been required obtain third-party assurance of their sustainability reports. An independent auditor must assess the quality of the reports and related systems and processes using ICMM's assurance procedure. Assurance for a sustainability report is for a reporting period, and assurance can be completed concurrently with the report preparation or just prior to publication. Assurance does not evaluate the sustainability performance of the company but rather assures that the sustainability report is accurate and appropriate.

Since 2010, the ICMM has conducted annual evaluations of member performance against their commitments and has published an annual review. This review primarily reports on member performance with regard to reporting on sustainability activities, as well as the ICMM's activities for the year and focus for the future. The report does not rank member performance.

ICMM PARTNERS

Creating a global consensus around sustainable development within an industry requires engagement with a variety of groups. In recognition of the need for a collaborative process, the ICMM works with many organizations as partners. The majority of ICMM projects are performed in collaboration with another organization, community, government, or other institution (ICMM 2013n).

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CRIRSCO

The Committee for Mineral Reserves International Reporting Standards (CRIRSCO) promotes uniformity in international reporting standards for mineral exploration. The ICMM provides financial and administrative support to CRIRSCO, and both organizations have agreed to promote the activities of the other as appropriate.

World Bank

The ICMM partners with the World Bank and its members in a variety of ways. Example partners within the World Bank are the International Finance Corporation (IFC) and the Oil, Gas and Mining Sustainable Community Development Fund (CommDev). The World Bank contributes to the ICMM's Resource Endowment Initiative (REI) and is a partner in publishing the *Community Development Toolkit*. The ICMM also regularly provides comments to the IFC regarding health and safety policy and guidelines.

IUCN

The IUCN and ICMM work together on issues related to biodiversity, Indigenous peoples, protected areas, legacy sites, and good practice guidance. The ICMM and IUCN signed a memorandum of understanding (MOU) that covered the period from 2004 to 2008 and included issues related to biodiversity conservation, protected areas, land-use planning, and mine legacy (ICMM and IUCN 2004b). Continued dialog between the ICMM and IUCN resulted in a most recent MOU in 2011 regarding biodiversity conservation, community interactions, and good performance practices (ICMM and IUCN 2011). Through partnership and dialog with IUCN, in 2003 ICMM members made the "no go" commitment not to explore or mine in World Heritage properties.

UNCTAD

The United Nations Conference on Trade and Development (UNCTAD) and ICMM have partnered on several projects. These include the REI in collaboration with the World Bank, and a Best Practices Website (UNCTAD 2013) in collaboration with UNEP and the United Kingdom Department for International Development.

EITI

The U.S. Extractive Industries Transparency Initiative (EITI) was formed to increase transparency regarding payments by companies to governments. Concern regarding payments to governments was identified in the MMSD report *Breaking New Ground* and may be an issue in developing and transition countries as well (IIED 2002). Partnership with EITI has resulted in several MOUs regarding the

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transparency of payments to governments. These MOUs are now superseded by the ICMM's (2009b) position statement on "Transparency of Mineral Revenues."

Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development

The Intergovernmental Forum on Mining, Minerals, Metals and Sustainable Development works on issues related to sustainable development through a variety of organizations, including the ICMM. The forum was organized by UNCTAD, United Nations Department of Economic and Social Affairs, the United Kingdom's Department for International Development, and Canada's Department of Foreign Affairs and International Trade. Much of ICMM's work supports the goals of the forum, including the *Community Development Toolkit* (ICMM 2012b) and the *Resource Endowment Toolkit* (ICMM 2008d).

CONCLUSIONS

Since its inception, the ICMM has made significant progress in identifying the issues of concern for sustainability in the mining industry, making member commitments to address these issues, and producing guidance information and toolkits to help members in addressing them. ICMM projects have increased the credibility of mining with workers, communities, and society. Through the SDF and its associated programs, the ICMM has partnered with international organizations in an attempt to create consensus on efforts to address the issues of sustainability in the mining industry. ICMM members are required to annually verify and report on their sustainability efforts and metrics. Although these reports use GRI guidelines, which are based on report content completeness, actual performance on the issues is not reported.

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CHAPTER 2

The Global Reporting Initiative: Sustainability Reporting for the Mining and Metals Sector

Michelle E. Jarvie-Eggart

INTRODUCTION

The Global Reporting Initiative (GRI) is a nonprofit organization that encourages organizations to manage their social, economic, and environmental impacts, and transparently report their performance in these areas. Sustainability reporting guidelines created by the GRI are used worldwide by organizations issuing sustainability reports, including special sector-specific guidance for mining and metals companies.

HISTORY OF THE GLOBAL REPORTING INITIATIVE

The GRI began in the 1990s as an effort of the Coalition for Environmentally Responsible Economies (Ceres), a US-based nonprofit. Ceres brings together major investors, environmental organizations, and other public interest groups to work with companies to integrate sustainability into day-to-day business practices. Initially, the GRI began as a project department within Ceres. The focus of the GRI was to create accountability to investors for companies following the Ceres Principles for corporate environmental conduct.

The Ceres Principles, established in 1989, are a 10-point code of environmental conduct to be publicly endorsed by companies:

1. Protection of the biosphere
2. Sustainable use of natural resources

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3. Reduction and disposal of wastes
4. Energy conservation
5. Risk reduction
6. Safe products and services
7. Environmental restoration
8. Informing the public
9. Management commitment
10. Audits and reports (Ceres 1989)

From the onset of establishing the GRI, the approach has been to include stakeholders from a broad group of interests and backgrounds to guide the development of the GRI. In 1998, Ceres established a multi-stakeholder Steering Committee, which advised the GRI to address more than just environmental reporting. Thus, the scope of GRI was expanded beyond the environmental emphasis of the Ceres Principles to become a broader sustainability reporting framework focused on the triple bottom line (TBL) of social, economic and environmental issues, as well as governance matters. In 2000, the first version of the *Sustainability Reporting Guidelines* was released (GRI 2000a).

In 2001, the GRI separated from Ceres and became its own organization, as advised by the Steering Committee. The GRI's sustainability reporting guidelines continued to develop with the 2002 launch of the second version of the guidelines (G2) at the World Summit on Sustainable Development in Johannesburg (GRI 2002). The United Nations Environment Programme (UNEP) strongly supported GRI, so much so that GRI was inaugurated as a UNEP collaborating organization. The Netherlands became the host country to the GRI organization with its relocation to Amsterdam. GRI remained a nonprofit, with a focus on multi-stakeholder involvement in continual development of sustainability reporting guidance. GRI has also continued to form relationships with other organizations beyond UNEP, including the Organization for Economic Co-operation and Development and the United Nations Global Compact.

Because of the focus on multi-stakeholder involvement, the GRI consulted more than 3,000 experts from civil society, business, and labor in developing the next generation of reporting guidelines, G3, which was released in 2006. GRI continues its effort to improve its guidelines. In 2011, the GRI updated the G3 guidelines as G3.1, with additional guidance for reporting on gender, community, and human rights performance of companies (GRI 2011b). Demonstrating their effort toward continual improvement, GRI launched yet another version of the guidelines, G4, in 2013 (GRI 2013a, 2013b). Like with all iterations of the GRI guidelines, generating G4 included significant stakeholder involvement from hundreds of reporters, report users, and professional intermediaries from around the world, which integrated open public comment periods on G4 priorities and draft content. In this manner, the guidelines are developed by global census of those concerned about sustainability reporting.

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WHAT IS SUSTAINABILITY REPORTING?

Within the business world, there is an increasing trend toward reporting impacts of an organization beyond the traditional financial transactions. Sustainability reporting is generally considered to be synonymous with TBL reporting, or reporting on the social and environmental impacts as well as the economic (Milne and Gray 2013). In the twenty-first century, the use of sustainability reports has been steadily on the rise. By 2007, approximately 80% of the world's largest corporations produced a social or environmental report separate from their financial reporting (KPMG 2008).

Sustainability reporting is still widely voluntary. When reports are issued, a focus is placed on transparency for social and environmental performance. Economic performance is covered in these reports, but this information is also available in standard financial disclosures to investors. Increasingly, companies are recognizing their need for the social license to operate, or the acceptance of their operation by stakeholders. Corporate stakeholder groups include internal and external stakeholders (those within and outside the business organization, respectively; Okoye et al. 2013). Research has shown that stakeholders believe that managing their needs is crucial for a long-term relationship between management and stakeholders; that disclosure of social and environmental performance improves trust among investors; and that sustainability reporting requires managers to identify key environmental and social performance indicators that serve as tools for understanding social and environmental stakeholder behavior (Okoye et al. 2013). Thus, companies may be driven to publish sustainability reports as a means of building relationships and trust with key external stakeholders. The process of developing the report can also help companies to understand key stakeholders' social and environmental concerns. Once these concerns are understood, they can be better addressed, which ultimately will improve their social license to operate. Additionally, there may be some reputational gains with direct financial consequences as a result of sustainability reporting, such as the inclusion in the Dow Jones Sustainability Indices.

Although the reputational and public relations motivations for sustainability reporting may be similar across companies, all sustainability reports are not the same. Information can vary among reports, as they are developed voluntarily, with self-determined content. Without external assurance of this information, nonverified reports can be criticized as green-washing public relations efforts. Sustainability reporting in general has been criticized because only about 40% of sustainability reports issued by larger corporations are assured by a third party (KPMG 2008). However, GRI-based reports have a much higher level of external assurance than the general population of sustainability reports. In fact, GRI reporting has become the accepted standard for organizations seeking to report on their TBL (Milne and Gray 2013). Approximately two-thirds of GRI-based reports are assured externally (Manetti and Toccafondi 2012).

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The GRI maintains a searchable Sustainability Disclosure Database of reports through its Website (GRI 2011a). According to the database, in 2013, 51 reports were issued by mining organizations using GRI reporting guidelines. In 2003, only seven such reports were issued. This database only includes those reports that are registered with the GRI. Additional companies may use GRI reporting guidelines but not register them with the GRI organization. Such growth shows that the GRI has become the standard for TBL sustainability reporting within the mining world by providing guidance on how to transparently report social, economic, and environmental impacts of mining and metals processing operations.

But some argue that reporting on TBL performance through GRI does not adequately reflect a company's actual contribution to sustaining the earth's ecology (Milne and Gray 2013) and thus does not adequately reflect the "sustainability" of a company. The GRI reporting system does not grade reporters based on progress or success in managing key sustainability indicators. Grades are based solely on reporting level, which is a measure of the number of indicators a company reports on, and will be discussed later in this chapter. The goal of GRI reporting is transparency in reporting information to the public. It is up to stakeholders to read the information and hold companies accountable for their performance.

REPORTING ASPECTS AND INDICATORS

When Ceres expanded the focus of GRI reporting to sustainability, it went beyond environmental reporting to also include reporting on economic, social, and governance performance. The content of individual sustainability reports are determined by the companies themselves and may include all of these topics. They are also referred to as TBL reports or corporate social responsibility reports. Integrated reports combine financial data with sustainability performance. Regardless of name, the GRI-based reports are meant to increase transparency with stakeholders regarding a company's performance on material sustainability issues.

To measure sustainability, a set of metrics is needed. GRI's efforts have focused on standardizing these metrics so that performance can be compared over time within a company and among companies. The *G4 Sustainability Reporting Guidelines: Reporting Principles and Standard Disclosures* (GRI 2013a) provides guidance to companies on sustainability reporting, which includes a list of various indicators that can be reported on as performance metrics, as well as standard protocols for the implementation and reporting on each indicator. Its companion document, the *G4 Sustainability Reporting Guidelines: Implementation Manual* (GRI 2013b), explains how to apply the reporting principles and prepare information for reporting.

Companies reporting on their sustainability performance determine for themselves what they will report. Some companies pick and choose from the GRI reporting requirements when developing their own reports, but if they do not meet certain GRI requirements, they cannot claim their report is "in accordance

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with" GRI guidelines. Organizations using GRI guidelines for their sustainability reports are asked to notify the GRI when the reports are issued and register the report with GRI's database.

The GRI offers two options for companies that would like to state that their sustainability reporting is in accordance with GRI guidelines. Reporters can issue Core or Comprehensive reports. When reporting under the Core option, the company reports on performance indicators that GRI has determined to be the relevant social, environmental, economic, and governance information for sustainability reporting, as well as one indicator related to each identified material aspect. Comprehensive reporters provide the Core information as well as reporting on all the indicators related to each identified material aspect. The company self-determines which aspects are material, or significant enough, to include in the report. They include the following aspects for which the GRI has developed performance indicators:

- **Economic aspects:** economic performance, market presence, indirect economic impacts, procurement practices
- **Environmental aspects:** materials, energy, water, biodiversity, emissions, effluents and waste, products and services, compliance, transport, overall, supplier environmental assessment, environmental grievance mechanisms
- **Social aspects:**
  - *Labor practices and decent work:* employment, labor/management relations, occupational health and safety, training and education, diversity and equal opportunity, equal remuneration for women and men, supplier assessment for labor practices, labor practices grievance mechanisms
  - *Human rights:* investment, nondiscrimination, freedom of association and collective bargaining, child labor, forced or compulsory labor, security practices, indigenous rights assessment, supplier human rights assessment, human rights grievance mechanisms
  - *Society:* local communities, anticorruption, public policy, anticompetitive behavior, compliance, supplier assessment for impacts on society, grievance mechanisms for impacts on society
  - *Product responsibility:* customer health and safety, product and service labeling, marketing communications, customer privacy, compliance (GRI 2013a)

The GRI has developed indicators related to each of these aspects, as discussed in the following sections.

Economic Aspects

There are nine main economic indicators on which a company may report under G4. The majority of these indicators pertains to the economic value of the company itself, the value of defined benefits provided to employees, and benefits provided

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Table 2.1 Economic aspects and indicators in GRI G4 guidance

Aspect	G4 Indicator
Economic performance	EC1: Direct economic value generated and distributed
	EC2: Financial implications and other risks and opportunities for the organization's activities due to climate change
	EC3: Coverage of the organization's defined benefit plan obligations
	EC4: Financial assistance received from government
Market presence	EC5: Ratios of standard entry-level wage by gender compared to local minimum wage at significant locations of operation
	EC6: Proportion of senior management hired from the local community at significant locations of operation
Indirect economic impacts	EC7: Development and impact of infrastructure investments and services supported
	EC8: Significant indirect economic impacts, including the extent of impacts
Procurement practices	EC9: Proportion of spending on local suppliers at significant locations of operation

to communities through local hires, infrastructure investments, and local supplier spending. This information shows the financial benefit provided by the report to shareholders, employees, and local communities. The economic indicators also include information on more controversial topics, such as financial assistance received by the government, gender salary ratios compared to the minimum wage, and the financial and other risks and opportunities due to climate change. Table 2.1 summarizes the indicators within the G4 guidance that cover various economic aspects.

Disclosure of the economic impacts of climate change is of significant concern for publicly traded companies. In the United States, the Securities and Exchange Commission (SEC) requires disclosure on climate change risks to the businesses of these companies. In essence, companies must disclose "material" information, which is information that "should be disclosed if a reasonable investor would want it in order to make an informed investment decision," and may include the impacts of climate change legislation or international accords, indirect consequences of regulation or business trends, and physical impacts of climate change (SEC 2010). However, the SEC and US Congress have experienced much debate about whether these disclosures are necessary and accurate due to the difficulty of predicting the effects of climate change on future operations and business practices. In fact, the Congressional Research Service provided a study of the issue to the US Congress (CRS 2013). This study summarized several reviews of climate change disclosures,

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indicating that they are occurring but entail a significant amount of speculation due to the uncertainty of climate change effects in the future.

G4 indicator EC2 covers the financial and other implications due to climate change, which may seem difficult to quantify. The G4 reporting guidelines instruct companies to

> Report risks and opportunities posed by climate change that have the potential to generate substantive changes in operations, revenue or expenditure, including:
>
> - A description of the risk or opportunity and its classification as either physical, regulatory, or other
> - A description of the impact associated with the risk or opportunity
> - The financial implications of the risk or opportunity before action is taken
> - The methods used to manage the risk or opportunity
> - The costs of actions taken to manage the risk or opportunity (GRI 2013).

Additional guidance on reporting the risks and opportunities associated with climate change is provided in GRI's *G4 Sustainability Reporting Guidelines: Implementation Manual*, which explains that operations may face physical risks and opportunities from changing climates, including increased frequency and intensity of storms, changes in sea level, temperature change, issues with water availability, workforce impacts, or the need to relocate facilities (GRI 2013b). Thus, by including reporting on the financial and other impacts of climate change, the GRI is addressing a relevant issue for business today, although it is one that may be difficult to define and quantify accurately.

The G4 reporting guidance provides significantly fewer economic indicators (9) than environmental (34) or social indicators (48), but this does not mean that economic reporting is not important. Publicly traded companies already have guidelines for financial reporting as a requirement for being listed on stock exchanges. Thus, it is the environmental and social performance information, which would not otherwise be available to interested parties, that becomes the focus of sustainability reporting.

Environmental Aspects

The 34 environmental indicators shown in Table 2.2 include reporting on materials used (recycled or virgin), energy consumption and reduction, water use and recycling, biodiversity impacts, air and water emissions, wastes, spills, impacts of products and services, environmental fines and expenses, transportation, supply chain impacts, and environmental grievances. Some of this information, such as water effluents and air releases, would be available through regulators, but it could

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Table 2.2 Environmental aspects and indicators in GRI G4 guidance

Aspect	G4 Indicator
Materials	EN1: Materials used by weight or volume
	EN2: Percentage of materials used that are recycled input materials
Energy	EN3: Energy consumption within the organization
	EN4: Energy consumption outside the organization
	EN5: Energy intensity
	EN6: Reduction of energy consumption
	EN7: Reductions in energy requirements of products and services
Water	EN8: Total water withdrawal by source
	EN9: Water sources significantly affected by withdrawal of water
	EN10: Percentage and total volume of water recycled and reused
Biodiversity	EN11: Operational sites owned, leased, managed in or adjacent to protected areas and areas of high biodiversity value outside protected areas
	EN12: Description of significant impacts of activities, products, and services on biodiversity in protected areas and areas of high biodiversity value outside protected areas
	EN13: Habitats protected or restored
	EN14: Total number of International Union for Conservation of Nature and Natural Resources Red List species and national conservation list of species with habitats in areas affected by operations, by level of extinction risk
Emissions	EN15: Direct greenhouse gas (GHG) emissions (Scope 1)
	EN16: Energy indirect GHG emissions (Scope 2)
	EN17: Other indirect GHG emissions (Scope 3)
	EN18: GHG emissions intensity
	EN19: Reduction of GHG emissions
	EN20: Emissions of ozone-depleting substances
	EN21: NO_X (nitrogen oxides), SO_X (sulfur oxides), and other significant air emissions
Effluents and waste	EN22: Total water discharge by quality and destination
	EN23: Total weight of waste by type and disposal method
	EN24: Total number and volume of significant spills
	EN25: Weight of transported, imported, exported, or treated waste deemed hazardous under the terms of the Basel Convention and percentage of transported waste shipped internationally
	EN26: Identity, size, protected status, and biodiversity value of water bodies and related habitats significantly affected by the organization's discharges of water and runoff

Table continued next page

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Table 2.2 Environmental aspects and indicators in GRI G4 guidance (continued)

Aspect	G4 Indicator
Products and services	EN27: Extent of impact mitigation of environmental impacts of products and services
	EN28: Percentage of products sold and their packaging materials that are reclaimed by category
Compliance	EN29: Monetary value of significant fines and total number of nonmonetary sanctions for noncompliance with environmental laws and regulations
Transport	EN30: Significant environmental impacts of transporting products and other goods and materials for the organization's operations, and transporting members of the workforce
Overall	EN31: Total environmental protection expenditures and investments by type
Supplier environmental assessment	EN32: Percentage of new suppliers that were screened using environmental criteria
	EN33: Significant actual and potential negative environmental impacts in the supply chain and actions taken
Environmental grievance mechanisms	EN34: Number of grievances about environmental impacts filed, addressed, and resolved through formal grievance mechanisms

be difficult for interested parties to find. Regulators would not have the information compiled on a company-wide or facility-wide basis. Sustainability reports can compile the information for various operating sites across a company and make it available for readers to gain an overall glimpse of performance on the macroscale or on a per-site basis.

With GRI's roots in Ceres, it is not surprising that many of the main themes which Ceres focuses on as an organization are included in the environmental indicators. Climate change, energy, water, and supply chain are the four issue areas that Ceres targets its initiatives toward. Each of these areas is well represented in the G4 indicators. Indicators addressing energy consumption and conservation, as well as greenhouse gas (GHG) emissions and reductions, are clearly linked to the issue of climate change. Water is covered under the G4 guidelines through indicators for withdrawals, recycling, and effluents. Supply chain issues are covered not only in the G4 environmental indicators, but in the economic and social indicators as well.

Social Aspects

More social indicators are listed in the G4 guidance than any other thematic area. The 48 indicators are broken down into subcategories for labor practices and decent work, human rights, society, and product responsibility.

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Table 2.3 Social aspects and indicators in GRI G4 guidance—labor practices and decent work subcategory

Aspect	G4 Indicator
Employment	LA1: Total number and rates of new employee hires and employee turnover by age group, gender, and region
	LA2: Benefits provided to full-time employees that are not provided to temporary or part-time employees, by significant locations of operation
	LA3: Return to work and retention rates after parental leave, by gender
Labor/management relations	LA4: Minimum notice periods regarding operational changes, including whether these are specified in collective agreements
Occupational health and safety	LA5: Percentage of total workforce represented in formal joint management–worker health and safety committees that help monitor and advise on occupational health and safety programs
	LA6: Type of injury and rates of injury, occupational diseases, lost days, and absenteeism, and total number of work-related fatalities, by region and by gender
	LA7: Workers with high incidence or high risk of diseases related to their occupation
	LA8: Health and safety topics covered in formal agreements with trade unions
Training and education	LA9: Average hours of training per year per employee, by gender and by employee category
	LA10: Programs for skills management and lifelong learning that support the continued employability of employees and assist them in managing career endings
	LA11: Percentage of employees receiving regular performance and career development reviews, by gender and by employee category
Diversity and equal opportunity	LA12: Composition of governance bodies and breakdown of employees per employee category according to gender, age group, minority group membership, and other indicators of diversity
Equal remuneration for women and men	LA13: Ratio of basic salary and remuneration of women to men, by employee category and by significant locations of operation
Supplier assessment for labor practices	LA14: Percentage of new suppliers that were screened using labor practices criteria
	LA15: Significant actual and potential negative impacts for labor practices in the supply chain, and actions taken
Labor practices grievance mechanisms	LA16: Number of grievances about labor practices filed, addressed, and resolved through formal grievance mechanisms

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Labor Practices and Decent Work

Sixteen indicators are given for labor practices and decent work, the greatest of the social subcategories, as shown in Table 2.3. The indicators for labor practices and decent work include information on new hires and employee turnover, employee benefits, parental retention, worker notification of operational changes, safety statistics, worker representation in safety committees, occupational disease rates, training programs, diversity statistics, ratio of pay between men and women by category, supplier assessment for labor practices, and labor grievances. Some of these indicators include information on the commitments companies have made with formal bargaining units.

More indicators are given for the occupational health and safety aspect than any other aspect covered in the labor practices and decent work subcategory. Mining has long been known as a dangerous heavy industry, and in the industrialized world, safety regulations abound for the industry. In the United States, the Mine Safety and Health Administration (MSHA) has been charged with protecting miners' health and safety since 1978. MSHA operates an on-line mine-data retrieval system that allows the general public to view information on mine inspections, accidents, and violations. Thus, it is possible for the pubic to discover information on injuries, included in the G4 indicator LA6 on types and rates of injury. However, a GRI report offers the convenience of having gathered this information for the reader. Additionally, the GRI requires a breakdown of the safety information by gender and region. Information on high rates of disease related to work at a mine (covered by indicator LA7) may be available to the public in SEC documents, especially where any lawsuits exist. But again, the GRI report offers a convenient place for the reader to find this information without performing personal research. The G4 reporting also includes health and safety indicators that report the percentage of total workforce represented on joint management–worker health and safety committees as well as health and safety topics covered in formal agreements with trade unions.

Human Rights

The social subcategory of human rights has 12 indicators, making it the second largest subcategory for social indicators in the G4 guidance. The international community has widely agreed to what are considered to be human rights through the United Nation's Universal Declaration of Human Rights (UN 1948). The declaration asserts for all people the right to life, liberty, and security of person, rights to personhood and equal protection before the law, freedom of movement, rights to own property, freedom of thought and religion, freedom of opinion and expression, freedom of peaceful assembly and association, right to work, equal pay, right to form unions, right to rest, and reasonable imitation of working hours, among others. The declaration also prohibits slavery.

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Table 2.4 Social aspects and indicators in GRI G4 guidance—human rights subcategory

Aspect	G4 Indicator
Investment	HR1: Total number and percentage of significant investment agreements and contracts that include human rights clauses or that underwent human rights screening
	HR2: Total hours of employee training on human rights policies or procedures concerning aspects of human rights that are relevant to operations, including the percentage of employees trained
Nondiscrimination	HR3: Total number of incidents of discrimination and corrective actions taken
Freedom of association and collective bargaining	HR4: Operations and suppliers identified in which the right to exercise freedom of association and collective bargaining may be violated or at significant risk, and measures taken to support these rights
Child labor	HR5: Operations and suppliers identified as having significant risk for incidents of child labor, and measures taken to contribute to the effective abolition of child labor
Forced or compulsory labor	HR6: Operations and suppliers identified as having significant risk for incidents of forced or compulsory labor, and measures to contribute to the elimination of all forms of forced or compulsory labor
Security practices	HR7: Percentage of security personnel trained in the organization's human rights policies or procedures that are relevant to operations
Indigenous rights	HR8: Total number of incidents of violations involving rights of Indigenous peoples and actions taken
Assessment	HR9: Total number and percentage of operations that have been subject to human rights reviews or impact assessments
Supplier human rights assessment	HR10: Percentage of new suppliers that were screened using human rights criteria
	HR11: Significant actual and potential negative human rights impacts in the supply chain, and actions taken
Human rights grievance mechanisms	HR12: Number of grievances about human rights impacts filed, addressed, and resolved through formal grievance mechanisms

The indicators for human rights, shown in Table 2.4, cover contracts with human rights agreements, employee training on human rights, discrimination incidents and response actions, freedom of association and collective bargaining, child labor, forced labor, human rights training for security, indigenous rights violations, operation-level human rights assessments, human rights for suppliers, and human rights grievances. Most of the human rights indicators are more relevant for mines operating in the developing world, where human rights may not be protected by law. For operations in the developed world, standard laws and constitutions protect human rights.

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Table 2.5 Social aspects and indicators in GRI G4 guidance—society subcategory

Aspect	G4 Indicator
Local communities	SO1: Percentage of operations with implemented local community engagement, impact assessments, and development programs
	SO2: Operations with significant actual and potential negative impacts on local communities
Anticorruption	SO3: Total number and percentage of operations assessed for risks related to corruption and the significant risks identified
	SO4: Communication and training on anticorruption policies and procedures
	SO5: Confirmed incidents of corruption and actions taken
Public policy	SO6: Total value of political contributions by country and recipient/beneficiary
Anticompetitive behavior	SO7: Total number of legal actions for anticompetitive behavior, antitrust, and monopoly practices and their outcomes
Compliance	SO8: Monetary value of significant fines and total number of nonmonetary sanctions for noncompliance with laws and regulations
Supplier assessment for impacts on society	SO9: Percentage of new suppliers that were screened using criteria for impacts on society
	SO10: Significant actual and potential negative impacts on society in the supply chain and actions taken
Grievance mechanisms for impacts on society	SO11: Number of grievances about impacts on society filed, addressed, and resolved through formal grievance mechanisms

Society

The social subcategory of society has 11 indicators in the G4 guidance, shown in Table 2.5. They include indicators to address local communities by reporting on the percentage of operations with implemented community engagement, impact assessment, and development programs, as well as operations with significant actual and potential negative impacts on local communities. Some of these indicators may build upon each other. For example, identifying and quantifying the negative social impacts of a mining operation on a local community (S02) may be difficult for a company to do without programs in place for engaging local communities (S01) to determine what the local public perceives as the negative effects of the operation.

The anticorruption aspect has more indicators than any other aspect covered in the social subcategory. Anticorruption indicators report whether operations are assessed for corruption risks, what the actual risks are, training on anticorruption, and actions taken against confirmed incidents of corruption. In the post-Sarbanes–Oxley world, large publicly traded companies are concerned with corruption and ethics. The Sarbanes–Oxley Act was passed in the United States in 2002 in response

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to company accounting scandals that mislead investors, such as those involving Enron and WorldCom. The intent of this act is to make top company management accountable for the financial information they release. Since this enactment of Sarbanes–Oxley, most publicly traded companies have ethics training and hotlines available to employees. However, smaller, more junior miners, especially those not listed on the stock exchange, may not have formally developed internal anticorruption programs.

Indicators also exist for political contributions made, legal actions for anticompetitive behavior, fines for noncompliance with laws, suppliers screened for impacts on society, actual and potential negative impacts on society in a supply chain, and grievances about impacts on society.

Product Responsibility

The social subcategory of product responsibility is the smallest of the subcategories, with only nine indicators, as shown in Table 2.6. It includes indicators to address consumer health and safety by reporting on the number of products for which health and safety impacts are addressed for improvement, and noncompliance with codes and regulations on product health and safety. The subcategory also includes indicators on customer satisfaction, sale of banned and disputed products, noncompliance with marketing codes, customer privacy complaints, and fines for noncompliance with regulations about the provision and use of products and services. Product service and labeling are also included in this subcategory with indicators on requirements and noncompliance with labeling regulations.

When it comes to product responsibility and labeling, one of the most relevant issues for the mining industry is the disclosure of conflict minerals. In 2012, the SEC adopted a new rule that requires companies to publicly disclose their use of the conflict minerals. Conflict minerals are minerals mined under conditions of armed conflict and human rights abuses, and defined by the SEC as originating in the Democratic Republic of Congo or an adjoining country, and include gold, tin, tantalum, and tungsten. Conflict minerals must be disclosed if those minerals are "necessary to the functionality or production of a product" (SEC 2012). By informing investors and consumers of the source of these materials, decisions can be made about purchasing and investment. Although reporting on conflict minerals may be relevant to report readers, it may not be a material issue for all mining companies, as not all companies have operations in conflict regions.

The list of G4 indicators on which a company can report is quite large. However, reporting is voluntary, and companies are not required to report on all indicators. Companies select which indicators they will report to the public from those described previously. Materiality exercises are used to determine which of the indicators are relevant to the company and should be reported. Different industries often have unique impacts to the environment, society, and the economy.

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Table 2.6 Social aspects and indicators in GRI G4 guidance—product responsibility subcategory

Aspect	G4 Indicator
Consumer health and safety	PR1: Percentage of significant product and service categories for which health and safety impacts are assessed for improvement
	PR2: Total number of incidents of noncompliance with regulations and voluntary codes concerning the health and safety impacts of products and services during their life cycle, by type of outcomes
Product and service labeling	PR3: Type of product and service information required by the organization's procedures for product and service information and labeling, and percentage of significant product and service categories subject to such information requirements
	PR4: Total number of incidents of noncompliance with regulations and voluntary codes concerning product and service information and labeling, by type of outcomes
	PR5: Results of surveys measuring customer satisfaction
Marketing communications	PR6: Sale of banned or disputed products
	PR7: Total number of incidents of noncompliance with regulations and voluntary codes concerning marketing communications, including advertising, promotion, and sponsorship, by type of outcomes
Customer privacy	PR8: Total number of substantiated complaints regarding breaches of customer privacy and losses of customer data
Compliance	PR9: Monetary value of significant fines for noncompliance with laws and regulations concerning the provision and use of products and services

Recognizing this, the GRI developed a sector disclosure supplement for the mining and metals industry that provides additional indicators of special importance for mining.

MINING AND METALS SECTOR DISCLOSURE

To develop the sector disclosure supplement for reporting, the GRI worked with the International Council on Mining and Metals (ICMM) through a multi-stakeholder working group and public consultations. The supplement began with a pilot version in 2003, which was finalized in 2010. In May 2013, the mining and metals sector supplement was updated to conform to the G4 guidelines and released as a sector "disclosure" (GRI 2013c). The ICMM requires its members to use the mining and metals sector requirements for reporting. The mining and metals sector disclosure adds 11 new indicators for the specific use of mining companies when compiling GRI reports, as shown in Table 2.7.

Two indicators address biodiversity. The first biodiversity indicator (MM1) reports the amount of land disturbed or rehabilitated. Mining companies often

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Table 2.7 Mining and metals specific indicators

Aspect	G4 Indicator
Biodiversity	MM1: Amount of land (owned or leased, and managed for production activities or extractive use) disturbed or rehabilitated
	MM2: The number and percentage of total sites identified as requiring biodiversity management plans according to stated criteria, and the number (percentage) of those sites with plans in place
Effluents and waste	MM3: Total amounts of overburden, rock, tailings, and sludges, and their associated risks
Labor/management relations	MM4: Number of strikes and lockouts exceeding 1 week's duration, by country
Indigenous rights	MM5: Total number of operations taking place in or adjacent to Indigenous peoples' territories, and number and percentage of operations or sites where there are formal agreements with Indigenous peoples' communities
Local communities	MM6: Number and description of significant disputes relating to land use, and customary rights of local communities and Indigenous peoples
	MM7: The extent to which grievance mechanisms were used to resolve disputes relating to land use, customary rights of local communities and Indigenous peoples, and the outcomes
Artisanal and small-scale mining	MM8: Number (and percentage) of company operating sites where artisanal and small-scale mining takes place on, or adjacent to, the site; the associated risks and the actions taken to manage and mitigate these risks
Resettlement	MM9: Sites where resettlements took place, the number of households resettled in each, and how their livelihoods were affected in the process
Closure planning	MM10: Number and percentage of operations with closure plans
Materials stewardship	MM11: Programs and progress relating to materials stewardship

hold large tracts of land for the purposes of owning mineral rights and exploration. However, they may not have significant biodiversity impacts on lands not used for mining or metals processing. Thus, this indicator reports not on total land holdings, but on both the area of land impacted and the area rehabilitated (or reclaimed), showing how much land will need future reclamation efforts.

The second biodiversity indicator (MM2) covers the number and percentage of total sites identified as requiring biodiversity management plans, and the number (percentage) of those sites with plans in place. Biodiversity impacts of a mining operation are site specific, depending on the location of the operation and unique species and ecosystems of the area. To report on this indicator, a company must first explain its organization-wide approach to biodiversity management, including decisions on whether, and to what degree, a specific site requires a biodiversity management plan (BMP). The GRI does not offer guidance or criteria as to which

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sites should have BMPs but only requires that companies explain their approach and criteria when reporting on this indicator. Companies also report the number of sites assessed using this criteria (in the context of the total number of sites), and the number found to require a BMP based on the company's criteria. This indicator is not for reporting on the progress of implementing a BMP, but rather whether or not a site should have one.

The third mining and metals indicator (MM3) covers the aspect of effluents and waste by reporting on the total amounts of overburden, rock, tailings, and sludges, and their associated risks. Overburden is the material (rock and soil) that must be removed to mine a coal seam or ore body. When rock is mined, some of it contains enough of the target mineral to be used or sent for processing, while some of it is waste rock that must be stockpiled elsewhere on site or backfilled into the mine. Tailings and sludges remain after the target mineral is extracted from the rock and must be deposited in contained areas after processing. Containment structures, such as dams and dikes, have safety considerations and long-term inspection requirements. The material left behind after mining not only alters the physical landscape, but it can chemically alter the local environment through the leaching of metals (acid mine drainage). In addition to these environmental concerns, long-term safety responsibilities exist for companies to maintain the structural integrity of any impoundments. The GRI requires the reporter to provide the weight of each material generated and perform a risk assessment to determine the relevance of the risks associated with each material. However, the GRI does not require any specific criteria for the risk assessment. The GRI does suggest that "the combination of waste material and disposal location may define the risk; for example, acid generating rock materials may leach acid products into water systems; inert materials may blanket ecosystems if disposed of in inappropriate settings; poorly engineered or maintained impoundments may give rise to toxic spills or structural failures" (GRI 2013c).

The aspect of labor/management relations is covered under the mining and metals indicator MM4, which requires the identification and number of strikes and lockouts exceeding 1 week's duration, by country. The GRI recognizes that "strikes and lockouts are indicative of a serious breakdown in labor/management relations, and a suspension of consultative processes. Data on the occurrence of such industrial incidents can convey a useful measure of the state of labor/management relations, and the direction of its progression over time" (GRI 2013c). However, this indicator only requires identifying the strikes and lockouts, not the resolution or efforts to prevent future occurrences. Thus, the approach a company uses for dealing with systemic or long-term labor issues may not necessarily be disclosed in the reporting of this indicator.

Indigenous rights are the topic of the mining and metals indicator MM5, which reports the total number of operations taking place in or adjacent to Indigenous

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peoples' territories, and the number and percentage of operations or sites where there are formal agreements with Indigenous peoples' communities. According to the GRI, "This indicator measures the level of risk associated with a company's exposure in operating on or near territory claimed by indigenous communities and the extent to which that risk is managed through formalized agreements recognized by all parties" (GRI 2013c). Identification of indigenous communities without formally recognized traditional territories may be difficult. The GRI defines indigenous territories as "areas in which Indigenous Peoples hold title to land, or have filed formal land claims or have long standing land tenure, including areas where ownership is claimed by multiple parties." Thus, nomadic people with widespread, not formally recognized territories may be overlooked.

The aspect of local communities is covered by two mining and metals indicators, MM6 and MM7. MM6 reports on the number and description of significant disputes relating to land use, and the customary rights of local communities and Indigenous peoples. MM6 requires reporting the nature of significant disputes related to current, planned, or future operations. The reporting company provides the criteria for classifying disputes as significant, as this is not provided by the GRI. Thus, there may be some variability in what is reported as a significant dispute between reporters. MM7 provides information about the extent to which grievance mechanisms were used to resolve disputes relating to land use, and the customary rights of local communities and Indigenous peoples. MM7 requires reporting on the disputes reported in MM6 and providing information on the status of the dispute and actions taken, including the outcomes of grievance mechanisms. In some developed countries, such as Canada and Australia, indigenous tribes have more formal consultation procedures built into the process of permitting mines on historic territories. In these proactive nations, land disputes can be addressed prior to the permitting of mines, and agreements can be made that may benefit local communities through job training, infrastructure improvements, and other efforts on behalf of the miner. Less developed countries may have little to no formal consultation processes in place. Thus, the likelihood of unresolved conflicts and importance of reporting on this indicator varies with the country in which a mining operation occurs.

Artisanal and small-scale mining (ASM) is reported in MM8 by detailing the number (and percentage) of company operating sites where ASM takes place on, or adjacent to, the site, and the associated risks and the actions taken to manage and mitigate those risks. These miners are essentially independent miners who do not work for any company, mining or panning for themselves. This form of mining most often has no appropriate means of treating or containing tailings. Environmental risks associated with ASM include mercury and cyanide pollution or the dumping of tailings into rivers, as well as other potential impacts. Social risks may also arise with ASM, such as potential conflict over land access and

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economic impacts to the independent miners and their families. These miners are unlikely to have proper personal protective equipment, and health risks may exist as a result of their practices. All of these risks should be reported under MM8, as well as efforts to manage the risks. This indicator may not be applicable to mines operating in the developed world, where the practice of ASM is rare when compared with developing economies.

The ninth mining and metals indicator (MM9) reports on sites where resettlements took place, the number of households resettled in each, and how their livelihoods were affected in the process. Minerals must be mined where they exist, which sometimes involves the displacement and resettlement of people to other areas. Potential impacts from these actions may include the loss of employment and income, loss of productive land, loss of housing, loss of access to common resources and public resources, and social fragmentation (GRI 2013c). Reporting on MM9 includes providing information on the consultation processes and measures put in place to reestablish the affected community and to mitigate any impacts of relocation, and the outcomes in terms of livelihoods, including sustainable land use. Reporters should also provide information on any significant disputes related to resettlement and the processes employed to resolve outstanding issues. Again, reporting on this indicator may not be as relevant for mines operating in the developed world where legal requirements are more likely to exist for the reimbursement of surface land owners by those exercising their mineral rights, such as through the purchase of surface lands and reimbursement for homes and moving expenses.

The number and percentage of operations with closure plans must be reported under MM10. Closure plans are meant to address more complex issues than just final reclamation and may include labor transition plans "to assist the established workforce to manage the progressive transition to post closure phase of operations" (GRI 2013c). Under MM10, companies identify the operations with closure plans in the context of total number of operations and report on the overall financial provision for closure. Reclamation plans and financial provisions for closure may not be as relevant in the developed world where reclamation efforts are overseen by regulatory agencies and mines are often required to bond for final reclamation costs. However, other aspects of closure planning, such as those that account for workforce transition, are less likely to be required by law and affect the final impacts of the mine on the community.

The final mining and metals indicator (MM11) reports on programs and progress relating to materials stewardship. Because of the long and complex production chains that can be involved in the mining and metals industry, high volumes of materials are often used. Material use efficiency can be applied during procurement, production, use, and disposal of metals. Under this indicator, companies report on programs and processes related to materials stewardship, such as

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- Communications of materials and product-related information to users up and down the value chain;
- Overall approach to, and progress with, use of a life-cycle assessment to improve processes and products;
- Processes for assessing the eco-efficiency and sustainability attributes of products (e.g., recyclability, material use, energy use, toxicity);
- Traceability schemes;
- Collaborative efforts with groups such as product designers, manufacturers, consumers, local authorities, and so forth; and
- Support of scientific research activities (GRI 2013c).

Metals remain a limited resource, yet our global population and demand for metals are increasing. Metal recycling and use efficiency is important in continuing to ensure that the global supply of metals can meet the needs of future generations.

These 11 mining and metals indicators are meant to represent the unique social, economic, and environmental impacts mining may present in a community. As a supporter of sustainability reporting, ICMM requires its members to use the GRI's mining and metals sector requirements for reporting at the self-declared application level A. As companies select which indicators to report, the GRI has developed a series of reporting levels to convey to report readers the extent to which the GRI indicators are used in the development of a specific report. The various reporting levels are explained in the next section.

REPORTING LEVELS AND ASSURANCE

Companies using GRI guidelines for sustainability reporting can select from various reporting levels: A, B, or C. Reporting levels are determined by the number of indicators on which a company reports. The levels do not reflect progress on the indicators or actual performance. At the C level of reporting, companies must report on a minimum of 10 performance indicators, including one each from the social, economic, and environmental categories. At the B level of reporting, a minimum of 20 performance indicators must be reported, including one each from the environmental and economic categories, as well as one each from the social subcategories of human rights, labor, society, and product responsibility. To achieve level A, companies must report on all of the core performance indicators, as well as the mining and metals indicators (or other relevant sector disclosures). A materiality screen is applied when reporting to determine which indicators are relevant to report. Credit for reporting on an indicator is given if an explanation is provided for its omission, such as its lack of material relevance. The ICMM supports the use of GRI reporting and requires its members to use the mining and metals sector requirements for reporting at the self-declared application level A.

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Reporters determine their own application level, but the GRI does offer a checking service. When the sustainability report is externally assured by a third party, a plus symbol can be added after the application level, so that readers may know the report was verified outside the reporting company. In this manner, a C-level report can become a C+, a B can become a B+, and an A can become an A+.

As reporting levels are determined by the number of indicators on which a company reports and not actual performance on any one indicator, the level can be misleading. For example, a company can have significant fines related to lack of environmental compliance but still receive credit for reporting on that indicator (EN29) and ultimately receive an A+ for its report. Thus, the GRI reporting system is meant to promote transparency in reporting on the indicators rather than to evaluate a company's performance on the indicators. The GRI has no mechanism for holding companies accountable for their performance in managing their social, economic, and environmental impacts.

GRI PARTNERSHIPS AND REPORTING SYNERGIES

GRI guidelines are often used by organizations that use other initiatives and guidance on sustainability. To help align programs where possible, the GRI has partnerships with the Organization for Economic Co-operation and Development (OECD), the UNEP, the United Nations Global Compact (UNGC), and the Carbon Disclosure Project (CDP). The GRI reporting framework also has synergies with the guidance of the International Finance Corporation (IFC), the International Organization for Standardization's (ISO's) ISO 26000, the United Nations Conference on Trade and Development (UNCTAD), and the Earth Charter Initiative (ECI).

The OECD's mission is to promote policies to improve the social and economic well-being of people globally by providing a forum for governments to work together. Since December of 2010, the OECD and GRI have had a memorandum of understanding (MOU) to promote use of both organizations' reporting instruments and cooperate in areas of mutual interest. This MOU makes it easier for organizations to use the GRI guidelines and the *OECD Guidelines for Multinational Enterprises* (OECD 2008).

UNEP strives to assist nations and people in improving their quality of life without compromising that of future generations. The GRI was inaugurated as a UNEP collaborating organization in 2002, and UNEP leaders sit on the GRI's Board of Directors, Stakeholder Council, and the GRI Governmental Advisory Group. Collaborative efforts between the GRI and UNEP resulted in the GRI Financial Services Sector Supplement (GRI 2000b).

The UNGC is a policy initiative for businesses that commit to 10 principles for humans rights, labor, environment, and anticorruption. In 2010, the UNGC and

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GRI signed agreements to align their programs. As a result, GRI reporting guidelines can be used to produce the UNGC's annual Communication on Progress, where participants demonstrate progress toward their 10 principles.

The CDP is a reporting organization where companies may choose to submit data on their GHG emissions (climate change), water, and forests. In 2013, the CDP and GRI signed an MOU indicating that they will work together to align their reporting frameworks around climate change and water data. The overall goal is to standardize the reporting scope and boundaries between the two frameworks so that the same methods can be used to gather data for each.

The IFC is a member of the World Bank and focuses its work in developing countries. The IFC has a sustainability framework that includes performance standards which private sector clients must adhere to during project development. The GRI has issued a guide connecting the IFC's sustainability performance standards to the GRI reporting framework for use by companies establishing projects in the developing world.

The ISO establishes international standards for business management issues, such as quality, safety, and environmental management. The ISO 26000 standard, *Guidance on Social Responsibility*, was published in 2010, which the GRI helped to develop. The GRI has also issued a document describing the links and synergies between the GRI disclosures and ISO 26000 for companies that use both. In 2011, GRI and ISO signed an MOU to leverage the activities of both organizations with regard to reporting and benchmarking on sustainable development.

The UNCTAD addresses trade and development issues such as finance, technology, investment, and sustainable development. In 2008, UNCTAD and the GRI signed an MOU to promote internationally recognized reporting standards. This partnership focuses on developing countries and transition economies.

The ECI promotes the transition to sustainable ways of living through its principles for building a just, sustainable, and peaceful global society. In 2008, the GRI signed an MOU, followed by a GRI document explaining the commonalities between GRI guidelines and the ECI's Earth Charter (ECI 2000).

Through these partnerships, the GRI reaches out to other organizations involved in both sustainability reporting and sustainable development to create programs with compatible goals and reporting requirements. These activities help build a global consensus on what it means to report and address sustainability within businesses today.

CONCLUSION

This chapter has discussed the rise of TBL sustainability reporting within the business world, including mining and metals companies. The GRI sustainability reporting guidelines provide a standardized set of reporting indicators across companies around the globe, including specific guidance for the mining and metals

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sector. GRI's efforts to include stakeholders and other organizations concerned with sustainable development help create a global consensus as to what are the significant sustainability issues that organizations should report. However, GRI reports do not evaluate performance of reporters, and it is up to the public at large to read these reports and hold companies accountable for the continual improvement of their sustainability performance.

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CHAPTER 3

Managing Business Sustainability in the Australian Mining Industry

Tapan Sarker and Virginia Munro

INTRODUCTION

This chapter provides an overview of the Australian mining and minerals industry and explains how this industry and its advisory and regulatory body, the Minerals Council of Australia (MCA), addresses business sustainability. First, a brief discussion on the Australian industry's minerals and resources sector, from early beginnings to present day, provides a context to understand current sustainability activities. Within this context, the overall regulatory framework and various industry regulatory licenses are discussed.

To further understand the MCA's commitment to sustainable development, the 10 sustainable principles developed by the International Council on Mining and Metals (ICMM) are examined alongside the elements recommended for each principle. The MCA has used the ICMM guidelines and principles to develop frameworks for its members to adhere to. These frameworks include the Enduring Value Framework (EVF) and the Water Accounting Framework (WAF), which are individually detailed in this chapter. The guidelines for each element developed by the MCA are explained, as are voluntary membership and commitments as well as obligations to the EVF and WAF guidelines.

Also discussed are the additional frameworks being developed by the MCA for land-use planning and natural resource management, and the MCA's current work toward biodiversity offset reform under the Environment Protection and Biodiversity Conservation Act.

The chapter concludes with a discussion on MCA stakeholders and stakeholder involvement and engagement with regard to their influence on reform and

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motivating voluntary compliance while also enhancing the movement toward themes supporting the "social license to operate."

THE MINING INDUSTRY IN AUSTRALIA

The Australian mining industry's minerals and resources sector has experienced unprecedented growth over the last decade, accounting for 60% of Australia's merchandise exports and about 8% of national gross domestic product (MCA 2012a). It is therefore acknowledged that mining is reasonably prolific in Australia with mining projects in every state and a variety of minerals and resources extracted from sites across the continent. The nine mining regions cover a large geographic area of Australia, stretching from remote interior communities in New South Wales (NSW) and central Queensland; to Kalgoorlie-Boulder in Western Australia; to the coastal mining, oil, and gas communities of Karratha; to as far north as Port Hedland in the Pilbara Region of Western Australia (MCA 2012a)

The last few decades have seen the development of sustainable programs and corporate social responsibility (CSR) policies in general, and this has led major mining companies to negotiate with Aboriginal traditional owners even in the absence of a legal requirement to do so (O'Faircheallaigh and Kelly 2001). A broad policy consensus in Australia then led to mineral development with the agreement of, rather than the opposition of, Aboriginal traditional owners (ATSISJC 2004; Beattie 2003).

The Australian government and the MCA have also agreed on an innovative partnership to improve the socioeconomic well-being of Indigenous Australians by expanding access to employment and business development opportunities available to Indigenous peoples and communities in mining regions. The new agreement builds on a partnership first commenced in 2005 and is set out in a memorandum of understanding officially launched in 2009 by the deputy prime minister (MCA 2009).

Mineral development in Australia today is increasingly controlled by a few large companies that operate across Australia's mineral-producing regions. The subsidiaries of these companies share information, and develop and implement policies and strategies across numerous projects and operations. Recognition of native title, legislative changes, and an emphasis on CSR policies creates opportunities for Aboriginal landowners to influence and benefit from mineral development (O'Faircheallaigh 2006).

As the impact of mining activity in communities has becomes more visible, "social performance" becomes one of the most widely disclosed categories. Other topics relating to controversial environmental impacts also began to be present and have been discussed in depth, such as the depletion of natural resources, economic impact on stakeholders, and comparability in a wider context. Each year stakeholders will expect more disclosure in all three dimensions of sustainability,

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as well as transparent and mature discussions about relevant impacts (Perez and Sanchez 2009).

With regard to advancing mining and human rights, on October 28, 2013, the MCA and the Global Compact Network Australia released a publication to advance mining and human rights in Australia. According to MCA's chief executive officer, Mitch Hooke,

> Australian mining companies operate in increasingly complex social and political environments in which the imperative and the practical measures of respecting human rights are integral to contemporary operations. Demonstrating respect for the rights of the people living and working in mining-affected communities is critical to building and sustaining a project's social license to operate. Respecting human rights is not just the right thing to do, it also makes good business sense to earn and maintain the confidence of the community, starting with their basic human entitlements (MCA 2013a).

Looking at current situations today, and confirmed by Hooke, the minerals resources sector is considered to be one of the most regulated industries in Australia, with mining approvals typically requiring consent from local, state, and federal governments. There are also extensive periods of public consultation, comprehensive environmental and social impact assessments, lodgment of environmental bonds or securities with governments, and ongoing reporting and assessment to ensure that the operation remains entirely consistent with the heavily conditioned approval (Hooke 2012).

Additional policies have also been designed to protect particular regions of Australia. As a result, mining approvals in Australia now typically take between 5 and 7 years to complete and comprise a complex array of licenses and approvals from a range of government agencies (Hooke 2012). Increasingly, therefore, the mining and minerals industry in Australia and globally is governed by a strong regulatory framework.

Command and control regulation occurs through the state directly intervening in the market and mandating particular corporate behavior. In contrast, *voluntarism* is based on the belief that the individual firm unilaterally undertakes to do the "right" thing, although it may also involve the government playing the role of facilitator and coordinator (Gunningham and Sinclair 1998; Fallon 2009; Barkay 2009). *Self-regulation* has emerged whereby an organized group regulates the behavior of its members (OECD 1994). This usually takes one of three forms. First, *voluntary self-regulation* involves an industry or profession establishing codes of practice, enforcement mechanisms, and other methods for regulating itself entirely independent of government involvement. The second form is *mandated self-regulation*, whereby the state requires the business to establish controls over its own behavior but leaves the details and enforcement to the business itself (subject to state

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approval or oversight). Finally, *mandatory partial self-regulation* is where the business is responsible for some of the rules and their enforcement, with the overriding regulatory specifications mandated by the state (Gunningham and Sinclair 1998).

An example of voluntary *self-regulatory* initiatives in the Australian mining and extractive industry is the Enduring Value Framework (EVF) developed by the MCA given that the MCA has developed a code of conduct for its members. The MCA may be considered to act as a surrogate regulatory organization, although its monitoring and enforcement abilities are limited. The adoption of the EVF is a condition of MCA membership.

The apparent gap between CSR policies endorsed by some companies and their level of compliance with the standards set out in those policies inevitably raises questions about the value of this type of regulation. It is important to understand that the weakness of much of the international and national indexes, and other soft regulation that form the base for most CSR programs, lies not merely in its voluntary form.

A significant body of literature, however, finds self-regulation to be more effective than command and control regulation, as it allows managers to act more proactively rather than reactively (May 2003; Newman and Bach 2004; Sarker 2008).

Notably, the principle of accountability in CSR provides an important conceptual linkage between the current risk paradigm and the notion of self-regulation. The former reflects a concern for corporate reputation through the well-known "audit" process, whereas the latter denotes a decidedly more ideal approach in which companies self-direct along agreed values and expectations (Kemp et al. 2012).

REGULATORY FRAMEWORK OF THE MCA AND THE AUSTRALIAN MINING INDUSTRY

The Minerals Council of Australia was formerly the Australian Mining Industry Council, established in 1960. Founded in 1995, the MCA is now the official advisory and regulatory body of the metallurgy, mineralogy, mining, and resources industry in Australia. Fundamental to the MCA's commitment to sustainable development is the concept of the "social license to operate": an unwritten social contract that supports and complements a "regulatory license" issued by government. The underlying regulatory framework of the MCA and mining industry discussed in this section describes this concept further.

The changing regulatory landscape in mining over the last two decades has seen an evolution in regulatory licenses from traditional *command and control* regulation to more flexible, principle-based, *voluntary* forms of regulation (Parker 2008; Posner 2007; Steinzor 1998). The MCA is embracing voluntary forms of regulation in the development of the EVF and WAF.

Very few studies have looked at the effectiveness of self-regulatory initiatives, such as the voluntary codes of conduct, in improving corporate performance on

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the ground (Puplampu and Dashwood 2011; Barkay 2009). This is particularly important for environmentally and socially disruptive sectors such as the mining and petroleum industries, which have generally had a track record of poor CSR in the past. In addition, the failure to uphold good CSR standards by mining and petroleum industries will cause long-term social, environmental, and economic harm (Pennington and More 2010). Therefore, a need exists to find a voluntary regulatory instrument that can encourage continuous improvement of CSR in the mining and petroleum industries, and the adoption of voluntary codes of conduct will assist with this endeavor.

EFFORTS TO ADDRESS SUSTAINABILITY

The MCA is the peak national body representing Australia's exploration, mining, and minerals processing industry, nationally and internationally, and contributes to sustainable economic and social development across the industry (Port Jackson Partners 2012).

Today, the MCA is one of the nation's most significant industry bodies and has a long-standing commitment to sustainable development (MCA 2013b). Mining and mining-related companies apply for membership with the MCA and this membership is approved or not approved by the MCA board.

As of August 2013, member companies produce up to 85% of Australia's mineral output including precious metals, base metals, light metals and iron ore, as well as energy materials such as coal (MCA 2013g). MCA member companies also account for more than 90% of mineral export earnings. The minerals produced by member companies are as follows:

- Base metals—copper, lead, zinc
- Precious metals—gold, silver
- Coal—thermal, metallurgical, lignite
- Iron ore
- Uranium
- Minerals sands—rutile, zircon, ilmenite, titanium
- Light metals—aluminum, nickel, manganese, magnesium (MCA 2013e)

The MCA's key belief is that the future of the Australian minerals industry is inseparable from the global pursuit of sustainable development and states that "through the integration of economic progress, responsible social development and effective environmental management, the industry is committed to contributing to the sustained growth and prosperity of current and future generations" (MCA 2013b). The recognized definition of sustainable development referred to here is from the Brundtland Commission: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Brundtland Commission 1987).

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By fostering sustainable development, the MCA hopes to enhance value for stakeholders and the broader community through its sustainable practices by creating industry awareness; maintaining uptake of sustainable development goals; providing leadership in environmental practices; providing continual improvement, excellence, and socially responsible minerals development; and increasing credibility and awareness of the industry's sustainable development activities. To achieve this, the MCA has recently established an Environmental and Social Policy Committee to better serve its member companies that are actively engaged in the effective integration of the environmental, social, and economic elements of minerals resource development. The council recognizes this as the key to operationalizing sustainable development.

The MCA advocates public policy and operational practice for a globally competitive minerals industry that is safe, profitable, innovative, and environmentally and socially responsible.

Key drivers of the MCA are as follows:

- An industry free of fatalities, injuries, and diseases
- A macro-economic framework conducive to sustainable economic growth and global competitiveness
- A skilled, productive, and flexible workforce
- Efficient transport infrastructure
- The reconciliation of energy security and climate change management as part of a sustainable global solution
- A seamless and efficient federation characterized by consistent regulation
- Access to competitive markets for capital, production inputs, human resources, and end products
- Access to natural resources and competitive markets for land, water, and energy
- A fair and stable society where effort is encouraged and rewarded, and support is extended to those in need
- Mutually beneficial relationships with indigenous and local communities through engagement and capacity building
- Improved environmental performance embracing long-term considerations for sustainable ecosystems beyond life of mine (MCA 2013e)

The self-assessment protocol of the MCA provides member companies with examples of the policies, practices, and standards a company might have in place to meet the requirements of the EVF and the WAF. Use of this self-assessment protocol is voluntary and is not a requirement for signatories to the EVF or WAF.

SUSTAINABLE DEVELOPMENT PRINCIPLES

The release of the sustainable development principles by the ICMM in May 2003 was integrated soon after into the practices of the MCA. The sustainable

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Table 3.1 The 10 ICCM sustainable development principles

Principle 1	Implement and maintain ethical business practices and sound systems of corporate governance.
Principle 2	Integrate sustainable development considerations within the corporate decision-making process.
Principle 3	Uphold fundamental human rights and respect cultures, customs, and values in dealings with employees and others who are affected by our activities.
Principle 4	Implement risk-management strategies based on valid data and sound science.
Principle 5	Seek continual improvement of our health and safety performance.
Principle 6	Seek continual improvement of our environmental performance.
Principle 7	Contribute to conservation of biodiversity and integrated approaches to land-use planning.
Principle 8	Facilitate and encourage responsible product design, use, re-use, recycling, and disposal of our products.
Principle 9	Contribute to the social, economic, and institutional development of the communities in which we operate.
Principle 10	Implement effective and transparent engagement, communication, and independently verified reporting arrangements with our stakeholders.

Source: Adapted from ICMM 2003.

development principles are the global industry's commitment to manage social, health, safety, environmental, and economic issues in order to deliver sustainable shareholder value as well as to improve its performance in managing these issues and to publicly report industry progress in doing so (MCA 2005a).

This section briefly outlines the ICCM principles and examines what is involved in each principle. This is necessary to understand how the MCA has integrated these principles into its voluntary EVF and WAF. The 10 ICMM principles are listed in Table 3.1.

The ICMM continues to be innovative in its development of global guidelines, funding projects to assist ICMM members and other stakeholders such as a current study with the Centre for Social Responsibility in Mining at the Sustainable Minerals Institute (SMI) at the University of Queensland, Australia. This study explores a range of social evaluation frameworks that measure the impacts and outcomes of programs and considers the extent to which they measure the human and social development outcomes and contributions of mining projects and associated investments (University of Queensland 2013).

The aim of this project is to help ICMM and MCA members understand the methods available to measure human and social development impacts and to provide guidance on how to measure the effectiveness of their investments. The project also hopes to identify and review a range of existing indicators, frameworks, and methods used by a range of private companies, development assistance

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organizations, and non-governmental organizations (NGOs). It also examines the extent to which such frameworks provide effective measures of impacts or outcomes and considers the potential for these to measure effectiveness of mining activities and associated investments, and their impact on the quality of life of communities (University of Queensland 2013).

ENDURING VALUE FRAMEWORK

The key role of MCA's EVF is to translate the principles of sustainable development given in Table 3.1 into practices and methods of reporting to ensure that the industry operates in a manner attuned to the expectations of the community and to maximize the long-term benefits to society through effective management of Australia's natural resources.

The EVF builds on the 1996 Australian Minerals Industry Code for Environmental Management—the platform for industry's continual improvement in managing environmental issues (MCA 2012b). Designed to assist managers, the EVF helps the MCA implement sustainable commitment in a practical and operational manner, targeted at site level (MCA 2005a). The EVF requires companies to seek continual improvement in environmental performance and implement effective and transparent engagement, communication, and independently verified reporting arrangements with stakeholders (MCA 2012b).

The framework provides practical ways to implement and report on these issues through a list of elements designed to address each principle. An element for each principle listed in the preceding section is given an implementation guidance factor for the EVF. For example, the first and second element listed for Principle 1 gives the implementation guidance shown in Tables 3.2 and 3.3, respectively.

The EVF is also complemented by a range of tools, guidelines, and extension activities such as training courses to deliver enhanced industry capacity in social and environmental competencies, leading to opportunities to improve performance "on the ground." Each element in the EVF also allows for cross-referencing between elements and therefore fully covers all aspects of training, implementation, and reporting.

The 10 principles and their elements and guidelines (Tables 3.1 through 3.3) reflect the potential that the mining and metals sector has in social development and poverty alleviation, where governments have implemented supportive policy and governance frameworks. In particular, members of the ICMM and MCA have committed to contribute to this through Principle 9, with the recent launch of a report that illustrates the methods available to measure human and social development contribution in the mining and metals industry. The report, titled *Approaches to Understanding Development Outcomes from Mining* (ICMM 2013a), is the first of two reports to be launched around the topic of social development in the industry. The report illustrates the methods available to measure human and social development contributions and consider the applicability of these methods for use in the

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Table 3.2 Element 1.1

Develop and implement company statements of ethical business principles and practices that management is committed to enforcing.
Implementation guidance: • Develop a company statement of ethical business principles and practices that the board of directors endorses and monitors. • This statement should reflect the 10 ICMM principles and their supporting elements, which are intended to deliver sustainable shareholder value through commitment to improving social, health, safety, environmental, and economic performance. • This statement could establish a business code of conduct for employees, consistent with sustainable development principles, and mandate mechanisms for reporting on adherence to the code. This code might cover expectations of behavior in relation to elements of the principles. • This statement should commit the company at every level to enabling its people to learn how to behave in principled ways and account for their performance. For examples of learning requirements that may impact on most or many employees and contractors, refer to Elements 1.2, 2.5, 3.4, 5.3, and 9.2 (in MCA 2005b).

Source: MCA 2005b.
Note: For a full list of implementation guidelines for each element and principle, please see the *Guidance for Implementation* document on the MCA Website.

Table 3.3 Element 1.2

Implement policies and practices that seek to prevent bribery and corruption.
Implementation guidance: • Bribery includes making promises as well as actually paying money or providing goods, services, or favors to illicitly influence official decisions or acts. Implement a "no-bribery" policy based on an informed view of relevant law, regulations, and international conventions. Competent legal advice is useful (see Element 1.3 in MCA 2005b). • Some payments that may be seen as attempts to influence official decisions and acts may be legal and regarded as proper within particular jurisdictions and recognized conventions. Transparency is a key issue, so policy should be developed and systems should be put in place to record and report on decisions and transactions related to – Political contributions, including direct or indirect contributions to political parties, organizations, or individuals involved in politics; – "Facilitation payments" to low-ranking officials for processing licenses or other functions; – Charitable contributions and sponsorships; and – Payments made to comply with particular statutes (see Elements 1.1, 1.3, 3.4, 10.1 in MCA 2005b). • Train employees to apply the no-bribery policy and use systems to ensure that relevant issues are recognized, recorded, managed, and reported transparently. – Implement systems for managing allegations or suspicions of business misconduct in confidential, professional ways consistent with due process (see Elements 3.2, 3.4 in MCA 2005b).

Source: MCA 2005b.
Note: For a full list of implementation guidelines for each element and principle, please see the *Guidance for Implementation* document on the MCA Website.

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mining and metals sector. The report provides ICMM member companies with a range of options to measure social return on investments in social and economic infrastructure and related projects.

The second report, *Community Health Programs in the Mining and Metals Industry*, focuses specifically on community health partnerships (ICMM 2013b). As part of this endeavor, the Partnerships for Development Toolkit (ICMM 2011) and the Community Development Toolkit (ICMM 2012) have been developed to evaluate the positive and negative economic and social effects of mining at local, regional, and national levels. The toolkits provide useful methodology for evaluating the positive and negative economic and social effects of mining at the local, regional, and national levels in mining countries. These methods will be of relevance in particular to the increasing numbers of lower- and middle-income economies that have high levels of mineral dependence. The application of the toolkit allows users to develop an improved understanding of what issues, policies, and practices may be helping or preventing host communities, regions, or the country from benefiting more fully from mining.

ADHERENCE TO THE EVF

Being a signatory to the EVF is a condition of MCA membership. Companies wishing to become signatories to the EVF need to sign a certificate pledging commitment to the EVF Principles and Elements, and its obligations. The principles of the EVF, therefore, apply to all activities of signatories and activities of contractors engaged by the signatories. All exploration, mining, and minerals processing companies and contractors are eligible to become signatories to the EVF provided they commit to the obligations.

Companies that commit to the EVF obligations are recorded on a register maintained by the secretariat, which is provided by the MCA. On occasion, signatories are asked to reaffirm their commitment to EVF, particularly following any review of its structure or requirements. In keeping with the voluntary nature of the EVF, a signatory may withdraw its commitment at any stage (MCA 2013d). To date, no withdrawals have been made from the EVF or MCA in this regard (Sarker and Gotzmann 2009).

In summary, commitment to the EVF requires the following obligations:

- Progressive implementation of the ICMM Principles and Elements
- Public reporting of site-level performance, on a minimum annual basis, with reporting metrics self-selected from the Global Reporting Initiative (GRI), the *GRI Mining and Metals Sector Supplement*, or self-developed
- Assessment of the systems used to manage key operational risks (MCA 2005b)

According to the MCA, the EVF will continue to be refined and developed in consultation with stakeholders as issues are identified that have not been addressed

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in the current framework. In the interim, a number of benefits are already outlined with regard to implementing the EVF. Using the framework, for example, provides a public demonstration of due diligence to the community, external investors, and internal acquisition, and it can drive real change in organizations through social, environmental, and economic performance to improve bottom line (MCA 2005a).

A supporting study of the benefits of the EVF is provided by the Institute of Business Ethics (Webley 2003), which found that between 1997 and 2000, companies with a code of ethics generated significantly more economic value and market value than those without codes, irrespective of the sector, and they had a significantly more stable price/earnings ratio than those without a code (MCA 2013d). However, the key benefit of the EVF overall is that it is expected to provide guidelines on how to look after, maintain, and enhance the environmental, social, and community aspects in the surrounding areas where mining companies operate, therefore maintaining a company's social license to operate. As further evidence of MCA's commitment to address the environmental and social impacts of mining operations within Australia, an infamously water-stressed country, MCA has developed a water accounting tool for its members to use.

THE WATER ACCOUNTING TOOL

The water sector in Australia has also experienced reform. Much of the reform is associated with the National Water Initiative (NWI), which was signed on June 25, 2004, between the Commonwealth of Australia and the governments of New South Wales, Victoria, Queensland, South Australia, the Australian Capital Territory, and the Northern Territory. This intergovernmental initiative is considered a national blueprint for water reform agreed to by the Council of Australian Governments and is aimed at increasing the efficiency of Australia's water use, leading to greater certainty for investment and productivity, for rural and urban communities, and for the environment. This initiative was one of the NWI goals to improve water resource accounting to underpin sustainable water resource management and efficient water markets (Cote and Moran 2009).

When the mining industry adopted a formal approach through the sustainable development principles (ICMM) listed in Table 3.1, three core indicators relating to water were also included. Despite the GRI *Mining and Metals Sector Supplement* to guide the calculation of the core water indicators across sites—philosophical, technical, and stakeholder—perspectives indicated that there remained a gap between a site's operational water balance and the GRI report card for water use (Cote and Moran 2009). In addition, there was no agreed national standard for water use accounting in Australia at the time. There was, therefore, a strong need for a WAF to provide information related to the minerals industry water use that could be reported to the NWI and other stakeholders in a consistent manner, but also used as part of the GRI and other sustainability indicators (Cote and Moran 2009).

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Table 3.4 GRI and WAF—source definitions mapping

	Water Accounting Framework	
GRI Category	**WAF Source Category**	**Input**
Surface water	Surface water	Rivers and creeks
	Surface water	External water storage
	Seawater	
Groundwater	Groundwater	Groundwater
Rainwater	Surface water	Precipitation and runoff
Wastewater	Wastewater	Third-party water
Municipal/utilities	Third-party water	Contract and municipal

Source: MCA 2012b.

The GRI indicators concerned with water management include

- EN8, total withdrawal by source;
- EN9, a list of water sources significantly affected by the withdrawal of water;
- EN10, the percentage and total volume of water recycled and reused;
- EN21, total water discharged by quality and destination; and
- EN25 size, protected status. and biodiversity of water bodies affected by discharge and runoff (MCA 2012b).

To understand how the GRI can be combined with the WAF, it is important to note the following source categories provided within the GRI.

- *Surface water:* Includes water from wetlands, rivers, lakes, and oceans
- *Groundwater:* (No definition supplied)
- *Rainwater:* Collected directly and stored by the reporting organization
- *Wastewater:* Supplied by other organizations
- *Municipal/utilities:* Includes water supplies from municipal and other water utilities

These categories can then be transferred from the input–output statement of the WAF model to show the interaction between the GRI and the WAF EN8. Table 3.4 illustrates this interface.

WAF development began in 2005 as part of a strategic program led by the MCA to gain improved understanding of minerals industry water use and use requirements among stakeholders involved in the water reform process and regionally with operations. The MCA's Sustainable Development Committee, which reports to the MCA board, has overseen the strategic development of the WAF, with the Water Working Group and the MCA secretariat responsible for the "hands-on" development.

In mid-2008, the SMI delivered its preliminary framework for consideration by the MCA's Water Working Group and Sustainable Development Committee.

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In 2009, a pilot project in Central NSW was undertaken. This was a joint initiative of the MCA, SMI, and NSW Minerals Council. Building on the feedback from industry and governments during the stakeholder engagement in 2008, the Minerals Industry Water Accounting Pilot Project, a partnership involving the MCA, the NSW Minerals Council, the National Water Accounting Development Committee, and the SMI was established in 2009. The pilot project was completed in October 2009, and, following its completion, the MCA engaged with industry and other stakeholders (MCA 2012b).

Based on the pilot study mentioned previously as well as relevant feedback, the WAF was amended to its current form and launched in 2011. This WAF allows sites to account for, report on, and compare site water management practices. It has also been designed to align to the GRI and the Australian Water Accounting Standards. According to the WAF, MCA member companies have endorsed an initial phase of WAF adoption that includes the alignment of company water metrics and definitions consistent with the WAF's input–output model, as well as using these metrics to meet an existing company water reporting requirement (e.g., GRI requirements). The boundary of the operational facility is defined by the mining company to meet its reporting requirements as necessary. Typically, it will consist of the mine site, including mineral processing operations if present.

Previous to the development of the WAF, the water accounting systems were often not consistent across companies or operations. Understanding industry water use by company, region, or sector was therefore difficult. The WAF allows these comparisons and for water use by all users in the landscape to be compared in a quantified and transparent manner (MCA 2013c), providing a consistent methodology for the communication of how an operational facility interacts with water. This methodology is based on the consistent representation of these water interactions with inputs (the receipt of water to the operational facility), outputs (the removal of water from the operational facility), and diversion (water that is moved around or through the operational facility). The task-treat-store cycle represents what an operational facility does with its water and how it is stored (MCA 2013f).

In summary, the input–output model mentioned previously represents the intersection of the facility with the surrounding environment and community, and is a consistent method for reporting a facility's water balance. It lists all inputs by source and all outputs by destination, and interacts with the GRI framework as previously mentioned.

The second component of the WAF is the operational model, which is a consistent method for the calculation and reporting of water reuse and recycling. This includes store, treat, and task cycles within an operation (MCA 2013f).

MCA member companies have, to date, endorsed framework adoption. This includes alignment of company water metrics consistent with the WAF input–output model, annual public reporting on company aggregated water inputs and outputs using the WAF definitions and metrics, and input into MCA surveys on

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water inputs and outputs for use in broader communication of aggregate mining sector water use by region or jurisdiction (MCA 2013f).

Water is not the only significant environmental issue that the MCA is addressing. The MCA is leading other efforts to concentrate on the environmental impacts of its member operations. This is discussed in the next section.

ALTERNATIVE MCA FRAMEWORKS IN DEVELOPMENT

The MCA is also developing alternative frameworks. These include land-use planning and natural resource management. The MCA has recently established an Environmental and Social Policy Committee to better serve its member companies that are actively engaged in the effective integration of the environmental, social, and wealth creation elements of minerals resource development and recognize this as the key to operationalizing sustainable development. The MCA's work in the sustainable development area is designed to achieve two overarching goals: (1) an Australian minerals industry enhancing value for stakeholders and the broader community through sustainable practices; and (2) a commitment by the Australian minerals industry to sustainable development through wealth creation, environmental leadership, and socially responsible development that is acknowledged by key stakeholders and decision makers.

The minerals industry continues to be actively engaged in the practical and effective integration of environmental, social, and economic aspects of resource development. Earning and maintaining the social license to operate and the practical implementation of sustainable development principles are defining features of modern mining operations.

Key features of the industry's approach to environmental management focuses on sustainable management of land, water, and energy; emissions management; materials stewardship; and biodiversity conservation. One of the key initiatives to give practical effect to this management approach, including the development of alternative frameworks for land-use planning and natural resource management, is to deliver transparent, rigorous, and sustainable decision-making processes founded in science and to better support the coexistence of mining, agriculture, and conservation. MCA acknowledges that there is a need for adopting more strategic land-use planning partly because the absence of a strategic planning approach to land use has led to increasing conflict regarding the intersection between mining and other land uses, particularly agriculture.

Reforms to regulatory approval processes for land-use planning are critical to ensuring effective decision making and project approvals. The MCA is currently establishing dialogue with the National Farmers' Federation and conservation organizations to develop better integrated land-use planning processes that balance social, environmental, and economic interests and that adopt the principle

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of multiple and sequential land use. One significant way in which land use affects the local environment is through biodiversity impacts.

WORKING TOWARD A BIODIVERSITY OFFSET REFORM

The Australian mining industry has adopted an increasingly sophisticated approach to the assessment and management of biodiversity centered on the prevention and management of biodiversity impacts from mining and the identification of opportunities to enhance biodiversity conservation within the reach of its operations. One of the key initiatives to give practical effect to this management approach includes reforms to biodiversity offsetting arrangements under the Environment Protection and Biodiversity Conservation Act 1999 (EPBC Act).

The EPBC Act is the Australian government's central piece of environmental legislation. It provides a legal framework to protect and manage nationally and internationally important flora, fauna, ecological communities, and heritage places, which are defined in the EPBC Act as matters of national environmental significance. These reforms are organized to recognize industry investments in land rehabilitation and to enhance biodiversity outcomes through better placement in the landscape.

Impacts of minerals operations on biodiversity values can occur within and surrounding an operation. Following the application of the "avoid–minimize–mitigate" environmental management hierarchy, targeted actions can be implemented to compensate residual losses that are significant in terms of biodiversity values. Such actions are more often being advocated as "biodiversity offsets" and are becoming an increasingly important consideration of project planning.

The MCA advocates the development and application of biodiversity offset measures in accordance with the following principles:

- In support of the social license to operate, many companies may voluntarily implement conservation programs. Offset requirements should be complementary to these initiatives.
- Offsets should not be an automatic requirement by regulatory agencies for all impacts.
- Offsets should be developed to ensure no net loss of impacted biodiversity values and overall environmental benefit over the long term.
- Offsets required through regulatory mechanisms should be limited to the proportion of residual losses that are significant in terms of biodiversity values, based on best available scientific evidence.
- Offsets for residual impacts can include a package of "direct" and "indirect" measures that must be flexible in their development and application, and implemented over an appropriate time frame.

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Consistent with the definitions of the Australian government, direct offsets provide on-ground protection and improved conservation outcomes for the impacted biodiversity values. On the other hand, indirect offsets are a range of other measures that improve knowledge, understanding, and management of the environment, leading to improved conservation outcomes for the impacted biodiversity values.

Where offset mechanisms are applied they should be

- Transparent in their calculation and development;
- Developed using the best available scientific information and include declarations about assumptions that underpin the science therein;
- Developed in a consistent, transparent, non-duplicative, and contemporaneous manner across jurisdictions involved in the regulatory process;
- Clear and certain regarding expectations for implementation and outcomes, including long-term management arrangements and liability for financial contingencies;
- Fair in sharing risks between the regulator and developer regarding the delivery of outcomes;
- Strategically developed to ensure that investments lead to the best value-for-money biodiversity outcomes across the landscape; and
- Clear in absolving the developer of reasonable responsibility in the delivery of outcomes when impacted by forces outside their control, including natural variability, acts of God, or willful damage by third parties.

MANAGEMENT AND ENGAGEMENT OF MCA STAKEHOLDERS

Stakeholder interests, needs, and feedback have become instrumental to the many changes within the industry and the adoption of voluntary codes and frameworks. Mining companies generally have a strong social license to operate. This unwritten social contract requires operating in a manner attuned to stakeholder and community expectations, while also acknowledging that businesses have a shared responsibility to government and, more broadly society to help facilitate the development of strong and sustainable communities (MCA 2013b).

In the MCA's *Enduring Value* guidelines booklet (2005a), the definition of *stakeholders* is taken from the Earth Summit (2002), which defines it as "those who have an interest in a particular decision, either as individuals or representatives of a group. This includes people who influence a decision, or can influence it, as well as those affected by it." The example that the MCA outlines is local community members, NGOs, governments, shareholders, and employees.

MCA stakeholders, therefore, are all those involved within the mining industry, including those who have an interest in the mining industry and those who are involved in or affected by mining and its processes. This also includes shareholders, internal stakeholders such as employees, and external stakeholders such as funding

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agencies, banks, and socially responsible investment portfolios, industry organizations, regulatory bodies, community groups, NGOs, and the media.

In general, there is a growing recognition in the stakeholder literature on "good" institutions and their impact on human security. Stakeholders—who have become cognizant of the ability of multi-national organizations to either positively or negatively impact the human security of individuals—have driven this move (Quek and Sarker 2011; Munro 2013a).

It is widely accepted that social and environmental performance has been on the increase since the 1990s (Schiavi 2005). This has given rise to pressures placed by stakeholders on mining and oil and gas sectors (Sarker and Gotzmann 2009), and is also driven by the increasing momentum of NGOs supporting social and environmental issues (Brereton 2002; Rondinelli and Berry 2000; Sarker and Burritt 2005a). Recent studies suggest that violations continue to occur, but there are a number of important developments toward the full realization of human security when institutions operate in conflict states (Voluntary Principles 2011). Ensuring that their operations do not contravene fundamental human rights is not only good corporate citizenship, but it also helps protect the extractive industry from a range of adverse legal, political, social, economic, and reputational risks.

By following principles of the social license to operate, not only do stakeholders have an important part to play pressuring the government to impose command and control regulation, but they also influence the level of voluntary compliance firms take on board. Organizations need community acceptance in order to continue to operate. Maintaining the social license to operate is therefore important because failure to respond to community and stakeholder concerns runs the risk of expanding the command and control regulation, since governments and regulators are required to be responsive to public concerns (Gunningham et al. 2002).

The self-regulatory initiatives in the Australian minerals and petroleum industries were developed in response to stakeholder pressures. It is therefore reasonable to presume that self-regulatory initiatives will continue to be responsive to the changing views of stakeholders in the future, as failure to do so could engender a legitimacy crisis. Success in this will be assisted by building employee morale and supporting social initiatives and CSR activities with a community perspective, which are relevant to CSR strategy and driven by a company's core business (Munro 2013b). Therefore, it is of utmost importance that stakeholders are engaged in dialogues regarding CSR.

One of the MCA's key objectives is to engage stakeholders and to report back utilizing the GRI and social and environmental reporting. Understanding stakeholders and their perspectives is therefore extremely helpful when engaging stakeholders (Munro 2013a). Engaging stakeholders is particularly important in the mining industry because of the high levels of social and environmental impact.

To further engage stakeholders, the MCA has as a primary goal—the creation of an industry that enhances value for stakeholders and the broader community

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through sustainable practices. It also acknowledges a commitment by the industry to sustainable development through wealth creation, environmental leadership, and socially responsible development. This in turn is acknowledged by key stakeholders and decision makers.

To achieve these goals the MCA promotes

- Industry awareness and effective uptake of sustainable development goals,
- Industry leadership in environmental practices and performance based on continual improvement and excellence,
- Continual improvement in socially responsible minerals development, and
- Progressively increased credibility and awareness of the industry's sustainable development activities (MCA 2013h).

In the present case, the MCA's EVF and WAF for mining, and the Australian Petroleum Production and Exploration Association's Principles of Conduct and Code of Environmental Practice were adopted in response to growing pressures from stakeholders requesting the industry be more socially and environmentally responsible. Numerous additional regulatory frameworks are also in the works.

CONCLUSION

As outlined in this chapter, the establishment of a regulatory framework in the Australian mining and extractive industry must be considered in a broader context of social and environmental scrutiny. The MCA has responded to industry needs by fostering sustainable development within the industry: establishing an Environmental and Social Policy Committee and developing the ICMM's 10 principles; implementing these principles by developing the EVF and WAF while also strengthening its own regulatory framework; and developing additional frameworks for land-use planning, natural resource management, and biodiversity offset reform.

A diverse range of regulatory mechanisms and frameworks with varying levels of enforcement that the government, minerals and mining industry bodies, and a range of stakeholders play a part in are necessary for proper regulation of the industry. In particular, the voluntary codes of conduct introduced by the mining and extractive industry and the oil and gas sector reflect the industries' need to engage in "beyond compliance" CSR activities to regain their legitimacy, or risk the imposition of costly command and control regulation as a result of public pressure on the state (Gunningham et al. 2002; Nilsen 2010).

Several researchers have noted that the adoption of the MCA's regulatory framework is regulation introduced in direct response to increased public scrutiny of the industry (Sarker and Gotzmann 2009). This suggestion is aligned to concepts of corporate accountability, whereby corporations have to account to their stakeholders, and hence their rights and freedoms should be balanced by obligations (Utting 2005). Fundamental to the existing regulatory framework is

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the social license to operate, which further illustrates the MCA's commitment to ongoing advancements in sustainable development. As part of the social license, a stakeholder can "give" or "retract" their acceptance of a company's license to operate, further making knowledge of stakeholder perspectives and stakeholder engagement paramount to all organizations (Munro 2013a).

The experience of the Australian mineral and petroleum industries shows that companies are responsive to the expectations of their stakeholders. Companies that breach their social license to operate by poor social and environmental conduct must regain their legitimacy by going beyond compliance of general CSR actions. To do so often includes the introduction of voluntary codes of conduct or other self-regulatory initiatives that are not only designed to avoid more formal command and control regulation, but also restore the legitimacy of the industry in the eyes of its stakeholders. For an organization to be legitimate, its actions must be seen as normative by its stakeholders. Hence, development of the social license to operate helps restore organizational legitimacy, as does adoption of a CSR strategy.

This chapter has highlighted that voluntary codes of conduct are an important self-regulatory mechanism for the Australian minerals and petroleum industries in response to concerns about their social and environmental conduct. The introduction of voluntary codes of conduct is a signal by the industry that their CSR practices have improved. Accordingly, the MCA's frameworks were introduced in response to stakeholder concerns in an effort to maintain their social license to operate. Rather than being purely voluntary, these codes of conduct have enabled both industries to avoid more formal command and control regulation. Voluntary codes of conduct are, therefore, an important part of the regulatory landscape, and are part of a new era of regulatory pluralism and method of preventing a legitimacy crisis and an operational disaster while also engaging stakeholders in the company's independent CSR strategy.

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CHAPTER 4

The Mining Association of Canada's Towards Sustainable Mining Program

Michelle E. Jarvie-Eggart

INTRODUCTION

The Mining Association of Canada (MAC) responded to public concerns surrounding the impacts of the mining industry by developing a program called Towards Sustainable Mining (TSM). The TSM program acknowledges the need for mining companies to address their triple bottom line throughout the life cycle of a mining operation. Public outcry against poor environmental and social performance from the industry in the past can stymie the permitting process, preventing new mines from being developed. The industry and public can benefit from an honest and realistic assessment of the social, economic, and environmental impacts of mining, as well as attempts to reduce and mitigate the most significant impacts. The TSM program requires member companies to report on sustainability efforts dealing with tailings management, Aboriginal and community outreach, energy use and greenhouse gas emissions, crisis management planning, biodiversity conservation management, and safety and health. This chapter provides a summary of the program, reporting results across the mining industry within Canada, the progress made by the industry since the inception of the program, and opportunities for further improvement.

BACKGROUND

Increasing global population and the industrialization of China, India, and other countries are driving increased global demand for metals. Countries rich in mineral

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deposits are facing increased exploration and mining. Canada has emerged in the twenty-first century as one of the major mining countries in the world. Canada has more than 3,000 mining companies producing aluminum, cobalt, diamonds, indium, nickel, platinum-group metals, potash, sodium, sulfate, sulfur, uranium and zinc (USGS 2011). It is one of the top countries for mining and exploration in the world. In fact, the Toronto stock exchange lists the majority of the world's publicly traded mining companies (MAC 2012a).

In addition to mineral wealth, Canada is rich in land. It is the world's second largest country, by area (CIA 2009), containing large expanses of undeveloped wilderness. Canada also has a rich cultural heritage, including a unique mix of Aboriginal cultures that have traditions and values strongly connected to the natural environment: the First Nations, Inuit, and Métis peoples. Canada's large mineral reserves, vast wilderness, and diverse society make it a unique country with great public awareness around the environmental and social impacts of the mining industry. At the close of the twentieth century, the public began to clamor for efforts to address these issues.

As public concerns about the environmental and social impacts of the mining industry gained more voice, the nonprofit group Mining Watch Canada was formed in 1999. The group's goal was to ensure that mineral development occurs in a manner that provides for sustainable communities and ecological health. It sought to increase the technical and strategic skills of communities faced with the impacts of mineral development, impose appropriate terms and conditions on mining, and advocate for policies that reduce the risks of mineral development (Mining Watch Canada 2012).

MAC recognized the need to respond to these calls for action. MAC is a long-standing industry organization, established in 1935. Its members are mining and mineral processing companies. As the actual operators of mining facilities, MAC members desired a better understanding of the public concerns regarding sustainability in the mining industry.

A previous stakeholder engagement effort by MAC, the Whitehorse Mining Initiative, attempted to provide a national roundtable for the mining industry, government regulators, and public groups including environmental, Aboriginal, and labor groups. This 1993 initiative allowed industry, government, and the public to hear each other's concerns. However, the Whitehorse Mining Initiative was criticized for its lack of any concrete follow-up by the industry on monitoring, verification, or reporting on performance (Fitzpatrick et al. 2011). Further action was needed to address performance.

Towards Sustainable Mining Program Development

To better understand public concerns about social and environmental issues related to mining, MAC performed social research from 1998 to 2002, meeting with

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community leaders throughout Canada. This effort identified areas for action and led to the development of the guiding principles and key performance elements for a new program called Towards Sustainable Mining (TSM). MAC tested the TSM program from 2001 to 2004 before launching it in 2004.

Although membership in MAC is voluntary, implementation of the TSM program is mandatory for MAC members at their Canadian operations. Many MAC members also have mining operations outside of Canada. MAC encourages, but does not require, members to implement the TSM program at their operations outside of Canada.

The TSM program is composed of a set of guiding principles with protocols addressing specific issues and guidance documents for how to implement the protocols. The guiding principles, published in 2004, establish MAC members' commitment to sustainable development and include

- Involving communities of interest in the design and implementation of the TSM program;
- Proactively seeking, engaging, and supporting dialogue regarding member operations;
- Fostering leadership throughout member companies to achieve sustainable resource stewardship wherever they operate;
- Conducting all facets of business with excellence, transparency, and accountability;
- Protecting the health and safety of employees, contractors, and communities;
- Contributing to global initiatives to promote the production, use, and recycling of metals and minerals in a safe and environmentally responsible manner;
- Seeking to minimize the impact of member operations on the environment and biodiversity, through all stages of development, from exploration to closure;
- Working with communities of interest to address legacy issues, such as orphaned and abandoned mines; and
- Practicing continuous improvement through the application of new technology, innovation, and best practices in all facets of member operations (MAC 2004).

MAC member companies also commit to respect human rights, respect local cultures (including Aboriginal), conduct business ethically, comply with laws and regulations, be responsive to community needs, and provide lasting benefits to communities. These guiding principles provide a context of overarching values for the TSM program. Specific issues are addressed through protocols for specific performance elements.

To put the values into action, the TSM program has developed six protocols that detail performance requirements regarding

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1. Tailings Management,
2. Aboriginal and Community Outreach (originally called External Outreach),
3. Energy Use and Greenhouse Gas (GHG) Emissions Management,
4. Crisis Management Planning,
5. Biodiversity Conservation Management, and
6. Safety and Health.

MAC provides details on the implementation of each of these protocols, as well as scoring for self-reporting. The requirements for each protocol are discussed in greater detail later in this chapter.

The TSM program was created with continual reviews and checks in place so that protocols could be revised and new protocols could be developed when appropriate. The program launched with four protocols. In 2008, the External Outreach protocol was revised and renamed the Aboriginal and Community Outreach protocol. In 2009, protocols were added to address biodiversity conservation management as well as health and safety. Through the revision of existing protocols, MAC can respond to feedback and criticism about the TSM program performance. By developing new protocols over time, MAC can keep the TSM program relevant for today, responding to new and emerging concerns about the industry.

MAC currently has plans to develop protocols on mine closure and water management. Adequate water supply for an increasing human population is a major concern, especially in the context of a changing global climate. Local and human rights to water is one of the emerging issues that mining companies are beginning to address, and about which will likely face increased pressure and scrutiny in the future (Kemp et al. 2010).

Program Oversight

The TSM program is overseen by MAC members and external stakeholders. The MAC Board of Directors sets the overall objectives for the program. The board approves all MAC positions, including the TSM guiding principles, strategy documents, frameworks, protocols, indicators, budgets, and work plans. Essentially, the board must give final approval to all elements of the program. MAC also has a TSM Governance Team, a subcommittee of the MAC board, that meets three times a year. The Governance Team makes recommendations to the board on all program elements, acts as an arbitrator in cases of dispute between a verification service provider and a MAC member, and provides directions to initiative leaders at MAC member companies. Initiative leaders are the individuals within each MAC member company responsible for implementing the TSM program and annually reporting on TSM progress for their companies.

MAC operates a Community of Interest Advisory Panel for the TSM program. The Advisory Panel includes approximately 20 representatives from communities

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where mining or mineral processing occurs, the financial community, labor organizations, environmental organizations, Aboriginal communities, and the mining community, including members of the MAC board. The advisory panel meets twice a year to provide MAC with a platform for open dialogue with external stakeholders. The panel may provide input on developing protocols or review the progress in implementing protocols. As an additional check on reporting, the panel also provides an annual review of a few of the MAC member's externally verified reports.

Reporting

For each of the TSM protocols, there are several performance indicators for which the mining operation reports a letter grade. For example, the Tailings Management protocol has five performance indicators:

1. Tailings management policy and commitment
2. Tailings management system
3. Assigned accountability and responsibility for tailings management
4. Annual tailings management review
5. Operation, maintenance, and surveillance (OMS) manual

For each of these performance indicators, the protocol provides assessment criteria for assigning a grade, answers to frequently asked questions, guidelines for interpretation of the performance indicator, definitions of key terms, and self-assessment checklists. For all TSM protocols, the performance indicators target institutional systems and management practices, not environmental or social outcomes. Good grades indicate that the company has established systems and practices that meet TSM standards. The TSM program is not designed to monitor the results achieved by the systems and practices.

The lowest possible performance level in the MAC scoring system is a C, and the highest is AAA. Although specific guidelines are provided for each performance indicator, the general scoring system is as follows:

- **Level C:** No systems are in place; activities tend to be reactive; procedures may exist, but they are not integrated into policies and management systems.
- **Level B:** Procedures may exist, but they are not documented, not consistent, or do not meet MAC's requirements; systems/processes are planned and being developed.
- **Level A:** Systems/processes are developed and implemented in accordance with MAC requirements.
- **Level AA:** Protocol requirements are integrated into management decisions and business functions.
- **Level AAA:** This level demonstrates excellence and leadership.

A level must be assigned for each performance indicator. There are no plus or minuses, only whole-letter grades. The company earns the highest grade for which

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Table 4.1 Tailings Management protocol performance assessment example

Performance Indicator	Performance Level
Tailings management policy and commitment	A
Tailings management system	AA
Assigned accountability and responsibility for tailings management	B
Annual tailings management review	A
Operation, maintenance, and surveillance (OMS) manual	A
Overall protocol performance	**B**

it meets all the criteria. For each performance indicator, assessors begin with level C criteria and work their way up until a specific requirement for a given level is not met. For example, if the performance indicator for tailings management policy and commitment was being assessed, and all the criteria for levels C, B, and A were met but only some of the criteria for level AA were met, the company would report an A grade for tailings management policy and commitment.

Once a grade has been assigned for each performance indicator within a protocol, the *lowest* indicator score determines the overall score for the protocol. See the example provided in Table 4.1.

The TSM program encourages MAC members to strive for a minimum performance level of A for every protocol at each Canadian operation, indicating compliance with MAC requirements. However, the required programs can take time to develop. New members of MAC are given 3 years to implement the TSM program before they must begin publicly reporting on performance. Existing members are also given 3 years to implement any new protocols developed by MAC. Each MAC member uses the evaluation criteria provided in the protocols to self-assess its performance at each operating site within Canada and reports the results to MAC. As a check on self-reporting, every 3 years the self-assessments must be verified by a MAC-trained TSM-verification service provider. Each year, MAC publishes an overall performance report for the public, providing a breakdown of performance by protocol for each operation by company. The next sections describe in detail the requirements of each protocol (Tailings Management, Aboriginal and Community Outreach, Energy and GHG Management, Crisis Management Planning, Biodiversity Conservation Management, and Safety and Health).

TAILINGS MANAGEMENT

MAC began its work on tailings management in 1996 with the establishment of a task force "to promote the safe and environmentally responsible management of tailings and mine rock" (MAC 2011c). The task force determined that the key to safe design, construction, operation, and closure of tailings facilities is the

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application of sound engineering capabilities within a supportive management framework. The task force arranged workshops on management of tailings and mine rock, and on tailings risk assessment, and ultimately determined the need for a guide to tailings management. Representatives of the mining industry worked collaboratively to provide guidance on good practices, which resulted in the 1998 publication of *A Guide to the Management of Tailings Facilities*, which was updated in 2011 (MAC 2011c).

This guide was developed to provide information on safe and environmentally responsible tailings management, to help companies develop tailings management systems, and to improve the application of good engineering and management principles to tailings facilities. The guide draws from approaches included in mining company manuals, MAC's environmental policy, ISO 14000, and Canadian Dam Association guidelines, among others. The guide suggests elements to be included in tailings management systems, with a focus on tailings facility life cycle from concept to closure. It includes checklists for tailings management and presents MAC's tailings management framework, which requires a commitment to design, locate, and operate tailings facilities such that structures are stable, and water and tailings are managed within their assigned areas. Management of tailings must also comply with any commitments made to communities of interest, company policies, MAC policies, and regulatory requirements. The guide also details the requirements for risk management at tailings facilities, emergency planning, tailings management system annual review, and corrective actions.

In 2003, MAC developed a supporting document to its original tailings management guide, *Developing an Operation, Maintenance and Surveillance Manual for Tailings and Water Management Facilities*, which was also revised in 2011 (MAC 2011a). This guide supplements the first and provides more details about the content that should be included in a tailings OMS manual. It suggests the type of data and procedures that should be documented, including content for emergency plans.

The last supporting document to the Tailings Management protocol is *A Guide to Audit and Assessment of Tailings Facility Management* (MAC 2011b). This guide assists auditors by providing protocols for auditing tailings facility management and qualitative assessment of the management. Together, these three guides—*A Guide to the Management of Tailings Facilities*; *Developing an Operation, Maintenance and Surveillance Manual for Tailings and Water Management Facilities*; and *A Guide to Audit and Assessment of Tailings Facility Management*—provide the necessary information to support MAC's Tailings Management protocol.

The Tailings Management protocol (MAC 2011d) was created as a tool for assessing compliance with the TSM tailings management requirements. The purpose of this protocol is not to assess compliance with laws and regulations, but with the TSM program. According to the protocol, an assumption is made that MAC members are in compliance with all legal and regulatory requirements. Although

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a well-implemented tailings management system should reduce the likelihood of violating laws and regulations, it is not a guarantee of compliance.

The following list describes the requirements to receive an A rating on each performance indicator. Performance on all indicators must be in conformance with recommendations detailed in *A Guide to the Management of Tailings Facilities* (MAC 2011c). Generally, to achieve the AA rating, a company must perform internal audits or assessments on the indicator every 3 years. The AAA rating is achieved though external audit or assessment, also every 3 years. Within the protocol, there are five performance indicators on which each operating facility is assessed.

1. **Tailings management policy and commitment.** At the A level of implementation, the company must have an official commitment and policy regarding tailings management that has been endorsed by senior management, implemented with budget allocations, and reviewed or developed with consolation from communities of interest (COIs). MAC views COIs as anyone who has an interest in or believes they are affected by the decisions made at a mining operation. Using the MAC definition, COIs may include the local population, Aboriginal peoples, special interest groups, employees, contractors, governments, the financial community, and so forth. More details on COI identification are provided in the Aboriginal and Community Outreach protocol.

2. **Tailings management system.** The A level of implementation requires a tailings management system that has a systematic approach to risk assessment, goals and objectives determination, COI consultation, proper assignment of responsibilities for tailings management, and an assurance process. Tailings management systems use the plan–do–check–act cycle seen in business improvement programs and the International Organization for Standardization (ISO) management systems.

3. **Assigned accountability and responsibility for tailings management.** At the A level of achievement, the company has formally assigned the accountability for tailings management to an executive officer, with appropriate delegation of responsibility and budgetary authority for implementing the tailings management system.

4. **Annual tailings management review.** To achieve the A level of implementation, a formal annual corporate review of tailings management is conducted to make those responsible for tailings management at the highest levels of the company aware of the status of each facility. The annual review must be reported to an executive who has the authority to ensure that any necessary corrective actions or improvements do occur so that tailings are managed in a safe and environmentally responsible manner at all facilities within a company.

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5. **Operation, maintenance and surveillance manual.** To achieve the level A rating, a facility-specific OMS manual must be developed and maintained to serve as a reference containing important information about the facility. An OMS manual includes design criteria, regulatory requirements, a site description, operation and maintenance procedures, and emergency plans, as well as roles for tailings facility personnel. Emergency preparedness and response plans must also be documented.

Examination of the performance indicators within the Tailings Management protocol shows how they build on each other. First, a company must be committed to tailings management before it is likely to invest in a management system. Management systems allow for continual improvement of operation through the plan–do–check–act cycle. The Tailings Management protocol also ensures that those making decisions about asset allocation at the highest level of a company are aware of the status of tailings management at each facility. Thus, if tailings dams need significant capital investment to maintain their safety or structural integrity, an executive is aware of the situation and responsible for managing it. OMS systems are not only useful in providing information on a facility, and standardizing procedures for operations and maintenance, they also help with management of personnel change within an organization by maintaining the institutional knowledge of the facility in one place.

One unique feature of the Tailings Management protocol is the requirement for COI consultation in the development or review of a company's tailings policy and a site-level tailings management system. The next section discusses the TSM program requirements for Aboriginal and community outreach, which includes the identification of COI.

ABORIGINAL AND COMMUNITY OUTREACH

Popular opinion can be the most influential factor in permitting a mining project. A favorable public opinion can result in "social" license to operate. Engaging with the public early and often during project planning, execution, and operation is a fundamental cornerstone in the concept of free prior and informed consent (FPIC). FPIC recognizes the community as ultimately giving the consent to mine, and its adherents advocate dealing fairly with local communities from the time of conception of a mining project (Whitmore 2006). Early engagement with those affected by the project can benefit the local community by ensuring that its desires, needs, and concerns are addressed. It benefits the mining company by building the social license to operate and reducing project opposition. In fact, for projects where communities are not engaged, opposition to the mine and confrontation may occur (Laurence 2011).

In the past, mining companies did not always recognize the value of their social license to operate until a project was being protested or challenged in court.

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Modern mining companies understand the need for the social license to operate. Today's mining companies regularly develop negotiated agreements to guarantee specific benefits to communities while maximizing their own certainty of being able to mine a specific resource (Fidler 2010).

Within Canada, Aboriginal peoples are some of those most affected by the mining industry, as much mining development occurs in remote areas. Historically, they have also faced barriers to participation in the discussions around a mining development, including less of a voice in formal government, less education, and fewer financial resources.

MAC began its efforts to address community outreach with the development of a framework laid out in the guidance document *Towards Sustainable Mining Framework: Mining and Aboriginal Peoples* (MAC 2008). These commitments include

- Respect Aboriginal and Treaty rights and seek to understand local perspectives on those rights;
- Acknowledge and respect the social, economic, environmental and cultural interests of Aboriginal Peoples;
- Engage with Aboriginal Peoples, in accordance with the TSM Guiding Principles, to develop open and effective relationships throughout the mining lifecycle. This includes:
  - Building cross-cultural understanding so that company personnel understand Aboriginal Peoples' culture, values and aspirations, and Aboriginal Peoples understand the company's principles, objectives, operations and practices;
  - Undertaking early, timely and culturally appropriate engagement with Aboriginal Peoples, including within the environmental assessment process, to ensure their interests in a project and its potential impacts are understood;
  - Consideration of traditional knowledge to minimize or mitigate potential adverse environmental and social impacts, and enhance positive benefits, of mining and related activities;
  - Developing agreements for participation, where appropriate, either directly with local Aboriginal communities or in conjunction with governments;
  - Working with governments and communities to support and encourage community development programs, which may include education, training, health, culture, employment and business development or other community needs and priorities, such as capacity building;
  - Supporting and encouraging Aboriginal involvement in environmental monitoring, closure planning and reclamation and other environmental activities that may be of interest to them; and

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- Develop and implement company policies and systems that support these commitments and encourage suppliers of goods and services to the industry to do the same (MAC 2008).

The Aboriginal and Community Outreach protocol, developed in 2008 as a modification of the External Outreach protocol, was updated in 2012 (MAC 2012b). The protocol assesses outreach efforts with Aboriginal and other COIs using the following performance indicators.

1. **Community of interest identification.** At the A level of implementation, there is a formal, documented system in place to identify "those affected or perceived to be affected by their operations or who have a genuine interest in the performance and activities of a company and/or operation," otherwise known as COIs (MAC 2012a). The system must have a process to consider those who may have raised concerns about the operation (challenging interests).

   At the AA level, the COI identification process should also consider those outside the area who may have issue-specific interests (such as provincial or national nongovernmental organizations).

   At the AAA level, there is an interactive process that allows a COI to identify other potential COIs. Supporting guidelines encourage research on treaty rights and ongoing traditional land uses.

2. **Effective COI engagement and dialogue.** At the A level of implementation, the company must have a formal and documented COI engagement system that includes appropriate participation assistance for the COI. The program must provide clear communication in local languages and designated employees with training in any Aboriginal consultation requirements. All materials should be made available for review in a timely manner, and the decision-making process must allow time for COI review.

   At the AA level, mining companies are "actively encouraged" to seek COI input into decisions that affect them. This level requires companies to identify capacity building needs of COI for effective engagement, hold senior management accountable for COI engagement, conduct annual senior management review of the engagement system, train employees on culturally appropriate engagement and dialogue, solicit and use traditional knowledge in site decisions and environmental monitoring, and integrate consultation processes established by Aboriginal peoples into company consultation processes.

   The AAA level requires formal mechanisms or agreements with COIs to ensure they effectively participate and influence decisions that may affect them. At this level, any appropriate negotiated agreements with Aboriginal peoples are in place, and COIs regularly review the engagement process.

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3. **COI response mechanism.** At the A level of implementation, this assessment protocol requires a formal system to receive and respond to complaints from COIs with processes for follow-up and tracking. It also requires that COI input be considered in decision making at the site. The facility should have a good understanding and documentation of COI concerns.

   At the AA level, the facility should have a more thorough understanding of COI concerns, and analyze and act on COI input. Senior management should consider the results of COI input at least once a year to determine appropriate actions, and adequate time should be built into site decision processes to consider and respond to COI concerns.

   At the AAA level, the facility should work collaboratively with COI to establish common objectives and community goals.

4. **Reporting.** The final assessment protocol for Aboriginal and Community Outreach ensures that open and transparent reporting occurs on COI engagement and dialogue activities. The A level requires formal reporting systems for COI engagement and dialogue, which includes responses to concerns raised by COIs.

   The AA level requires that the company publicly report responses to COI concerns and that the COIs have the opportunity to provide feedback on the reporting.

   At the AAA level, COIs provide feedback on the scope of public reporting. This level also requires that COI feedback is solicited on the engagement, dialogue, and consultation process, the results of which are also publicly reported.

The overall goal of the TSM program is for operating facilities not only to engage with COIs but to formally respond to their concerns. This does not imply that all COI requests are met but that a response is provided to them in a clear and transparent manner. This approach is meant to extend into the broader decision making at the mine level, where decisions may affect COIs. As such, the protocol on Aboriginal and Community Outreach touches several of the other protocols within the TSM system. For example, TSM requires policies for tailings management systems and biodiversity management to be developed or reviewed in consultation with COIs.

ENERGY AND GHG EMISSIONS MANAGEMENT

The Energy and GHG Emissions Management protocol was one of the first protocols developed for the TSM program. MAC's commitment to managing members' impacts on climate change is also evidenced by its 2009 endorsement of the International Council on Mining and Metals' policy on climate change. Also in 2009, MAC published the *Energy and GHG Emissions Management Guidance*

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Document to provide additional guidance on the assessment criteria used in the associated protocol. The document provides information on performing GHG emissions inventories and energy/carbon management. It also serves as a compilation of best practices for energy management in the Canadian mining industry.

The *Energy and GHG Emissions Management Protocol* document was revised in 2013 (MAC 2013c). The original protocol had six performance indicators including energy management systems, energy reporting systems, energy performance targets, GHG management systems, GHG reporting systems, and GHG performance targets. As energy is an operating cost, mining facilities are likely to measure and manage energy use. GHG emissions may not be actively managed other than accounting for reporting. However, managing energy consumption most often results in reductions of GHG emissions. Thus, in the revision of this protocol, the original six performance indicators were combined into three:

1. **Energy use and GHG emissions management systems.** At the A level of implementation, a management system must be in place that

    - Identifies and annually reviews material energy and emissions sources based on facility-specific criteria;
    - Assigns accountability to operational managers for energy use and GHG emissions management;
    - Regularly reviews energy data for energy-intensive processes and integrates results into operator actions;
    - Includes actions and process controls for material energy and emissions sources; and
    - Provides general energy and GHG awareness training to staff, with extra training for key staff.

    At the AA level of implementation, energy use and GHG emissions are considered in facility or business unit planning, and the energy/GHG management system has been internally or externally verified.

    At the AAA level, energy use and GHG management is incorporated into a broader business strategy, including at least two of the following practices:

    - Incorporating energy efficiency and GHG reduction into procurement and supply chain management policies
    - Voluntarily investing in research and development, feasibility studies, and/or technology demonstration for methods to increase energy efficiency and reduce GHG emissions
    - Investing in renewable energy or energy recovery projects
    - Participating with COIs to reduce emissions and improve energy efficiency

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2. **Energy use and GHG emissions reporting systems.** At the A level of implementation, the company must have a reporting system that includes regular reporting of energy use and GHG emissions so that corporate management and other decision makers are informed. Public reports of energy use and GHG emissions must occur annually. When offsets are used to meet commitments, public reporting must include the amount of offsets as a percentage of total emissions generated, and the source and nature of offset accreditation.

   At the AA level, the reporting system is internally verified, performance of the facility against its target is reported annually, and an overview of the corporate energy and GHG strategy is publically available.

   At the AAA level, energy use and scope 1 (direct emissions from sources a facility owns) and scope 2 (indirect emissions, such as from electricity purchased) GHG emissions are externally verified, and some scope 3 emissions (indirect emissions not owned or controlled by the site, such as third-party deliveries) are included in reporting.

3. **Energy and GHG emissions performance targets.** At the A level of implementation, the energy and GHG emissions performance targets must be met in the reporting year. In addition, when the facility or business unit establishes energy and emissions targets and objectives, it must consider:

   - Significant energy uses identified in their energy management system, as well as its financial, operational, and business conditions;
   - Legal requirements and technological options;
   - The views of potentially affected parties; and
   - Opportunities to improve energy performance.

   At the AA level, performance targets must have been met for 3 of the past 4 years, and performance must be internally or externally verified.

   At the AAA level, some of the performance targets must meet an additionality test, which means that the energy use or emissions reductions must be greater than the baseline scenario as provided by regulatory requirements, tax incentives, grants, or other financial reasons. The AAA level must also meet two of the following conditions:

   - Return-on-investment thresholds set for implementing energy efficiency or GHG reduction projects
   - Continuous improvement targets established that demonstrate reductions based on historical trends
   - Meaningful reductions as a result of investments in new technologies and/or new processes

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Although there are environmental benefits to energy management, the significant energy costs involved in mining often drive the establishment of energy management efforts at mining operations. The formal management systems required by the TSM program may be more detailed than those typically established for cost measures. Additionally, in Canada, all facilities that emit the equivalent of 50,000 metric tons, or t (50 kt) or more of GHGs in carbon dioxide equivalent units (CO_2 eq) per year are required to submit an emissions report to the government. Thus, the requirement of emissions reporting is also part of normal operations at a Canadian mine. At the time of this writing, some Canadian provinces have cap-and-trade systems, but not the federal Canadian government. Therefore, depending on the province in which one mines, meeting a performance target (or cap) may or may not be a new way of doing business. Overall, the energy costs associated with mining have caused the industry to track and manage these expenses, indirectly managing their GHG emissions through energy management. Although this protocol requires more formal systems, the requirements may not be that different than normal business practice for MAC members.

CRISIS MANAGEMENT PLANNING

MAC's recommended criteria for site-specific crisis plans is detailed in MAC's Crisis Management Planning Guide (MAC 2013b), which includes a sample crisis management plan. This guide is meant to help facilities when developing, revising, or assessing plans. The guide explains how to determine when to initiate a crisis plan, site vulnerability assessments, crisis plan objectives development, crisis management teams, plan activation protocols, crisis communication, debriefing post-crisis, crisis management plan training, and review of crisis plans.

When assessing performance for crisis management, the Crisis Management Planning Protocol document (MAC 2014) is the only of the TSM protocols that does not rank performance on a letter scale. Instead, for each performance indicator, the facility can only report a yes or no response. The protocol includes the following three indicators for assessing crisis management planning at a mine site.

1. **Crisis management preparedness.** This performance indicator requires that member companies have a crisis management plan in place that has corporate and facility requirements. It is assessed on a yes/no basis. All criteria must be met to provide a yes answer for meeting the TSM requirements. Self-audit checklists are provided in the protocol.

   At the corporate level, the crisis planning must include the following:

   - The President and CEO endorsed and demonstrated support for crisis management planning.
   - Credible threats and risks have been identified for the company and protocols established to address them.

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- The results of these evaluations have been shared between corporate and operations levels.
- A Corporate Crisis Management Team has been established, with defined roles and responsibilities.
- A media spokesperson has been assigned and trained.
- The Crisis Management Plan is a "page-dated," controlled document.
- All key personnel have been provided with copies of the plan and a portable key contact list.
- A crisis room has been established and equipped.
- Key media contact and telephone log sheets have been prepared.
- Crisis communications programs have been established to effectively alert employees to a crisis and its developments.
- Contact information for key stakeholders has been prepared and prioritized (MAC 2014).

At the facility level, crisis planning must include the following:

- Credible threats and risks have been identified and protocols established to address them.
- The results of these evaluations have been shared with the corporate office.
- A Local Crisis Management Team has been established, with defined roles and responsibilities.
- A media spokesperson has been assigned and trained.
- The Local Crisis Management Plan is a "page-dated," controlled document.
- All key personnel have been provided with copies of the plan and a portable key contact list.
- A crisis room has been established and equipped.
- Key media contact and telephone log sheets have been prepared.
- Crisis communications programs have been established to effectively alert employees to a crisis and its developments.
- Contact information for key local stakeholders has been prepared and prioritized.
- The facility meets annually with senior members of the local emergency response authorities (where they exist) (MAC 2014).

2. **Review.** Companies must regularly review and update their crisis management plans. At the corporate level, the crisis management plan must be reviewed and updated whenever there is a change in business (such as a new mine). At the facility level, the site-specific crisis plans must be shared with

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the corporate office. The facility and corporate levels must meet the following criteria:

- The crisis management plan must be reviewed and updated whenever there is a change of personnel associated with implementing the plan, and/or every 18–24 months.
- The plan's notification system must be tested at least twice per year.
- Processes must be in place to make sure new crisis team members are familiar with the plan within 2 months of joining the team.

All requirements must be met at the corporate and facility levels for a "yes" to be assigned to this performance indicator.

3. **Training.** Annual "table top" crisis simulation exercises should be performed at the facility and corporate levels. The operating site must also conduct a full crisis simulation every 3 years. Again, all requirements must be met at the corporate and facility level for a "yes" to be assigned to this performance indicator.

BIODIVERSITY CONSERVATION MANAGEMENT

When it originally launched in 2004, the TSM program did not include a protocol for biodiversity. As the program grew and received feedback, it became apparent that biodiversity conservation management should be addressed. MAC initially stated its commitment to conserving biodiversity at member mine sites in its 2007 Biodiversity Conservation Management Framework (MAC 2007). The framework includes the following commitments:

1. MAC members will positively contribute to the conservation of biodiversity through all stages of the mining life cycle.
2. MAC members will work with key communities of interest to develop and implement responsible policies and practices to:
   a. Integrate the importance of biodiversity conservation, including respect for critical habitat, into mining and land-use planning and management strategies, including considering the option of not proceeding with a project.
   b. Assess and monitor the state of biodiversity throughout the project cycle.
   c. Avoid, minimize, mitigate and/or compensate for significant adverse biodiversity effects.

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d. Enhance, through research, information sharing and/or partnerships, the industry's understanding of and contribution to biodiversity conservation, science and traditional knowledge.

e. Establish, finance and implement comprehensive reclamation plans that, wherever practicable, return mine sites to viable and diverse ecosystems that will serve the needs of post-mining use, recognizing that mining can permanently alter landscapes and that other desirable land uses may be considered in reclamation plans when justified by site-specific circumstances.

3. MAC members are committed to transparency and public reporting on issues related to mining and biodiversity conservation.

4. MAC members, recognizing that protected areas can contribute to biodiversity conservation, will comply with the requirements of legally-designated protected areas and are committed to working with key communities of interest to develop transparent, inclusive, informed and equitable decision-making processes for the establishment of protected areas.

5. MAC member companies undertake not to explore or develop mines in World Heritage sites. All possible steps will be taken to ensure that pre-existing operations in World Heritage sites as well as existing and future operations adjacent to World Heritage sites are compatible and co-exist with biodiversity goals.

6. MAC and its members will demonstrate leadership by informing others of this Mining and Biodiversity framework and encouraging its adoption (MAC 2007).

Some may doubt whether mines can be considered to positively contribute to biodiversity (commitment 1 above). However, the commitments do allow for the mitigation of adverse biodiversity effects (commitment 2c), which could result in a net positive impact on biodiversity metrics.

In 2009, the Biodiversity Conservation Management protocol was added to the TSM program (MAC 2013a). Like the Tailings Management protocol and the Energy and GHG Emissions Management protocol, COI feedback is encouraged. It includes the following performance indicators for assessment:

1. **Corporate biodiversity conservation policy, accountability, and communications.** At the A level of implementation, companies must have a policy in place for biodiversity management that is endorsed by senior management and consistent with MAC's framework on biodiversity conservation management detailed previously. The policy must be communicated to all staff and

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to COIs. Roles, responsibilities, and accountabilities for those implementing the policy must be clearly established and supported by adequate resources.

At the AA level, the biodiversity policy and its implementation is independently verified or reviewed, internally or externally.

At the AAA level, the biodiversity policy provides a commitment to partner on biodiversity conservation with other organizations, with appropriate roles, responsibilities, and resources for support.

2. **Facility-level biodiversity conservation planning and implementation.** The second performance indicator on biodiversity management confirms there are facility-level plans and management systems for managing significant biodiversity aspects. Although not clearly defined in the TSM program, significant biodiversity aspects are site specific and can be of micro- or macroscale, such as a certain species or its habitat. Clearly, to develop a plan to manage biodiversity, a facility must perform some sort of ecological assessment and determine which aspects (specific species, habitats, or ecosystems) are significant to the site and should be managed. These may be aspects that have regulatory protection, such as endangered species, or have unique cultural significance to COIs, such as traditionally harvested plants.

   The A level of implementation requires either a facility-level plan or a formal management system be in place to manage significant biodiversity aspects. The site must perform at least the following activities though its plan or system:

   - Assess potential impacts/risks to biodiversity.
   - Identify targets for significant biodiversity aspects, and develop and implement associated action plans.
   - Assign responsibility for biodiversity conservation management at the site.
   - Include biodiversity conservation training in site training.
   - Consult COIs on biodiversity conservation management.
   - Regularly track and report to senior management on the biodiversity conservation plan implementation and progress.

   At the AA level of implementation, biodiversity planning is integrated into the annual business planning and budget process. This level also requires an independent internal or external review of the biodiversity conservation management system implementation. The final requirement for the AA level is that the facility "participate with" biodiversity conservation organizations or COIs to support biodiversity conservation.

   At the AAA level, the broader business strategy integrates biodiversity conservation management by including at least two of the following activities:

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- Research investments to enhance the industry understanding of and contribution to biodiversity conservation, science, and traditional knowledge.
- Provide contributions to the greater understanding of biodiversity protection.
- Provide contributions to guidance documents that foster biodiversity conservation in the region or industry.
- Enhance biodiversity outside company property.
- Receive national or regional recognition for biodiversity conservation.
- Provide ecosystem service valuation.
- Encourage employees to volunteer for biodiversity initiatives.

3. **Biodiversity conservation reporting.** The A level requires a formal biodiversity conservation reporting system that includes internal and public reporting.

   The AA level requires that the public reporting is independently verified either externally or internally.

   At the AAA level, COI feedback on the biodiversity conservation reporting is solicited and publicly reported.

The COI consultation requirements for biodiversity conservation management can be used to integrate the local populations' needs and values. Species that have unique cultural significance for native populations can be incorporated into the management plans. Special habitat to encourage the presence of species for hunting and fishing can be incorporated into overall land and reclamation management. Biodiversity management is intimately tied with reclamation efforts, and plans for the two should be developed simultaneously.

SAFETY AND HEALTH

The original TSM program did not include a protocol for safety. In 2009, a protocol was added to address health and safety, and updated in 2013 (MAC 2013d). The commitments member companies make are expressed in the *Safety and Health Framework* (MAC 2012c). Member companies make the following commitments, with the ultimate goal being "zero harm":

- Provide safe and healthy workplaces by building, supporting, and sustaining behavior and controls; recognizing that injury and occupational disease can be prevented, fatalities eliminated, and that the related controls are a shared responsibility of the company, employees, contractors, and suppliers.
- Establish clearly defined and communicated responsibility and accountability at the board and senior management level for the company's safety and health performance. Implement and review policies, strategies, standards,

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metrics, and accountability mechanisms to ensure that everyone understands company requirements and can fulfill them.
- Implement recognized safety and health management systems to ensure safe and healthy workplaces, a culture of prevention, and improvements in performance.
- Ensure effective injury prevention and disability management programs are in place, and actively promote health and wellness at work and at home.
- Actively encourage and support contracting, supplier and community partners in building their capacity to be safe and healthy.
- Recognize that governments play an important role in enabling effective safety and health controls.
- Set clearly defined and communicated performance targets that are integrated into business and risk management plans. Report on the related metrics for both employees and contractors using tracking with systems that help assess and communicate performance and include both leading and lagging indicators (MAC 2012c).

Although Canadian provinces and territories have laws and regulations governing occupational health and safety, the requirements of the Safety and Health protocol are intended to go beyond these requirements by ensuring that a management system is in place for managing safety and health at the mine level (2013d). This protocol includes the following five performance indicators:

1. **Policy, commitment, and accountability.** At the A level of implementation, policy commitments consistent with MAC's Safety and Health Framework (MAC 2012c) are authorized by the company's senior management and communicated to all who work at the facility, including staff, contractors, and suppliers. In addition, these accountabilities are understood and documented at all levels.

   At the AA level, internal audit/assessment confirms that the policy meets the requirements of the Safety and Health Framework.

   At the AAA level, the policy is confirmed by external audit/assessment.

2. **Planning, implementation, and operation.** At the A level of implementation, a formal safety and health management system is fully implemented when it incorporates

   - Documented objectives and targets, with supporting plans to achieve them;
   - Formal hazard identification, risk assessment, and control processes;
   - Documented safety standards and procedures;
   - Defined and documented roles and responsibilities for safety and health management;

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- Workplace inspections; and
- Maintenance of safety and health records.

Appropriate resources must also be assigned to ensure that the safety and health management system is established, implemented, maintained, and improved.

At the AA level, an internal audit/assessment must have been conducted within the last 3 years to confirm that all level A requirements are met for the safety and health management system.

At the AAA level, the safety and health management system has been confirmed within the last 3 years by external audit assessment.

3. **Training, behavior, and culture.** The third performance indicator for safety and health confirms that employees and contractors are provided proper safety and health training in identifying hazards, preventing incidents, and understanding the shared responsibility of safe behavior for risk control. At the A level of implementation, a documented, formal, fully functional safety and health training program must be in place. The program should include a formal analysis of training needs that covers required skills and competencies, risk-based training, and orientation for all employees, contractors, and visitors to the site. The training program must be updated annually, and resources must be assigned to ensure program implementation. Both trainers and trainees must be formally assessed for competency. Training must focus on prevention and proactive measures through the implementation of hazard identification and reporting programs. A formal worker/job observation program that supports the training and ensures coaching is in place to encourage safe behavior is also required.

   At the AA level of implementation, facility senior leaders demonstrate a continuous commitment to safety and health, provide leadership to drive the organization to zero harm, assess and respond to high potential events as learning opportunities, and hold all individuals accountable for safety and health. The facility encourages a safety-based culture, incorporating safety and health criteria into core business practices and planning, including the annual business plan, purchasing decisions, staff performance appraisals, and compensation. The facility's programs also promote wellness and a healthy lifestyle.

   At the AAA level, management has one-on-one interactions with employees that demonstrate commitment to safety and health. Risk management is done primarily through integrated systems that include safety and health requirements. The safety and health commitment is visibly embedded throughout the facility.

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4. **Monitoring and reporting.** At the A level of implementation, a formal, documented, and functional safety and health monitoring program is in place that includes

    - Consistently applied, regularly assessed and reported, clearly defined performance metrics that are used for trending and prioritizing improvements;
    - A monitoring program that tracks and internally reports leading and lagging indicators, inspects and monitors safety and health, performs health surveillance, and investigates incidents with appropriate follow up;
    - A formal audit program in place for safety and health, and compliance and management system audits that are conducted as planned;
    - Annual facility assessments of the safety and health management system, with recommendations for continual improvement;
    - Regular management review of safety and health performance, the results of which inform decision making;
    - Workplace monitoring/inspection results and follow-up actions that are reported or posted within the facility routinely; and
    - Annual public reporting on safety and health performance.

    At the AA level of implementation, an internal audit/assessment is conducted to verify that consistent processes are used to collect, compile, and report reliable safety and health information.

    At the AAA level, these processes are verified through external audit/assessment.

5. **Performance.** The final performance indicator for safety and health recognizes the need of continual improvement toward the goal of zero harm. At the A level of implementation, employee and contractor performance targets are established and communicated annually. Site management is involved in performance improvement, including setting and reviewing the performance targets. A formal process exists for communicating performance results to the workforce and facility.

    At the AA level of implementation, the performance targets include both lagging and leading indicators. Senior management meets regularly to review the site targets and improvement plans. Safety and health performance is benchmarked against peers at the facility or company level.

    At the AAA level, the facility has met its improvement targets for 3 of the last 4 years and has had no fatalities in the last 4 years. The facility must also externally audit/assess safety and health performance to ensure information is accurate.

    The MAC requirements for safety and health establish a management and reporting system with continual improvement targets. Even with a safety

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culture that recognizes shared responsibility for safety, some events are not preventable. Special planning is required to handle crisis situations, which includes response actions that are flexible enough to be used in a variety of situations.

CONCLUSION

The Canadian mining industry's efforts to address sustainability have been recognized as a sign of progress (Fitzpatrick et al. 2011). The organization of the TSM program, with formal measures for providing stakeholder critique through the advisory panel, allows for continual review and revision of the program when necessary. In addition, this program is unique in reporting on its degree of implementation, creating greater transparency in sustainability efforts by the mining industry. By focusing on the use of management systems, the TSM protocols allow each facility to actively and continually manage their unique social and environmental risks and impacts.

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PART II

STAKEHOLDER ENGAGEMENT AND PARTICIPATION

Rachel E. Durkee Walker and Michelle E. Jarvie-Eggart

Mining operations that earn the acceptance of local communities are said to have "the social license to operate." Social license to operate is not easy to measure or define, but mining companies recognize it as a valuable commodity. When communities lack trust in a new development, it can be apparent through protests and court challenges of regulatory approvals and operations. Increasingly, mining companies around the world have taken an interest in stakeholder engagement and participation programs that facilitate better involvement with indigenous and other local communities. Some of these programs are legislatively mandated, and others are carried out on a volunteer basis. Each of the chapters in this section provides examples of community engagement programs or processes in which mining companies and local communities participated to elicit better project outcomes.

These programs and processes are diverse, including indigenous educational and jobs-training programs, community environmental monitoring, scorecard feedback of mining operations from local community members, and alternative methods for reviewing technical data to include the traditional knowledge of First Nations. The authors discuss some of the successes and failures of these programs and practices. They also raise important questions regarding the challenges that governments (federal and local), mining companies, indigenous populations, and local communities face in designing and implementing community engagement programs. Each chapter provides a list of lessons learned. These lessons portray an evolving dialogue regarding what is responsible mining in the context of community engagement.

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These chapters suggest that, at a minimum, responsible mining involves ongoing cooperative interaction between governments, mining companies, and indigenous and local communities. Second, mining companies are increasingly concluding that it makes good business sense to address social and environmental risks by engaging with local communities during mine scoping, permitting, and operations. Third, some mining companies have implemented important and successful practices of engagement, born out of many trials and failures. In particular, Peter Plastrik's case study on designing and implementing the Community Environmental Monitoring Program (CEMP) in Chapter 6 provides specific steps companies can take to build trust with local communities. These practices serve as best-practice examples to other companies whose activities affect resources important to local and indigenous communities.

Part II begins with Chapter 5 about a case study in Australia, where the 1993 Native Title Legislation requires mining companies to carry out vocational educational training (VET) programs for mining vocations. Although this legislation provided a framework for indigenous VET programs, the law lacked any concrete requirements for carrying out the programs, leaving companies to enact site-specific curriculums with little to no guidance. The authors examine the implementation and results of an indigenous education and jobs-training program for mining vocations in the Northern Territory. This case study documents a successful VET program to train and place Aboriginal peoples in mining jobs. It also describes the challenges of two other VET programs where many graduates do not have the necessary skills in literacy, mathematics, and/or work readiness to find and retain mining jobs. However, these programs appear to have some approaches and curricula that work well for developing other local employment skills. Therefore, despite the low success rate of hiring graduates from these two VET programs at mining operations, an Indigenous middle class is emerging that is developing its own commercial opportunities.

The importance of the social license to operate is well understood by mining companies. The foundation of social license is trust. At times, the public may not trust the environmental data gathered by a mining company and may also lack faith in regulators' commitment to protecting the environment. One way to build public trust in environmental data, and to involve the local community in gathering and interpreting the data, is to develop a CEMP.

The three case studies in Chapter 6 focus on building trust between a local community and a mine. For those interested in developing effective CEMPs at mining operations, the first case study presents methods for design and implementation of a CEMP.

The second case study in Chapter 6 provides details of the Eagle Mine's CEMP in the state of Michigan in the United States. The mine addresses the local community's skepticism about environmental data provided by the company and state

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regulators by funding independent monitoring through a local third party trusted by the community. The mine provides funding to a local agency, Marquette County Community Foundation (MCCF), to independently monitor the environmental impacts of the Eagle Mine. The MCCF established an oversight board with representatives from the environmental community, the mining industry, the community at large, and the local Native American tribe, Keweenaw Bay Indian Community. The Superior Watershed Partnership (SWP), a local nonprofit, is contracted by the MCCF to implement the CEMP by working with universities, contractors, and approved laboratories. The SWP monitors air quality, groundwater, surface water, wildlife, and plants, and then independently reports the results to the public, which is encouraged to provide input on additional monitoring activities. The CEMP transparently reports data to the public from a trusted source and provides a mechanism for feedback about future monitoring.

Chapter 6's third case study describes the Eagle Mine's community scorecard. Through real-time public feedback, those attending public meetings can vote using remote controls and view the results of everyone's voting regarding the mine's performance on various categories. Performance is ranked in five areas: environmental performance, local hires, safety, transparency and communication, and "leave more wood on the woodpile." This last metric refers to leaving a community better off through the growth of new and existing businesses; the amount of land set aside for biodiversity, recreation, and cultural use; and new and improved infrastructure. This effort is relatively new at the time of this writing, and the long-term effectiveness of this program in building community trust has yet to be determined. However, it certainly sets a progressive example of transparency and accountability for mining operations facing local community's opinions.

Chapter 7 is a case study that explores the experiences of West Moberly First Nations' implementation of a First Nations Independent Technical Review (FNITR) process. West Moberly First Nations conducted an FNITR of the Quintette coal mine environmental impact assessment in British Columbia, Canada. The FNITR process incorporated core principles: Aboriginal values, scientific rigor, and collaborative problem solving with members of the project proponent and Aboriginal groups (review team). Generally, an FNITR review team hires consultants to assist them. Consulting teams should be composed of persons with appropriate scientific and cultural training and credentials; they should be trained to examine scientific issues while taking into consideration traditional knowledge, including traditional ecological knowledge.

The FNITR has a five-step process that includes the review team screening and selecting project proposals for review; evaluating all technical documents; having technician-to-technician discussions; discussing face-to-face "Main-Table" workshops of all major issues; and providing community verification. Results from the Main-Table workshops are reviewed by community elders, chiefs, and councils.

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Their feedback is a critical part of the FNITR process. Through the Quintette coal mine FNITR process, project proponents and Aboriginal groups were able to collaboratively work together on a level playing field to evaluate the project documents and studies. Main-Table face-to-face discussions successfully incorporated traditional knowledge during the review process. This case study exemplifies how the FNITR process can successfully engage Aboriginal groups and mining project proponents in evaluating the environmental science, field investigations, and subsequent project design considerations necessary for mining project development.

Together, these three chapters provide an overview of how mining companies can engage local stakeholders, including indigenous populations, through employment programs, independent environmental monitoring, performance feedback, and technical review of environmental data for the inclusion of traditional knowledge. In particular, some of these progressive programs strengthen the environmental science behind a mine development by including local and indigenous knowledge and offering means for members of local communities to become data owners and gatherers.

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CHAPTER 5

Indigenous Engagement in a Vocational Educational Training Program in Australia

Cecil A.L. Pearson, Sandra Daff, and Klaus Helms

INTRODUCTION

Since the mid-1850s, mining in Australia has extraordinarily and unexpectedly shaped the destination of the nation. Resource extraction operations have sparked entrepreneurial activity, mining has been a magnet for high levels of immigration, and the operations have significantly influenced Australia's financial status. Indeed, the associated boom-and-bust cycles have not only made many people exceedingly rich in unanticipated ways, but the operations have ignited clashes over land ownership and mineral resources. From 1851 when the miners first scoured the Ballarat goldfields until the early 1990s, the mining industry had "been accustomed to almost uninhibited access to land" (Crawley and Sinclair 2003). After the 1993 Native Title Act legislation, however, international corporations have become major investors in the world of Indigenous Australians.

Broadly, Australian mining has been undertaken in three phases. First, there was the period of the alluvial miners, who dug the pits and drives to refigure the landscape with heaps of mullock in a process of leading to nationhood. Initially, in the 1850s, the search was for gold in the eastern states. When the surface ore bodies were depleted and gold was found at Coolgardie and Kalgoorlie in 1893, the mining activity moved to Western Australia. The economic focus shifted because the eastern colonies were in a depression, which led to tens of thousands of miners from the colonies of South Australia and Victoria coming to Kalgoorlie, bringing with them their radicalism and right to vote, a franchise that had been won in a violent rebellion at the Eureka Stockade in 1854 (Toscano 2001). These miners, tagged as the *T'othersiders* (miners from the other side of Australia), provided the

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impetus for a referendum on July 31, 1900, to transform the colonies of Australia into a federation of states.

The second phase of the Australian mining industry is identified as the rise of capitalism. By the 1880s, yields from the surface diggings were declining and the capital needed to mine the deep gold-laden quartz veins enticed the involvement of corporations in Australian mining activity. Notable was the birth of the richest mining corporation, Broken Hill Proprietary (BHP), in 1885. By the 1960s, corporate mining had transformed Australia because foreign investment was needed for the considerable capital required to maintain the mining boom—predominately in bauxite, coal, iron ore, and nickel. These extensive operations that were undertaken in licensing agreements between the miners and the Australian governments (federal and state), while dispossessing and marginalizing the local Indigenous inhabitants, provided a departure point for a land-rights-based agenda in Aboriginal affairs.

The third phase of the Australian mining sector development exemplifies an emergence of radical reforms to the previous antipathy toward acknowledging the rights of Aboriginal people. An *Indigenous person* is defined as a person of Aboriginal or Torres Strait Islander descent. When exploration and mining leases were granted by the Australian government for bauxite mining on the Gove Peninsula of the Northern Territory (NT) in the mid-1960s without the consent of the local Yolngu people, formal claims were made to the Darwin Supreme Court in the early 1970s (McNeil 1990; *Milirrpum* 1971) as the mining company was on Aboriginal land. Although the initial legal application by the Yolngu people (*Milirrpum v. Nabalco Pty Ltd and the Commonwealth of Australia*) was unsuccessful, public debate and pressure from the local and international communities, together with a range of other actions from the 1960s to the 1980s (e.g., Ranger and Jabiluka Uranium mines in Kakadu National Park, Noonkanbah Station) (Banerjee 1999; Hintjens 2000), promoted constitutional reforms to dismantle structural barriers to civic equality of Indigenous Australians. Incessant momentum for the rights of Aboriginal people led to the historic 1992 Mabo decision (*Mabo v. Queensland* 1992) by the High Court of Australia, recognizing that Indigenous people are entitled to native title. Within a year, the 1993 Native Title Act legislation was enacted by the Australian federal government to profoundly change how mining companies are involved in the sponsorship of Australian Indigenous educational, vocational, and community activities. Previously, community interaction was secondary to the technical aspects of operating a mine, but today there is a concerted drive for community engagement practices.

This chapter embraces how these several nominated factors have collectively divided and forged the lifestyles of the inhabitants on the Gove Peninsula of the Northern Territory. Preluding the contemporary mining period is an account of the historical heritage of Arnhem Land, which is the expansive homeland of the

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Yolngu clans whose forebears were the first immigrants about 50,000 years ago. Later generations were among the first Australian international entrepreneurs who traded with seafarers from the 1600s for more than 300 years. Written records also reveal that in the early twentieth century, Methodist missionaries began to develop the coastal regions. In 1928, the Reverend Shepherdson built a sawmill at Milingimbi (that in August 1942 was transferred to Elcho Island) and the Yolngu people were engaged in the business of merchandising a soft wood timber industry for more than 50 years (Shepherdson 1981; Trudgen 2000). This section is followed by descriptions of how the alluvial high-grade bauxite ore deposits on the Gove Peninsula were found, how the development of the infrastructure to refine the ore to alumina led to a significant change in demographics (reverse immigration), as well as the results of initial endeavors to engage the local Indigenous communities in the mining operations. Greater attention will be given to the unique Indigenous vocational educational training (VET) program that was installed at Nhulunbuy in 2007 and continues to be sponsored by the resident mining corporation. The challenges to prepare members of the local and more distant Indigenous communities to become participants of mining workforces or incumbents of sustainable mainstream vocations are delineated. The places of interest mentioned in this chapter are presented in Figure 5.1.

BEGINNINGS

East Arnhem Land is the homeland of the Yolngu clans. Within this area of 97,000 km^2 is Yirrkala, which is one of the remaining early coastal settlements, and the most recently established townsite, Nhulunbuy. Yirrkala was founded by Methodist missionaries in 1935, whereas Nhulunbuy was created as a closed town in 1968 to service the developing nearby mine site and the refinery. Archaeological, linguistic, and historical evidence documents that the forebears of the current Yolngu people came by way of a land bridge to inhabit northern Australia from southern Asia (Muir 2011; Suter 2003). Much debate has been undertaken that Chinese mariners may have visited northern Australia long before the earliest European voyagers sighted the same coastline in the sixteenth century. More definitive is the written evidence that Arnhem was the name of the ship captained by Willem Joosten van Colster when he sighted the land in 1623. Macassan fishermen from the southern Celebes (now Sulawesi) visited annually from the mid-1700s and conducted extensive trade with the Yolngu clans for nearly 300 years (Berndt and Berndt 1999; Worsley 1955) until the South Australian government, then responsible for the Northern Territory, cancelled their fishing licenses in 1904.

During 1911, the Australian federal government assumed responsibility for the Northern Territory and the welfare of the Indigenous Yolngu. In 1912, an interdenominational committee of churches with an explicit interest in Australian

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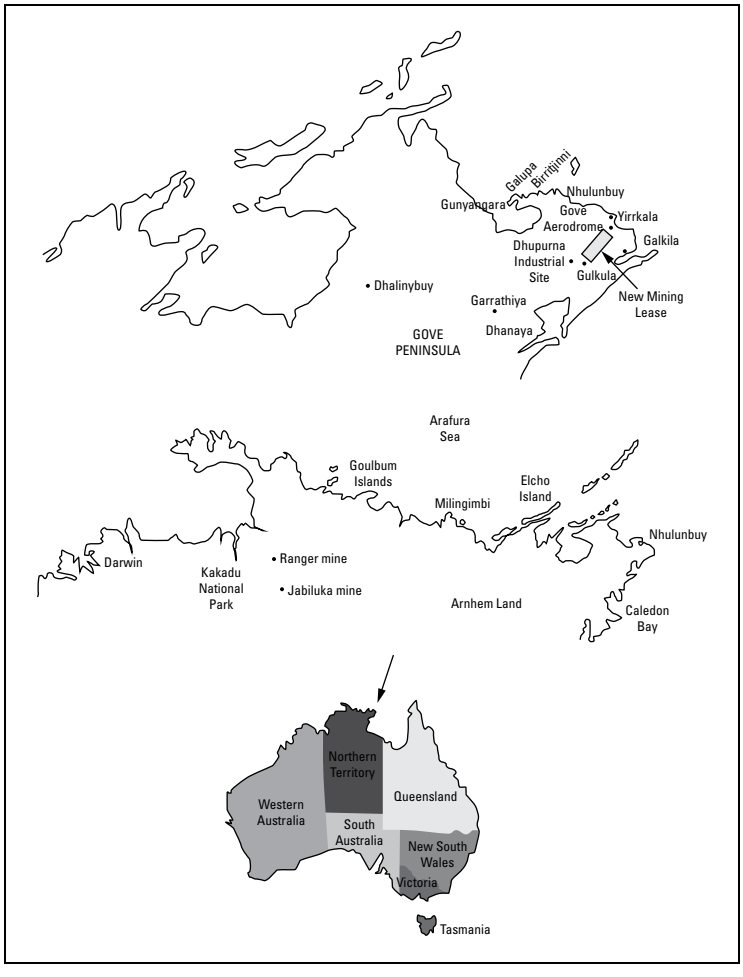


Figure 5.1 Gove Peninsula and places of interest

Aboriginal missions was formed. By 1913, this entity had negotiated with the Australian government to establish missions in the Northern Territory. The Methodist Church Mission was established in South Goulburn Island in 1916, which was followed by missions on Elcho Island in 1922 and Milingimbi in 1924 (McKenzie 1976; Shepherdson 1981) to provide education and health services as well as physical and religious sustenance to the congregated populations of Indigenous people.

In 1935, two church buildings were constructed at Yirrkala. This work was done by the Reverend Shepherdson, two Yolngu carpenters, and the Indigenous community members with cypress pine that was transported by lugger from Milingimbi. But by the mid-1960s, technological advances in newer building materials eroded the importance of cypress pine timber. In addition, the NT government assumed

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responsibility for health and education, two of the core functions of the missions. Consequently, the missions became anachronisms and the Yirrkala mission closed in 1975. However, local events during the World War II had profoundly changed the lifestyle of the Yolngu clans long before the closure of the Yirrkala Methodist Church Mission.

Almost a century after the Victorian gold miners began shaping the destiny of Australia, alluvial operations on the Gove Peninsula became the catalyst for the first Australians' land rights movement. In the early 1940s, the escalating aggression by the Japanese in northern Australia led to numerous military aerodromes being constructed in the Northern Territory, including Gove, which is 15 km southeast of Nhulunbuy. The Gove Peninsula acquired identity in 1943 when Sergeant William Julius Henderson Gove was killed at Rabuma Island, near Milingimbi, while flying an American Hudson bomber. The original Gove 1,524-m airstrip was constructed in late 1943 by number eight Mobile Works squadron, but when gravel was unavailable, high-quality bauxite ore was used (Department of Defence 1978). In 1951, the Australian Aluminium Commission requested the federal government to reserve the bauxite deposits, and in 1954, British Aluminium began a program of exploration of the Gove and Melville Bay regions that was later extended in the 1960s by Klaus Helms and a small band of Yolngu men. The Commonwealth Aluminium Corporation Pty Ltd (COMALCO) was granted a special minerals lease near the Yirrkala Methodist Church Mission. However, during 1956 the COMALCO lease was canceled, allowing Swiss Aluminium and a group of Australian companies to form the Northern Australian Bauxite and Alumina Company (NABALCO), but opposition to the development on Aboriginal land near Yirrkala was beginning to arise in the Yolngu clans.

Opposition to the mining activity on the Gove Peninsula gained momentum during the 1960s and 1970s. The Yolngu elders created the Bark Petition with illustrations proclaiming Indigenous law, and this remarkable document of sacred designs and English words was presented to the Australian Parliament in Canberra on August 14, 1963. Nevertheless, the federal government deemed the mineral extraction project to be in the interest of Australia, and leases for a mine site, a refinery, and the region around the new town of Nhulunbuy were granted in 1968. Greater social dislocation was to follow when alcohol became available and badly affected the Yolngu community. Consequently, the Yolngu elders sought legal action in the Darwin Supreme Court to have the liquor license of the Walkabout Hotel revoked, but this case was lost. Substance abuse in the large Yirrkala Indigenous population (as well as other nearby Aboriginal communities) escalated and, coupled with grievance for the lack of consultation by the Australian government and NABALCO, led to a mass exodus of the Indigenous people back to their ancestral homelands on the Gove Peninsula (Altman 2003). Legal dissent continued, and when it was combined with the broader Aboriginal movement, the establishment of land rights legislation followed.

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MINING AND THE CHANGING SOCIAL CLIMATE

To deal with the implications of the Mabo High Court decision, the Keating Labor Government introduced the 1993 Native Title Act legislation. Procedures to retrospectively validate land title of occupiers, together with mechanisms for addressing native title claims, were key elements that were accepted in a historic compromise by the Indigenous community (Barker 2006; Hogan and Tedesco 2003). Acceptance was in exchange for guaranteed rights of the Traditional Land Owners, on whose land the mining operations were to be conducted, to negotiate land-use agreements (Brereton and Parmenter 2008). Although these agreements contained direct financial benefits, a prominent feature that rekindled interest in Indigenous well-being was the provision for training and employment of local Aboriginal people (MCA 2011). These ideals were not fully implemented on the Gove Peninsula until 2012 when the Ralpa and Goyurr VET programs were installed. The historical journey toward this significant outcome was strongly influenced by the political, economic, and corporate rationalism prior to 1993. In short, colonial relations operated in a post-colonial era.

Mining-Related Jobs and Training

In spite of the continual opposition by the Yolngu people, the Australian government granted leases to NABALCO. Years of exploration from the 1950s had confirmed large deposits of commercial-grade bauxite, and the Australian government granted a lease agreement for exploration and mining to be conducted for 42 years in the designated area. During 1968, a feasibility study was undertaken for a 500-metric-tons-per-annum (Mt/a) capacity alumina refinery, a mine site, and a fully serviced town together with a range of auxiliary features for administration and service provisions for the region (The Gove Bauxite Development 1968). Construction began the following year, and mining commenced in 1971.

Three main types of mine-related jobs were available for Indigenous people during the construction phase. A number of young Yolngu women were employed in a large industrial laundry to wash and iron bed linen for the non-Indigenous workers. However, these women left their jobs when the clans returned to their ancestral homelands in the early 1970s. The second stream of work arose from a considerable demand for bricks. The Yirrkala Brickworks, later to become Yirrkala Business Enterprises (YBE), was established in 1968. Under non-Indigenous supervision, a number of Indigenous men made sand cement bricks, but when the building program drew to a close, their employment ceased. The third main stream of Indigenous employment was at the refinery site where several Yolngu men were engaged in semi-skilled or laboring work. However, once the refinery was operating, NABALCO ceased to employ Yolngu people. In their book *Aboriginals and the Mining Industry*, Cousins and Nieuwenhuysen (1984) say that NABALCO claimed the Yolngu people did not meet the technical skill or work ethic requirements

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for the available positions. These authors report as late as 1982 that no Yolngu people were directly employed in the mining and refining operations on the Gove Peninsula.

The regulatory regimes of the Australian mining industry decisively influence the entry level of employees regarding formal education and training. Most people working in the Australian minerals industry have either a trade qualification or a university degree. Additionally, they must be older than 18 years of age, physically fit, and committed to safety, and they must attend punctually and regularly, be prepared to work in remote areas in difficult conditions, and be 100% free of recreational drugs and alcohol (Banks 2003; Industry Snapshots 2010). Seldom are the Yolngu people able to fulfill these regulatory conditions. In the bilingual education system of the Northern Territory, Indigenous people are unlikely to embrace English or numeracy studies until the final years of primary school. Consequently, few of them successfully complete secondary school (Hughes 2008; Kral 2009; Pearson and Daff 2010). Long-standing evidence reveals that the Australian Indigenous people have suffered marginalization and exclusion from mainstream educational institutions, and understandably this sector of society lacks critical literacy and numeracy competencies (Gray and Hunter 2002; Prime Minister's Report 2010).

Creation of an opportunity pathway for local Yongu people to acquire contemporary mainstream work skills and be eligible to participate in the Gove mining workforce was to take almost three decades. When the intensity of construction declined after 1972, the brickworks facility closed and the YBE diversified into transportation and earthworks—all jobs for skilled operators. While the Gove extractive mining operations expanded, the regional infrastructure increased, and Aboriginal support groups evolved and flourished (often with non-Indigenous managerial and administrative personnel, and government funding of Indigenous assistance programs). Overall, the Yolngu unemployment rate remained high in a rapidly growing Indigenous population (Altman et al. 2005). However, during the 1980s "the worldwide interest and debate about ethics and social responsibility of business" was gathering traction (Coronado and Fallon 2010). Criticisms for failing to seriously consider the social and economic impacts of Australian mining activities on the local Indigenous community were beginning to be voiced internationally and in mass rallies on the streets of Australian cities. Political and corporate pressures were aligned to establish a VET scheme at Nhulunbuy for Indigenous people in 2000.

NHULUNBUY INDIGENOUS VET PROGRAMS

At Nhulunbuy there have been three distinct endeavors to operate Indigenous VET schemes. The first program was the Y(BE) N(ABALCO) Operator Training Scheme (YNOTS), which was installed on July 16, 2000, to improve employment

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opportunities for Yolngu men. Flowing from YNOTS was the Arnhem Learning Education Regional Training (ALERT) scheme. This initiative began in mid-2007 and continues to be sponsored by the resident mining corporation on the Gove Peninsula. The third scheme, which is a variant of ALERT with specific features of Indigenous ownership and objectives, has streams named Ralpa and Goyurr that were to become operable within 6 months of signing the historic land-use agreement in 2011. Each of these three specific VET schemes are described in the following sections.

The YNOTS Program

YNOTs was a tripartite initiative between YBE, NABALCO, and the Australian federal government Department of Employment and Workplace Relations. These partners expressed commitment to the training and development of local Yolngu people, and, in particular, the graduates (men) would be licensed as moveable machinery operators with a Certificate II in open cut mining (metalliferrous). Initially, training was undertaken on the NABALCO mine lease 22 km from Nhulunbuy (beyond the Gove airport) where the trainees could operate earth-moving equipment. In the second year, the 30-week program was extended to provide job opportunities for Yolngu women as well as men. A number of modules, including literacy, numeracy, communication, and management, were offered to focus effort on preparing Yolngu people for mainstream jobs in the wider community.

Paradoxically, success underpinned the demise of YNOTS. By 2004, the resident mining operator was Alcan Gove, and the company began in that year to undertake a massive expansion program. The refinery, which at that time had a capacity of 1.9 Mt/a of alumina, continued to operate while being expanded to have a capacity of 3.8 Mt/a by 2007. Policy dictated this action would secure the future of the region and deliver major ongoing economic benefits locally and nationally. A local workforce of nearly 2,000 people would be required to work more than 35 million hours, and the expenditure was estimated as US$2.5 billion in less than 4 years.

Extensive temporary accommodation was established in Nhulunbuy for a new immigrant skilled construction workforce. But it was recognized there would still be a shortage of labor, and the decision was made to transition YNOTS from a training and development program to a labor pool. The YNOTS personnel undertook stevedoring functions when unloading some 630 preassembled models that were shipped from Asia. Each module was at least 4,000 t, and, in addition, 18,000 t of structural steel and 120 km of pipes were unloaded at the port and moved to the refinery site. Refurbishing the 17-km conveyor belt (from the mine to the refinery), which was vital for increasing production capacity, and undertaking massive civil construction works as well as a variety of industrial type tasks

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Figure 5.2 Nhulunbuy ALERT training school

was the new course for YNOTS. When the expansion was completed in 2007, the labor demand evaporated; YBE now had an experienced team of workers and was unsympathetic to recommencing YNOTS. More importantly, the new mining corporation Alcan Gove saw an opportunity to divest the NABALCO experiment, as the mining corporation had a new vision for Indigenous VET, and this new direction was the genesis of the ALERT scheme.

The ALERT Program

The primary objective of ALERT was to prepare Indigenous Yolngu for working in mainline jobs in the Nhulunbuy refinery. Despite the intention of Alcan Gove to install a 36-months scheme commencing in 2007, a fundamental priority was to garner support from a wide array of stakeholders. The identified relevant constituents were the Traditional Land Owners, Indigenous organizations (national, tertiary, local), Australian governments (commonwealth, state, local), educational institutions, the wider business community, the mining industry, and, importantly, the local Indigenous people. Once the ALERT program commenced, records were maintained of the educational and vocational achievements of every applicant. ALERT graduates have completed a nationally accredited program that has been delivered at the Nhulunbuy Technical and Further Education (TAFE) premises or the ALERT training center (shown as Figure 5.2) to the stringent conditions of the Australian VET system. This certification enables entry to an Australian mine site or refinery.

Attention was given to the expected linguistic and numeric competencies of the ALERT applicants. Logistical issues and managerial direction determined that each ALERT intake would have 15 candidates with two programs per year. An equitable selection process for Indigenous applicants who were overly dependent on welfare, structurally detached from the labor market, and who had an acknowledged literacy and numeracy deficit (Hughes and Warin 2005) precluded the use of standard Western pen-and-paper recruitment procedures.

A search of nonliteracy and numerary selection practices revealed two potential schemes. First was the Raven Test, and second was the Queensland Q Test.

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However, both of these systems have boundary conditions. The Raven Test is available online, allowing contemporary candidates to become increasingly experienced with the test profile. Indeed, it has been demonstrated that the mean scores have regularly increased over time irrespective of the country of testing. The Queensland Q Test, although empirically sound, has a different set of restrictions. A skilled psychologist is required to administer the test, and a psychologist is needed to interpret the results. Moreover, the Q Test is a propriety licensed tool and, therefore, is subject to commercial application. Using the Q Test is not only a recurring expenditure, but it is labor intensive and can only be employed at the convenience of the owner firm, not the mining company. Overall, these caveats are considerable barriers in remote regions, such as Indigenous outstations, which encouraged diversification into an alternative system.

Author Pearson was invited by the resident mining corporation to design an oral-based tool for assessing whether the Indigenous ALERT applicants were capable of learning industrial work skills. An instrument devoid of written symbols was prepared, pilot tested, and has been used with all ALERT applicants since May 2007. A primary objective of employing the instrument was to discover the level of 18 aptitudes possessed by a candidate, so the tool was labeled the Discovery Session 1. According to the seminal work of the renowned American motivationalist E.E. Lawler (1973), an *aptitude* is a function of ability. Hence, the scores on the aptitudes become surrogate measures of ability. Five years of data have been evaluated to demonstrate that the Discovery Session 1 is a reasonable predictor of employability (Pearson and Daff 2011).

Participants

ALERT participants are Indigenous Australians. A requisite entrance qualification is a certificate of Australian Aboriginality. Both genders are entitled to apply to join the program, but they must be older than 18 years of age. Initially, ALERT attracted Yolngu people from the outland centers of Galaru (now closed), Galupa, Gunyangara, and Yirrkala. All of these centers are within a 15-km radius of Nhulunbuy, as the candidates had to be transported daily to and from the training center by a mining corporation bus. In late 2009, the mining company was able to provide single-person, fully messed accommodations at Nhulunbuy, enabling the catchment area to be extended. Coupled with this action that same year, the ALERT program was awarded the most innovative education vocation scheme by the NT Department of Education and Training, which led to a surge in applications. The melding of these two events enabled the catchment area to be extended, not only to more distant centers homelands on the Gove Peninsula but across Australia. A favorable outcome was that the applicants were more literate and numerate, and many had previous work experience. Notably, applicants from regions outside the Gove Peninsula who were accepted into the ALERT VET

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program (after 2009) had statistically greater employability duration than local Yolngu participants.

Since the beginning of 2012, only local Yolngu people have been ALERT participants. The engagement of this select clientele has been a deliberate outcome of the historic Land Use Agreement (LUA) that was signed at Yirrkala by the Australian prime minister (Julia Gillard), the Traditional Land Owners (Gumatj, Rirratjingu, and Galpu clans), the Northern Land Council, and the mining corporation (Rio Tinto Alcan) on June 8, 2011. By November 7, Leaders of the Traditional Land Owners had agreed to the formation of a working group, represented by the Gumatj and Rirratjingu clans and the mining operator Pacific Aluminium. This three-member body was assigned the responsibility of developing a Regional Employment Strategy, which was in accordance with Clause 11.2(a) of the LUA. On Thursday, December 1, 2011, the working group met and identified a number of critical issues that had to be considered for achieving short-term and long-term educational and vocational goals.

The Ralpa and Goyurr Programs

The short-term objective of the Regional Employment Strategy was to quickly get Indigenous people into jobs. Hence, the evolution of Ralpa, which is translated from the home language/mother tongue as "get moving quickly." The urgency to place unemployed Yolngu people in jobs within 3 months, to create jobs, and to form partnerships with industry and government was identified. Pathways for involving families and ensuring community support in the collective Indigenous societies was recognized as an integral component of the short-term strategy. The long-term issue of preparing children for the future was a more distant aspiration. The working group recognized that getting younger people to learn the relationships of going to school to receive an education in order to engage in work would be a longer, worthwhile process to be achieved through building education partnerships with the local schools. Consequently, the working group prepared a list of "green jobs" (preserving or restoring environmental quality) that Yolngu people could do with a short period of training, as the first 8-week program was scheduled to commence with 15 Yolngu people on January 30, 2012.

The participants of the first four Ralpa (and one Goyurr) programs held a range of endowments. Of the five programs completed by mid-2013, almost one-third of the participants were women. Most of these women (n = 21) were in the second program (named Goyurr, meaning "a journey"), the majority of them lived at the Gunyangara Aboriginal community, and several of the ladies had small children. To enable the women to attend the Goyurr program, the men of the first Ralpa and earlier ALERT programs had built a school at Gunyangara where the children would be left in the morning at 7:30 a.m. and supervised for the day. Both genders exhibited a range of work-related behaviors, demonstrated as nonpresenting on the

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first day, irregular attendance, and presenting with an alcohol reading higher than zero, while other participants had an attendance rate of 100%. Although some did not graduate, a majority did and those who graduated were awarded a certificate at the graduation ceremony. Some of the candidates were fluent in English, and others could read and write English to an acceptable level while being more orally proficient. A number of the women were English deficient and were more comfortable speaking in their home language/mother tongue. However, these features were not a learning barrier of significance, as within the classroom or at work sites, the problem space and pragmatic solutions are determined by bilingual members engaging with colleagues in effective transactional communication (Pearson and Chatterjee 2010). A handful of the participants had been in employment, often in Indigenous organizations, and were able to return to their company enriched in work practices. The Gumatj Corporation, which arguably is the largest employer of Indigenous people on the Gove Peninsula, has announced that the firm will only employ Yolngu who have graduated from a Ralpa program. All of the Ralpa (and Goyurr) graduates have been offered mainline jobs in the Nhulunbuy region.

Candidates of the Ralpa and Goyurr programs usually began work on the first day. In the morning, the participants attended the ALERT center and the TAFE premises. During the afternoon, the Ralpa and Goyurr trainees worked in green-type jobs at the ALERT center, in Nhulunbuy on mining company property (e.g., special accommodations, grounds of mining houses and town flats), or on Aboriginal projects in Indigenous communities. Initially, the focus was on gardening-type work such as mowing lawns, pruning shrubs, raking and clearing grounds, which require care and safe working practices with small power and hand tools. As the candidates gained more exposure to the course work at TAFE, they were able to diversify into more complex jobs like catering in the Sodexo kitchens, building maintenance, log conversion to timber, horticulture, and furniture making at locations other than the mine site or the refinery.

The ALERT, Ralpa, and Goyurr Scaffolding

A major challenge for the deliverers of the Nhulunbuy Indigenous VET programs was a lack of epistemology. A strategic pathway for Australian Aboriginal education and training for employment in the national mining sector is infrequently delineated. Most of the literature is normative and founded on secondary information, emotionally flavored, and inclusive of percentages to hide missing data as well as relevant microlevel information. The disclosure of the work roles of Australian Indigenous employees by branding them as semiskilled or laborers deceptively conceals their competencies or key skills. Furthermore, the accreditation from training and development programs in terms of the Australian Quality Training Framework is seldom disclosed. And while commentators and others argue that the information is commercially sensitive and restrictive to the particular LUA, this position is not

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helpful to practitioners responsible for designing and installing VET programs for improving the participation rate of Australian Indigenous people in mining work forces. Consequently, the deliverers of the Nhulunbuy Indigenous VET initiative were obliged to identify relevant underpinning linked to cultural, social, and economic principles to facilitate evolutionary implementation approaches.

Working with Indigenous communities is a cornerstone for engaging participants of the ALERT, Ralpa, or Goyurr program. Embracing family and community support is a bottom-up approach that strengthens the capacity to respond to emergent crises and unforseen events that arise during the program. A demonstration of community support was reflected in an early ALERT program when a small group of male Yolngu elders visited the center to enquire about the progress of a particular male candidate. When told the person was absent and had not attended for several days, the men moved away and, out of earshot, were seen to be using their mobile phones. The next day and thereafter, the "absentee" was present, as men "talk" discipline to men. Preparing Indigenous people who lack literacy and numeracy competencies necessary for working in contemporary mainline jobs, and especially in the Australian mining industry, is a daunting task. A reluctance to attend class and learn behaviors considerably different from the more common activities of hunting and fishing may be reconciled by the intervention of family members and/or by legitimate community leaders. Connections between these individuals define their identity through a set of beliefs, values, and customs that require additional considerations, as they are impacted by the realities of modernity and the displacement of traditional roles.

Long before a Nhulunbuy Indigenous VET program commences, there is a strong element of family and community engagement. Deliverers of the programs visit the communities and speak to family members, elders, community groups, and unemployed Indigenous people to advise of the start date and the content of the next ALERT, Ralpa, or Goyurr program as well as the job opportunities. Sometimes this is done on a one-to-one basis while on other occasions there may be a local exposition to attract a large congregation that can obtain information from attending government and industry groups involved with training and career development of Indigenous people. As Indigenous people regularly move to different geographic locations, the local media (press, TV) and mobile telephones are used to contact those who were unable to attend the formal meetings, with the expectation that the relevant message is conveyed across the community spectrum. Follow-up calls and visits are undertaken by the ALERT personnel, and Indigenous people are welcome to visit the center or telephone staff. Other federal government departments that share responsibility for funding Indigenous training and vocational initiatives on the Gove Peninsula are also connected with the Indigenous communities and the ALERT infrastructure. Also employed, but likely to be less impacting in the Yolngu oral culture, is a host of publications outlining a collective

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set of Indigenous training and vocational information that feature photographs of ALERT, Ralpa, and Goyurr graduates at work. Over time, these approaches have been refined from only oral, personal, and print mechanisms to now incorporate Websites likely to be more attractive to the younger Indigenous population.

There has been considerable refinement to the pedagogy and structural design of the initial Nhulunbuy Indigenous VET program. In 2007 when Alcan was the resident mining corporation, the ALERT scheme was designed to have a

- One-week induction period,
- Three months in work preparation,
- Four months in the work readiness period, and
- Twenty-nine months in the work-starts period.

On completion of these stages, the graduates would be awarded a Certificate I in Resources and Infrastructure Operations and would be eligible for employment in mainline jobs in the Australian mining sector.

The need for a relatively long education vocation scheme was substantiated during the selection process. Interviewing candidates revealed a lack of work experience, and from the use of flash cards, seldom were the English reading ages beyond year two primary school. A 3-month period (4 days a week) to get participants ready to start training and build their confidence to commit to learning and training, followed by a 4-month period (4 days a week) to instill work habits of attendance and punctuality, to learn how to listen and follow instruction, and to begin to manage their social, cultural, and work obligations was considered to be a sound foundation for work starts. During a 7-month period of time, an adult learning pedagogy was used to develop a practical level of the five core skills (learning, reading, writing, oral communication, numeracy) of the Australian Core Skills Framework. While the inaugural Yolngu apprentice was to evolve from the first ALERT program, and there were eight graduates from the first two programs, the obverse result was that one-third of the trainees withdrew while another one-third returned to their communities. Although the pragmatic principles of selection, induction, and vocational training continue to be endorsed in the Nhulunbuy Indigenous VET programs, substantive shifts in the operational contexts have led to significant changes in the course content and pedagogical delivery.

The first major change to the Nhulunbuy Indigenous VET program was in late 2009 when accommodation was made available for nonlocal participants, while the second renaissance was provided by cultural underpinning in 2012. The unexpected availability of single-person, fully messed accommodations provided an opportunity to substantially extend the catchment area. When coupled with large numbers of applications while constrained by the limit of 15 persons at each bi-annual intake, the program deliverers were compelled to install a rigorous selection process. A more intense induction was conducted as a 1-week residential course, enabling the

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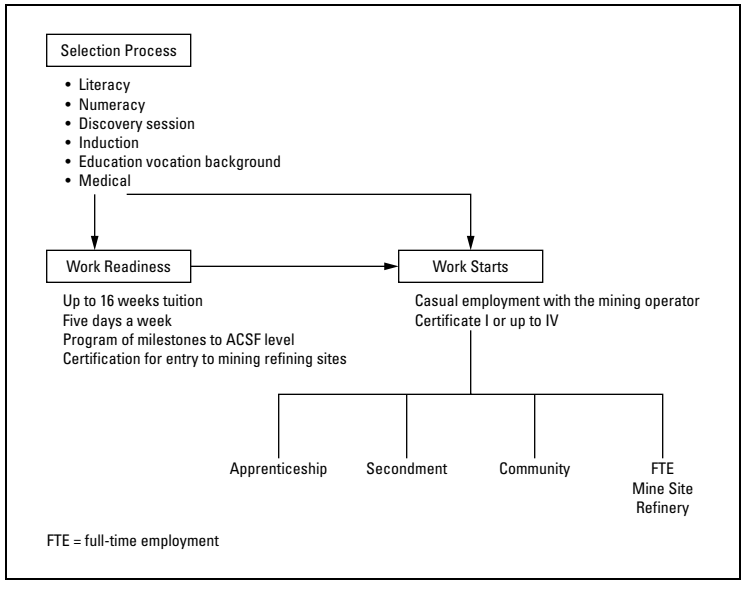


Figure 5.3 Core elements of the ALERT program

gauging of team-related aptitudes (Discovery Session 3) and a close observation of other work-related behaviors. Candidates with lesser vocational attributes (literacy, numeracy, aptitudes, work experience) were offered the Work Readiness module, while those Indigenous candidates with higher employability potential were offered a work-starts contract. Greater delineation of the scheme is presented in Figure 5.3.

The second substantial directional variation to the Nhulunbuy VET program was subsequent to the 2011 lease agreement. Indeed, the historic 42-year LUA has a dedicated section containing guidelines for the Traditional Land Owners to formulate a regional employment strategy for Indigenous people, and this initiative has shaped the Nhulunbuy VET programs of Ralpa and Goyurr. Although the agreement is a negotiated commitment of the Traditional Land Owners, the Australian government, and senior executives of the mining corporation, it is vital that the spirit of the sensitive content is translated into the training and employment of the Indigenous participants. Specifically, an inference of the content has been provided to the deliverers of the VET programs as objectives to be pursued. Vocational training is to be undertaken for 60 jobs per year, with 50 in the Indigenous communities and another 10 as direct or indirect positions of employment in the Nhulunbuy mining operations. For instance, a graduate of the larger group is likely to work in a local Indigenous organization (i.e., Bunuwal, Dhimurru, Mungurr), while graduates of the smaller group may be employed at the mine site or refinery, or they could also be working for a subcontractor (e.g., Giovenco, Gumatj Corporation, Sodexo) that provides a service for the mining corporation.

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Within these guidelines there are caveats. Resource implications sustain the limit of 15 Indigenous people per intake with a maximum of three programs per year. A second caveat is the focus on the geographical distribution of the participants with emphasis on local Yolngu residents. The order of selection priority is

1. Yolngu,
2. Nhulunbuy region,
3. Northern Territory, and
4. Elsewhere in Australia.

The third caveat is vocational experience and educational qualifications. For instance, previous work history is a promotional requirement for 10 chosen Indigenous people (per annum) to participate in an intensive fast-track course of 4 to 6 weeks in duration. Preference will be given to those applicants who have successfully completed their formal education to a minimum of year 10 (third year of secondary school). A fourth caveat is provision for one ALERT program to be completed per year providing a career path for chosen applicants or outstanding graduates of Ralpa or Goyurr programs to advance into a mining sector career. Collectively, these features provide a great deal of flexibility in the preparation of sustainable Indigenous VET programs at Nhulunbuy.

The short-duration Ralpa and Goyurr programs are sensitive to regional interests. Ralpa is an 8-week program while Goyurr is conducted over 6 weeks, but the implementation of both schemes reveals commitment to sustaining and nurturing partnerships between the deliverers of training, stakeholders who can provide employment, supportive government agencies, and local Indigenous communities. Since the first Ralpa program, these linkages have been facilitated by innovative and flexible approaches in the pursuit of aspirations of the Indigenous people, the mining corporation, and the wider community. Industry representation led to the birth of the Goyurr scheme when the international service corporation Sodexo sponsored the program as a corporate social responsibility agenda. At Nhulunbuy, Sodexo is responsible for the quality of life services (catering, security, technical maintenance) for single-person accommodations at Arnhem Village (710 occupants) and Gove House (431 clients). The partnership with Sodexo enabled customized training that was uniquely useful and explicitly relevant for employment in the company or within the local community.

The Ralpa and Goyurr programs had similar timetable patterns. In the week prior to commencement of the program, there were 2 days of orientation. Despite the family signing a contractual agreement with Indigenous leaders and the mining company, expressing that the trainee intended to present punctually and regularly throughout the program, these two orientation days were effectively a "cooling-off" period. Those trainees who continued with their agreement were transported each morning from their Indigenous community to the ALERT center, arriving about 8:15 a.m. where they first voluntarily completed a Breathalyzer test. Those who

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registered higher than zero were returned home while the remainder changed into personal protective equipment (PPE) (reflective jacket, long pants, boots) to begin the day's schedule. At Australian mine and refinery sites, a lack of work fitness (including recreational drugs, alcohol, and health issues) is unlawful. Offenders are immediately removed from the workplace, counseled, and reprimanded. It is usual for dismissal to follow the third offense.

A program day is structured into two main sessions (before and after lunch), each with repetitive formats. After donning the PPE, trainees are assembled in the classroom and prepared for the first activity each morning, which is a vehicle inspection by pairs of trainees under supervision. Within half an hour, this activity is completed and all the trainees are reassembled in a classroom where they are addressed by a guest speaker who talks about personal welfare and work. For example, on the first day, Indigenous leaders come to welcome the trainees to the program and tell the gathering about the job opportunities for graduates. The general manager of the mining operator independently welcomes the trainees. On other occasions, medical representatives discuss health issues and personal hygiene, at home and at work; small-business owners come to talk about job opportunities; and the police attend to demonstrate with special goggles the effect of alcohol and, consequently, how substance abuse is detrimental to social and vocational lifestyles. To close off the morning session, the focus is on expectations of employers, notions of how to prepare to do a job safely, care of equipment, and working safely with team members. Often these concepts are taught/learned through experiential learning either at the ALERT center or at TAFE. After lunch, the focus is on work sites, initially as tours and visits (e.g., Sodexo warehouse, industrial laundry, Gunyangara furniture shop), but by the second week the trainees are working at these sites. On returning to the ALERT center, the trainees place their PPE into the washing machines and at 4:30 p.m. are transported home. Ralpa and Goyurr programs are 4 days a week, and trainees are paid for attendance.

PROGRAM ASSESSMENTS

The ALERT, Ralpa, and Goyurr programs were assessed with perceptual and objective data. Perceptual data were provided by the assessors. The assessors observed and gauged the behaviors of the ALERT respondents when they completed the six tasks of Discovery Session 1. Objective data from the ALERT participants were provided as

1. The English reading age in years;
2. The length of time in months a trainee was in the work readiness stage; and
3. The length of time in months a trainee was in the work-starts phase.

Statistical comparisons between the Yolngu and other Indigenous participants of the ALERT program were undertaken. The vocational career paths of the

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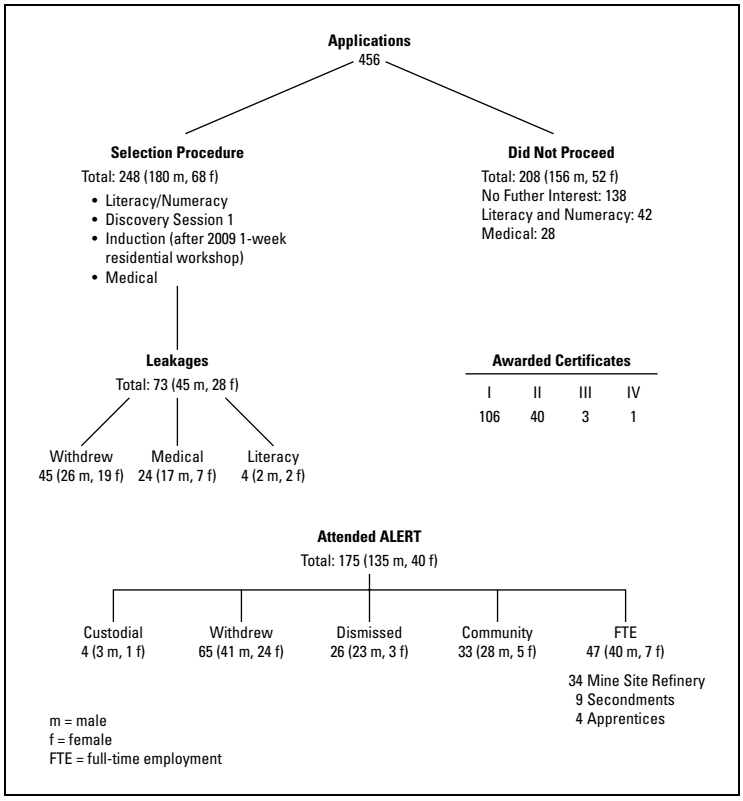


Figure 5.4 Vocational and educational pathways of the ALERT program from May 2007 to July 2012

ALERT, Ralpa, and Goyurr participants are delineated in Figures 5.4 and 5.5 as well as a sample of job types pictorially presented in Figure 5.6.

ALERT Participants

Applicants were selected after a comprehensive assessment process. Before attending an interview session, the applicants were required to provide evidence of relevant educational and vocational documentation as well as nominating two referees who were independently interviewed. Local Yolngu candidates, who often did not possess more than a rudimentary formal education and had not been exposed to industrial-type work, were generally appraised from character references. Included in this process was a high level of informal family and community enthusiasm and support for the candidate who completed a formal contract acknowledging commitment to punctual and regular attendance to the ALERT framework. After reviewing the accumulated information, potentially successful candidates were invited to attend a selection appointment.

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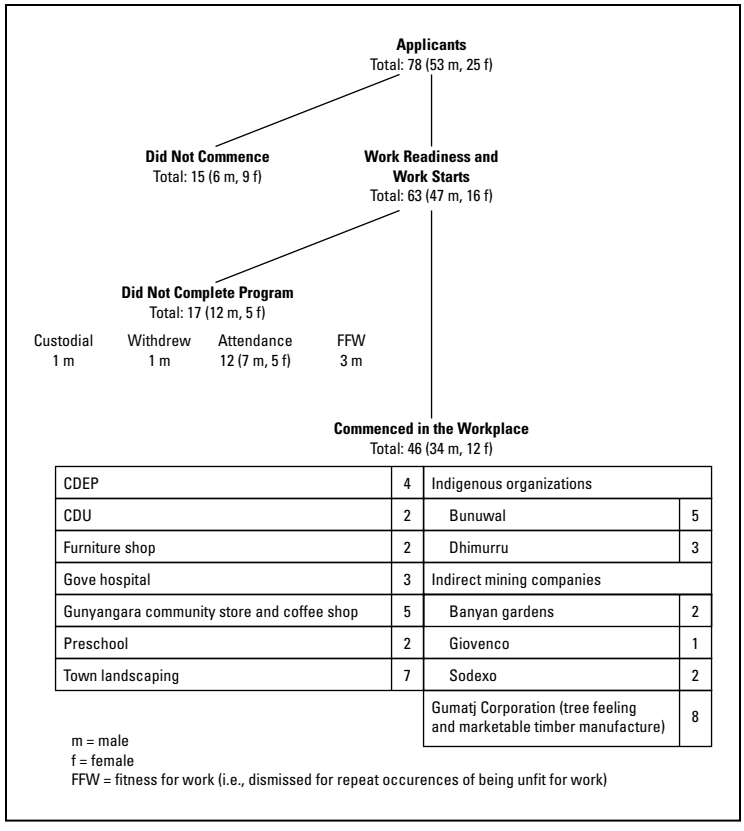


Figure 5.5 Vocational career paths of Ralpa and Goyurr applicants

During the selection process, applicants were evaluated in three ways. First, literacy was superficially assessed with flash cards, each one with a common word (e.g., stop, danger, Nhulunbuy). Candidates were also given seven plastic letters and asked to make words. Although most of the participants could form a number of three-letter words, fewer words of four or five letters were compiled. More advanced candidates were invited to read from two or three shown cards on which one of the days of the week or a month of the year was printed. At the close of this session, candidates were invited to write a few words to questions like "What are the things you like to do?" and "Where do you want to be in five years?" Applicants were also given an opportunity to show the differences between writing their name and their signature. Later, the ALERT participants were invited to complete two national English literacy tests to identify their reading age in years (the Burt Test) (Shearer et al. 1975; Burt Reading Test 1974) and the extent of their comprehension (TORCH, Test of Reading CompreHension) (ACER 2003), which is generally 2 years less than their reading age. English reading ages of primary school years can

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Legend

1. Lucas Mill operation in the savanna forest
2. Using a Mahoe saw at Dhupuma
3. Building the accommodations at Garriathiya
4. Refinery operator cleaning the work site
5. Operator with heavy haul vehicle
6. ALERT forklift trainee
7. Refinery logistics operator and supervisor
8. Inaugural Indigenous fabrication shop apprentice
9. ALERT graduate in the Gove Management Team Office
10. Warehouse and logistics Certificate II ALERT graduate
11. ALERT graduate laboratory technician
12. Clerical training for Certificate II at the refinery
13. Environmental testing of water discharge from the refinery
14. ALERT graduate apprentice in the machine shop

Figure 5.6 Collage of workplaces

be determined relatively accurately (e.g., 6.8 years), but secondary school scores are less robust. The measures obtained from the available instruments were secondary school (first 3 years) and upper secondary (last 2 years). Consequently, a secondary school reading age was estimated at 12.5 years of age and upper secondary was 15.5 years for each applicant with a secondary education.

The second way of assessing applicants was to obtain an estimate of their numeracy competency level. A long strip of paper on which was written numbers from 1 to 100 was shown to the candidate. The assessor announced a number and the candidate had to point to and say the next number. To obtain the level of fluency of decimals, four cards were used with the same four numbers on each card, but with the position of the decimal point in a different place on each card. The candidate was asked to put the four cards in ascending or descending order. Candidates were also asked the number of days in a week and the number of months in a year. The more exceptional students were asked to name the days of the week and the months of the year in calendar order.

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The third assessment was the administration of Discovery Session 1. There are six tasks, and each one contains three prominent aptitudes, and each aptitude is assessed with seven 7-point-interval scales. One assessment of an aptitude is done with a 7-point Likert scale, and a second set of assessments of that aptitude is done with six 7-point bi-polar scales. For each candidate, a mean score is obtained for each aptitude as well as a total score for all the aptitudes. The minimum total score is 126 (18×7×1) and the maximum score is 882 (18×7×7).

One hour is allocated for completing Discovery Session 1. For each task there is an introductory period when the problem space and the object of the task are explained until the candidate is comfortable starting. The goal is not necessarily to complete the task in 5 minutes but to observe the behaviors of the candidate. An observer employs the scales to assess each aptitude. To standardize the scoring over time, an A4 page of single-space type was written for each activity to guide the assessor how to use the scales. During the period from May 2007 to July 2012, 14 people were assessors (50% were Indigenous), and the consistency of reporting the behavioral responses was estimated with reliability assessments. Across the 18 aptitudes, the minimum reliability assessment was 0.90 and the maximum reliability assessment was 0.98. Hence, the data are robust.

The vocational period involves objective data. The time an ALERT participant was in the work readiness or work-starts phase was obtained from administrative records. Vocational time was scored in units of months; thus, a week was 0.25 month. Work readiness was always less than 1 year, but work starts could be a number of years. For example, from the May 2007 intake, one ALERT graduate transitioned to an apprenticeship and has worked at the Nhulunbuy refinery since the close of 2007. Conversely, ALERT participants who commenced work starts in 2011 could only have worked for slightly more than 1 year for the assessment period. To ensure the stability of the vocational measures of work starts so the score was free of time distortion (i.e., early ALERT program participants have potential for longer vocational periods), the maximum length of work starts was assessed as being 12 months.

Applicants who were admitted to the ALERT program from May 2007 to July 2012 were assessed. Of the 456 applicants, only 248 progressed to the selection process; and of these, 244 provided the following information:

- Discovery Session 1 score
- Reading age in years
- Work readiness period in months
- Work-starts period in months (maximum of 1 year)

Of the 244 Indigenous participants, 125 were Yolngu people and 119 were from elsewhere in Australia. For convenience, they have been identified as "externals." The data of these two groups were compared with two-tailed T-tests, and the results are presented in Table 5.1.

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Table 5.1 Means contrasts of vocational relevant competencies for local and external Indigenous ALERT participants

Variable	Yolngu (n = 125)	External (n = 119)	t Statistic	P<
Discovery Session 1	599.7	678.91	7.24	.0001
Score	(99.64)	(69.55)		
Reading age	7.88	13.29	13.96	.0001
Years	(3.20)	(2.86)		
Work readiness	2.78	1.56	2.85	.005
Months	(4.39)	(1.84)		
Work starts	1.58	5.37	6.46	.0001
Months	(3.42)	(5.45)		

Note: The values in parentheses are the standard deviations of the means, t is the level of analysis, and P is the probability of the level of significance.

The content of Table 5.1 presents more favorable outcomes for the external ALERT participants. External Indigenous people had higher Discovery Session 1 mean scores and higher reading ages, and both of these comparisons were statistically significant. The work readiness period, which is by default the learning period to prepare for work, was statistically less for the external Indigenous respondents, who also worked for a considerably longer time on average than the local Yolngu ALERT participants. The work-starts period was capped at 12 months so as not to unfavorably assess later ALERT program participants. Relatively high standard deviations for the work-starts variable reflect that 26 graduates withdrew (or were dismissed for being unfit for work) shortly after graduating, while others continued their employment for a considerable period. Some of the first ALERT intake participants are still employed in the refinery operations. Nevertheless, the data of Table 5.1 provide some insights as to why Australian Aboriginals are overly represented in weak labor market engagement and, consequently, are marginalized as some of the most disadvantaged citizens. The discrepancies understate the educational disadvantage of this sector of Australian society and give some credibility to claims that educational apartheid operates in the NT "pretend" schools (Hughes and Warin 2005).

Data were also collected and assessed for the vocational pathways of all the ALERT applicants. A total of 456 Indigenous people applied to join ALERT, but 208 did not proceed, either from a lack of further interest or because they were unable to attain a minimal level of literacy, numeracy, or medical criterion. Of the 248 who were invited to attend the selection process, 73 departed for personal and structural reasons. Thus, from May 2007 until July 2012, 175 Indigenous Australians entered the ALERT program. Delineation of the vocational career paths of these Indigenous people is presented in Figure 5.4.

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Figure 5.4 presents categories of success in the pursuit of a vocational career by ALERT applicants. Prior to the job outcomes, the gender ratio of males to females was about 3:1, but the work placements ratios are nearer to 7:1, demonstrating a greater rate of female turnover. Females are particularly vulnerable because they are expected to provide family social support. Some women left the ALERT program when they were required to care for the children of other elder women who attended funerals or cultural ceremonies. Some of the women VET participants withdrew from the program to attend these events. Many of the Yolngu women had lesser English linguistic and numeric competence because in the paternal framework the men had greater opportunity.

Although most of the information presented in Figure 5.4 is apparent, what is not shown are the types of jobs and the occupants in terms of their geographical sources. For instance, community jobs were dominated by Yolngu (n = 24) who showed a preference to work in their homeland organizations on the Gove Peninsula. Most of the external Indigenous ALERT participants, who chose not to work in mining jobs, initially returned to their communities in northern Australia. In contrast, the 41 ALERT graduates who came from geographical regions outside the Northern Territory became employed in well-paid mining jobs (e.g., heavy vehicle operator, laboratory technician, refinery operator). Five of the six Yolngu ALERT graduates were seconded to organizations that were indirectly connected to mining activity (e.g., Dhimurru, Giovenco, Sodexo, YBE), while the sixth became the inaugural Nhulunbuy refinery apprentice. Arguably, the relative success of the nonlocal Indigenous participants was linked to higher educational competencies and a more positive work ethic that is likely to have been formed from being previously employed in poorly paid work (e.g., laborer, semi-skilled).

Ralpa and Goyurr Participants

A feature of the jobs listed by the working group was the absence of jobs that required the incumbent to hold extensive work-related qualities (i.e., educational vocation experience). Hence, jobs at the mine site or the refinery as well as quarry work were excluded, despite both the Gumatj and Rirratjingu clans owning quarries. Consequently, the nominated jobs were those aligned with held knowledge or task properties that could be learned relatively quickly. Thus, the list of jobs was flavored with green-type work such as agriculture, horticulture, land management, and timber processing.

The choice of job enamored with the land encourages affective encounters. Indigenous Australians have provided stewardship of their landscape for thousands of years, demonstrating close relationships and spirituality seeking communication with nature. A continuity between people, place, flora, and fauna is expressed by Australian Aboriginals as the "Dreamtime" when the Ancestral Beings came as ancestor spirits in human form to create the animals, plants, and rocks. Later they

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assumed these forms to give sacred sites as well as relationships between individuals, the land, and the animals. This important knowledge and the ecological responsibility of caring for the land is passed to generations through the Dreaming Stories, which set the protocols for Indigenous social behaviors, the clan laws, and the lifestyle traditions. Keeping the stories alive is the responsibility of the clans, and it is expressed in ritual practices at ceremonies, in song, and in art. Although Dreaming Stories vary throughout Australia, the complex network of knowledge, faith, and practice derived from creation are a significant impediment for Indigenous people to be involved in the Australian minerals extraction industry.

Australian Indigenous links with the land have been credibly voiced. Stanner (1979) emphatically reveals the connection in his book *White Man Got No Dreaming*. Galarrwuy Yunupingu, AM, highlighted that Indigenous Australians value their ancestral land far beyond the imposed economic potential when he was reported to have stated the following:

> For Aboriginal people there is literally no life without the land. The land is where our ancestors came from in the Dreamtime, and it is where we shall return. The land binds our fathers, ourselves, and our children together. If we lose our land, we have lost our lives and spirits, and no amount of social welfare or compensation can ever make it up to us (Resource Indigenous Perspectives 2007).

More recently in 2012, David Collard, a leading Indigenous spokesman for the Noongar people of the south west of Western Australia, reinforced the spiritual land linkage. At an international conference, he stated that Australian Indigenous people would rather have green-friendly jobs that heal the land and not mining jobs that tear up the landscape (Macdonald 2012). On the Gove Peninsula, the Gumatj clan has used mining royalties to establish a range of land-based industries, which have hosted Yolngu graduates of the VET programs in the Nhulunbuy region (Pearson and Helms 2010a, 2012a, 2012b; Yunupingu 2009). The choice to work in these occupations is demonstrated in Figure 5.5, which depicts the vocational careers of 46 (59%) Ralpa and Goyurr applicants.

Only four of the Ralpa and Goyurr graduates chose to be employed in the Community Development Employment Projects (CDEP) program. The first CDEP scheme was established in early 1977 in Bamyili in the Northern Territory to provide a resolution to criticisms that Indigenous people were paid welfare money but they did not have to work. Paying participants to undertake local community projects for 15 hours per week as provided by the CDEP scheme was a social experiment designed to serve needs in employment creation, income support, and community development. In 2004, the CDEP scheme peaked with about 50,000 participants (about 11% of the total Australian Indigenous working-age population). In spite of positive assessments of the program, its social aspects attracted negativity, and it was described as sit-down money, legal apartheid, a poverty trap,

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entrenched welfare, and a barrier to real employment opportunities (Altman et al. 2005). Recently, the Australian federal government has reformed the CDEP scheme to an income support system obliging participants to engage in basic skills training and accredited VET programs, and these notions have been integrated into the Ralpa and Goyurr programs.

Providing real jobs for graduates of the Ralpa and Goyurr programs is a milestone in a long-term vision. In the early 2000s, the Garrathiya cattle station had about 350 head of brahman stock and operated without purpose, but there was a need for timber to plank tops of bridges and tank stands. Yunupingu formed an alliance with the Jack Thompson Foundation (the renowned Australian actor), and John Mofflin from that company went to Garrathiya to instruct Yolngu men how to fell local NT stringy bark (*Eucalyptus tetrodonta*) trees and convert the logs to building timber with a Lucas mill (Territory 2008). During the next decade, the Gumatj Corporation has employed Yolngu men who have selectively felled trees on their ancestral lands, milled the logs, and built accommodations at Garrathiya, houses at Dhanaya and Nhulunbuy (Pearson and Helms 2010b, 2012a), and commercial buildings at Gunyangara (coffee shop, furniture display room, school, a community store, and a variety of other retail structures). The company has recently contracted to perform maintenance on houses in Nhulunbuy.

The Garrathiya cattle station is an important component within the vision for Yolngu well-being. During 2009–2010, the Garrathiya holding paddocks were extended to hold double the initial herd size. In 2012, an abattoir was built at Garrathiya where two animals are now slaughtered each week, and the chilled "boned out" carcasses are transported to cutting rooms at Gunyangara. In these rooms, women graduates of the Goyurr program are supervised by a butcher to prepare retail meat cuts and products (i.e., mince, sausages), which are sold in the Gunyangara community store. In a separate arrangement, mince is supplied to the Nhulunbuy bakery to make pies for sale in the Gunyangara store, where women of the Goyurr program work.

Signing of the LUA has provided two streams of income—royalties and job sources. Mineral leases are applicable to what is under the surface. Currently, a team of Yolngu men is harvesting marketable logs on the new mining lease, which are then transported to the Dhupuma site where other Yolngu men use Lucas mills to produce building timbers. These men also have the use of a Mahoe saw, which has two blades, enabling the cutting of a side and an edge on one pass. In addition to being more efficient (than a Lucas mill), the Mahoe saw is more accurate, and the sawn product is then transported to the drying kilns at Gunyangara where furniture is manufactured in the furniture shop. This furniture, which is available for retail sale, is housed in a display room that was constructed by the Gumatj Corporation.

Although Australian Aboriginal people may be reluctant to be directly employed in the minerals extraction industry, the mining operation on the Gove Peninsula has provided acceptable alternative lifestyles. Inspired opportunistic

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endeavors by community elders is a prominent dimension of the Indigenous communities on the Gove Peninsula. As early as the entrepreneurial endeavors of Daymbalipu Munungurr, who sold oysters to the non-Indigenous Nhulunbuy caterers in the late 1960s, and the enterprise of Narritjm Maymura, who pioneered the contemporary cottage art industry of female Yolngu on the Gove Peninsula, to the current Indigenous leaders, there has been a continual blending of ethereal potential and physical substance of the environment. These defining events have contributed to the evolutionary progression of Indigenous communities since the inauguration of mining operations on the Gove Peninsula.

LESSONS LEARNED

Administration of the Nhulunbuy Indigenous VET program has identified effective pathways for cross-cultural encounters. Being very much influenced by a holistic spiritual view of the world, formal education and training are not the most important aspects of the lifestyle of Indigenous Australians. Specifically, they have obligations to family that are likely to override commitment to a VET program. Complexities of Australian Aboriginal culture compound the difficulty, as there are discernible differences in language, art, and fundamentally diverse lifestyles between the Yolngu people, who regularly practice hunter-gatherer pursuits, and Indigenous people from other remote regions and cosmopolitan urban settlements. Nevertheless, distinctive features of contemporary industrial domains are codes of conduct and work practices that imbue in employees a homogeneity of attitudes and behaviors. These converging forces are pervasive in the Australian minerals industry; they encompass not only specific and generic award provisions for health and safety but also determine the level of skill acquisition and the formal education profile.

The primary objective of the ALERT program was to prepare participants for employment in the Nhulunbuy mining operations. Attaining this goal obliged the graduates to possess skills, attitudes, and knowledge for work, and it was pivotal for the graduates to have English and numeracy competencies recognized by the former federal Department of Education, Employment and Workplace Relations (DEEWR), which in September 2013 was split into two departments. Achieving this outcome required an integration of factors that have been identified by organizations in the educational and industry sectors. In practice, the blending ensured the protocols of the Australian VET sector, the mining corporation (i.e., the client) requirements, and what the primary Registered Training Organisation (RTO) (i.e., Charles Darwin University) could remotely deliver at Nhulunbuy. Ultimately, the appropriate qualification would be a Certificate I in Resources and Infrastructure Operations.

Acquiring this Certificate I award required students to successfully complete four mandatory units and four elective units to nationally recognized standards

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(e.g., Australian Quality Training Framework, RTO delivered). A feature of the first two ALERT courses is the English reading ages of the participants. Of the 30 ALERT participants, 5 had an upper secondary school English reading age, 7 had secondary school exposure with an average English reading age of 9 years, and 18 had an average English reading age of 6.1 years. To prepare the candidates for their targeted vocational careers, the Australian Core Skills Framework standard promoted by DEEWR was employed. Adult learning techniques underpinned the pedagogy that incorporated milestones of achievement, with experiential training and high levels of pastoral care. Despite the considerable investment, only 4 of these 30 ALERT participants joined the Nhulunbuy mining operations.

Until the availability of single-person, fully messed accommodations at Nhulunbuy, most of the ALERT applicants were local Yolngu. Seven Indigenous people from outside the region, with relatives close to Nhulunbuy, were applicants to the 2008–2009 intakes, but all have left their employment in the mining operations. During the period prior to providing accommodations, the ALERT program had been continually restructured to provide a variety of training and vocational pathways—from a new shorter period of work readiness to work starts where a number of initiatives were trialed, enabling graduates to seamlessly transition into local or national jobs in different sectors (e.g., child care, construction, health). In addition, a more stringent medical assessment was developed to detect substance abuse in particular, and partnerships were forged with federal and territory agencies with core responsibilities of education, training, and vocation pursuits. The entrance to the work-starts period had a minimum requirement of a year-10 (third year secondary school) English reading comprehension level. These changes were encouraged on three fronts: to lessen leakages, to transition more Indigenous people into useful work, and to select the best people from a growing body of applicants.

The installation of these practices had two main effects. First, leakages persisted, but second, a greater number of applicants transitioned into mining-related jobs, and many of these people have continued to advance and are now employed in the industry. Another favorable outcome has been that although many graduated and initially began working in the minerals industry, where it has been possible to track their careers, they are now in sustainable full-time work in other industries. From exit interviews and occasional contacts, much information has been acquired to better understand the motivations for these behaviors. This knowledge has been particularly useful when administering the Ralpa and Goyurr programs.

The foremost priority of the Ralpa and Goyurr programs was to quickly get graduates into nonmining jobs in local Indigenous organizations. Accordingly, the courses were shortened to 8 weeks and 6 weeks, respectively; the program had fewer VET courses; and the content of each course was aligned with client imperatives. For example, all graduates of the first Ralpa program completed a minimum of three accredited VET courses (some graduates completed a maximum

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of four) from a range of courses that could be delivered by the RTOs. The types of available courses were

- Work safely in the construction industry;
- Undertake a basic construction project;
- Apply first aid;
- Use hand tools; and
- Use construction tools and equipment.

The Ralpa and Goyurr programs are designed to meet skill gaps in the local and regional industries. Within the programs, candidates were introduced to workplace communication practices (use and care for telephones and radios, reading and understanding signs) as well as personal well-being (diet, nutrition, health fitness) and time management (planning a job, attendance, punctuality). These course components closely corresponded with the milestones set by the potential employers wherein candidates were to be trained to minimize workplace risk, to be able to communicate with work colleagues, to have a basic understanding of work planning, and to be able to employ practical workplace documentation. However, delivering these notions obliges program participants to functionally understand English literacy and numeracy, which had been problematic in the earlier ALERT programs. Integrating experience and knowledge from the previous Nhulunbuy VET programs with the information from exit interviews realized a pedagogy for delivering the theoretical and practical course material to participants with literate and numerate issues.

The Ralpa and Goyurr content was presented by graphics and seldom with written English words to articulate the theoretical knowledge and task to be undertaken. For instance, reporting the results of a vehicle inspection is normally undertaken by completing a form with words to record items examined (e.g., engine oil, battery, brake-light condition) with a coding indicating the urgency for attending the mechanical item. This was the standard operating procedure for vehicles at the mine site or the refinery and was the technique used by ALERT participants; but for the Ralpa and Goyurr trainees, a visual method was used. The vehicle inspection sheet used by the Ralpa and Goyurr trainees was A4 in size with a column of eight pictures (2cm × 2cm) on the left side of the form, which was accompanied with a vacant central column and a vacant right-hand column. Each picture showed the item to be inspected, and it was matched with three to six words (e.g., check the tires, check the oil on the dipstick). If the item required remedial action, an × was placed in the adjoining central column next to the picture, but if no action was required, a check ($\surd$) was marked in the right-hand column aligned with the picture. The notion of employing visuals is closely linked with Indigenous art works because Australian Aboriginals do not have a written language; the stories, songs, and laws are expressed in paintings (Ayre and Verran 2010; Brody 2011). Implementation of strategies with lesser English usage became

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justified when a sample of 33 Ralpa applicants had an English reading age mean score of 6.2 years.

Although instruction is mainly undertaken with oral and visual techniques, these practices are supplemented with a five-step tuition arrangement. On-the-job training of relatively common urban tasks, such as using a garden rake, pushing a wheelbarrow, or using a shovel, requires supervisory vigilance when an important goal is to minimize risk of personnel and to equipment with users who have not previously used these hand tools. The work tasks become even more complex when using machinery such as line snippers, rotary lawn mowers, and other mechanical equipment. Instructing novice trainees to safely engage with their workplace is undertaken in five steps that have cultural linkages:

1. Demonstrate,
2. Explain,
3. Trainee describes orally,
4. Test the operation done by the trainee, and
5. Feedback one to one.

These stages of instruction are reminiscent of Indigenous heritage and are at the heart of Yolngu society, as they replicate the way elders pass the songs, stories, and all elements of their culture to the younger generations (Harrison 2010; Harrison and Greenfield 2011).

A lack of attendance preceding eventual withdrawal was a major source of leakage from the ALERT and variant programs. Few of the Yolngu trainees and graduates were able to adjust their hunter–gatherer lifestyles to meet the mining corporation's expectations that the employees would present for consecutive days (cycles of 21 days on, followed by 7 days off) of 12-hour shifts. To match Indigenous aspirations with sustainable business work agendas, the Ralpa and Goyurr programs were scheduled for 4-day weeks of 6 hours per day. The adoption of this framework enabled participants, on the one hand, to engage in a hybrid customary economy, which is fundamentally different to the mainstream culture, while on the other hand, participate in dominant work sectors in the broader Australian community. This cross-vergence paradigm was designed to suit the personal expectations of the Indigenous candidates; nevertheless, leakages from the programs continued. The withdrawals usually occurred during the induction days or within the first 2 weeks of the program, which did not severely disrupt the training. To graduate, candidates were required to have an attendance rate of 90%.

Structural and cultural factors underpin withdrawal behaviors. A major structural issue is welfare, and even the Indigenous leaders have acknowledged that this form of income support leads to abandonment of individual responsibility, community breakdown, and social problems. Royalties from the mining operations to family members of the Traditional Land Owners is another source of nonwork payment. Slightly aligned toward the full remuneration model is the CDEP scheme,

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which is a passive welfare system, where Indigenous people can at their convenience be recipients of occasional work. A major cultural impediment to working is "humbugging," which is practiced in the Yolngu obligatory gift-giving society; and at exit interviews, a common line given by the Yolngu is "why should I continue to work? When I get home, my things have been used or taken. I might as well join them and take from others." Those who work have resources, and it is expected by nonresource holders within the clan that the held material commodities will be shared by other family/clan members who prefer not to work. Warren Mundine, executive chairman of the Australian Indigenous Chamber of Commerce, identified humbugging as a major hurdle to Aboriginal prosperity and a source of antisocial behavior: "I have known companies who've hired Indigenous workers only to see them quit because the pressure to hand over wages was too much" (Mundine 2013). Withdrawal from learning and working environments to attend funerals, cultural days, and ceremonies can be unexpected and of long duration of many weeks. Intermittent, long periods of absence are a considerable impediment to work schedules, individual learning progression, and the economic vitality of a firm.

Mining on the Gove Peninsula has had a profound impact on many Indigenous Australians who have a heritage in a very different set of cultural and economic circumstances to the contemporary dominant national society. At one extreme are the family nomadic groups who continue to hunt and gather on their ancestral lands and are on occasions seen in the major centers obtaining material goods. These groups, said to be "longrassing," are engaged in a fundamentally different customary economy to those at the other end of the spectrum who now work in full-time employment at the refinery or mine site. They also travel to Nhulunbuy, but in the construct of fly-in-fly-out workers. Notably, most of these employed people come from homelands beyond the Gove Peninsula, they have lesser cultural ties with the region, and many of them have one non-Indigenous parent. Spinning off this group are those Indigenous people who attended ALERT, graduated, worked for a while in the local mining industry, and then extended their vocational careers when they moved into sustainable full-time employment in the public or private sector at other distant locations.

Within these extremes are Indigenous people who have chosen Western educational vocational pathways flavored with universalism and hybridization. Some women and men "tested" the ALERT initiative or the Ralpa and Goyurr programs, but they found the experience uncomfortable or too distant and then returned to their homelands to enjoy the features of a cultural lifestyle and the government-funded income support system with auxiliary benefits. Some of these people may occasionally rejoin the workplace of a CDEP scheme. Other Indigenous people have made a more serious attempt to blend their strong cultural continuities, which incorporate an emphasis on mutual obligation, with the Australian contemporary consumptive market-oriented economy. These people chose to begin their working

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careers in the Ralpa and Goyurr programs, and after graduation have joined the workplaces of Indigenous organizations on the Gove Peninsula. Within this framework they are able to build lifestyle aspirations while maintaining strong spiritual and religious connections with ancestral lands. Specifying the educational and vocational achievements of every Indigenous person who has had an involvement with the Nhulunbuy VET schemes is beyond the scope of this chapter, but to outline the extensiveness of the vocational sites a representative sample of the range of undertaken jobs is presented in Figure 5.6.

CONCLUSION

The globalization of business has a profound effect on the host community. This influence is particularly significant in the Australian mining industry, which is undertaken in remote regions where the population is relatively small with scant infrastructure, often obliging the building of new towns or the refurbishment of existing hamlets. Usually, the resident population is in outstations where the few people live on their traditional lands. Indeed, as large multinationals, and specifically mining corporations, move their operations into sparsely occupied remote regions of the world, the imperative of social responsibility and functional business practices compel the organizations to engage with the marginalized local people. Often these residents are socioeconomically disadvantaged compared to the mainstream population of the country.

Although the 1993 Native Title Act legislation provided a normative adoptive framework for Indigenous VET programs, the compulsory enactment of this law lacked prescription. Furthermore, strategies for enhancing Indigenous employment in the Australian mining industry have seldom been disclosed in the public domain, nor is the information likely to be shared across geographical sites within the same corporation. Much of the available knowledge is broadly couched with many shortcomings and ambiguities because it lacks Indigenous voice, while, in turn, mining reports, which are often based on Indigenous LUAs, remain confidential. Understandably, a recurring, debatable theme remains for how to maintain Indigenous culture together with the achievement of equity in socioeconomic well-being of the Aboriginal sector in Australian mainstream society. Argument has been advanced that appropriate VET is a departure point for contributing to Indigenous workforce development, leading to economic independence and better social development.

This chapter describes the resurging interest in Indigenous VET at a remote Australian mining location during a particular point in time to embrace latent challenges. A resurgence of interest in Indigenous employment in the Australian mining sector has attracted a new set of unforseen challenges. Despite mining companies in Australia taking a proactive approach to increasing Indigenous participations in

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their workforces, the broad rhetorical assumptions—driven by legal and political developments, that mining extraction activity will deliver Aboriginal employment and better socioeconomic outcomes—exceeds the reality. The statutory and regulatory regimes of Australian mine sites and refineries rely on employees and contractors who are well educated, highly trained, multi-skilled, and physically and emotionally prepared to work long shifts in onerous job settings. The evidence presented in this chapter shows that very few of the local Yolngu people were able to acquire national occupational standards and certification to work in the Nhulunbuy operations. Unexpectedly, these people learned to balance cultural connections to the Dreamtime with the emergent commercial opportunities of the local mineral boom time to swell the ranks of a manifesting Indigenous middle class.

More optimistic Indigenous employment levels of local residents were realized after ratification of the 2011 LUA. The implementation of learning and business partnerships, which was facilitated by a host of green-type jobs, was an unexpected reality when the Indigenous Traditional Land Owners assumed their new positions of responsibility. Contemporary entrepreneurial venturing may have heritage in the mid-seventeenth century when the coastal Yolngu clans began their extensive trade with the Macassans, which continued for more than 300 years. This period was a precursor to a major regional softwood timber industry that was centered at Milingimbi and Elcho Islands and operated for 50 years to give the foundation for a hardwood timber venture on a Gove Peninsula in the early 2000s. Notable is that three participants of the inaugural ALERT program seeded the hardwood timber business at Garrathiya where today a viable cattle station operates to provide fresh meat to the Gunyangara community. The Yolngu clans are fortunate to have extensive savanna forests from which they can selectively fell mature trees, with marketable timber to build infrastructure for the local communities. The opportunity to conduct Ralpa and Goyurr programs has provided a trained workforce for the many emerging small social businesses operated by the Yolngu people on the Gove Peninsula.

A latent enigma for Indigenous LUAs is employability responsibility. Training and employment provisions have become a common feature of Indigenous LUAs, with conventional wisdom encouraging a focus on preparing Aboriginal people for mining-related jobs. This chapter highlights a newer realm of jobs and, accordingly, future directions for suitable training, but pathways for reaching mature cross-cultural relationship building in this arena has yet to be delineated. Generating sustainable Indigenous enterprises is likely to be implemented when there is alignment between the content delivery mode, the prior skills of the participants undergoing the VET program, and the aspirations of the local Indigenous people.

This chapter is a historical account of contemporary Indigenous VET on the Gove Peninsula. Although the information may be useful, caution is urged not to

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employ the knowledge as a deficit model—to repeat it elsewhere. Since inception of the ALERT program, the pedagogy has been continuously refined in endeavors to obtain valued milestones, and now there are different steams to accommodate emerging opportunities. A strong inference of the evidence being collated since 2007 is that job preference was a function of remoteness. Participants from less remote centers held a lesser attraction for traditional lifestyles and a greater preference for urban values of a market economy. The evidence is that a rigorous, nationally accredited program to prepare Indigenous people for working in the Australian mining industry has a place for participants with cosmopolitan backgrounds. Also, it is evident there is a place for alternative Indigenous VET programs to maximize the benefits of individuals, families, and communities. A salient observation of the evidence presented in this chapter is that mining companies, government employment and funding agencies, and Indigenous people can broker partnerships in learning that will strengthen training and vocational investments.

ACKNOWLEDGMENTS

Deep appreciation is given to the Traditional Land Owners who allowed their ancestral homelands to be visited by the authors. A sincere thank-you is given to the mining corporation that allowed the authors to access the Gove Peninsula operational sites. Gratitude is expressed to Simon Lander, the Gumatj foreman, who provided photographs of Indigenous people working at Dhupuma.

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CHAPTER 6

Building Trust*

Simon Nish
With Contributing Authors: Peter Plastrik, Larry Dixon, and Luc Zandvliet

INTRODUCTION†

The three case studies in this chapter are about building trust. All resource project proponents say that the economic and other benefits of a project will outweigh negative impacts. Regulatory approval processes are designed to assess the rigor of project preparation but are no guarantee of future performance. Notwithstanding trusted personal relationships that community members may build with individuals from the proponent company, communities grapple with the decision of whether to support a project largely on the basis of trust in the long-term outcome. These case studies are about two ways in which a company has tried to build trust with the local community.

The first two case studies, written by Peter Plastrik, describe the development and early implementation of the Community Environmental Monitoring Program (CEMP). The third case study, written by Larry Dixon and Luc Zandvliet, describes how a community scores company performance. These two approaches are outliers in the spectrum of how resource companies engage with local communities. Each approach touches on familiar themes—how communities can find a trusted source of information about potential environmental harm, in the case of independent monitoring, and how companies get a clear view of what the community thinks of their performance, in the case of the community scorecard. What is common

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† This introduction was written by Simon Nish. The views contained within it are those of the author.

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to both approaches is that the company and community tried something new, and there had to be a meeting point between the company and community for it to work. There is a great deal of innovation across the resource sector's relationships with local communities, driven by both companies and local communities. My hope is that the approaches outlined in this chapter do not remain outliers for long: that they are adapted to other contexts and overtaken by other innovations that build trust and assist communities to grapple with the choices arising from resource development.

Community Environmental Monitoring

A community facing the question of whether to support a resource development is balancing the benefits against the potential negative impacts, particularly those on the environment. What information can the community trust when it has concerns about environmental harm? All too often, a community can turn to one of two sources for data and interpretation: company-generated data, which it may not trust, or the regulator, in which there may be a lack of confidence for a range of reasons, often due to resource constraints. Plastrik's work explains how independent community environmental monitoring introduces a third option for the community. This option is a trusted, independent voice that is based in the community, monitoring and reporting on the company's environmental performance.

Plastrik tells the story in two parts. The first part is how people came together; the second is what they agreed to. The coming together of a mining company and two community institutions to create independent community environmental monitoring, above and beyond the mine's existing monitoring, is so unlikely that it warrants the attention Plastrik has given it. His second case study unpacks the agreement in more detail, offering step-by-step guidance for developing a CEMP. The idea of community environmental monitoring is not at all new: communities and environmental groups have been advocating for it for a long time, and companies have grappled with how to implement it in a way that manages their risks. Plastrik's second case study was written with a wider audience in mind. It offers a road map of questions to work through and balances to be struck for those who want to develop independent monitoring in other contexts.

If the Eagle Mine CEMP is a bridge too far for others to apply in its comprehensive form, it may be applied in more limited circumstances. What may be more achievable is community environmental monitoring for a particular ecosystem, such as a watercourse or aquifer, or for a defined emissions source, such as defined airborne particulates. It might be applicable for a period of time, such as during a construction phase when there are particular sensitivities about impact on the environment. The mechanism for achieving arm's-length funding may well look different in other contexts. One of the most common questions about the CEMP is its applicability where a strong community-based environmental organization,

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such as the Superior Watershed Partnership, does not exist. In that case, the scientific monitoring expertise could be secured on a contractual basis, reporting to a community board or some other mechanism of community control.

Plastrik concludes his first case study with the challenge facing all long-term agreements among companies and communities: they are generated through a relationship of trust among individuals but need to transition into institutional arrangements that endure personnel and leadership changes. Plastrik captures the benefits of establishing the CEMP for the community and the company. Continuing to evaluate and understand the mutual benefit of community environmental monitoring over time will support its longevity, as will clear mechanisms for review and amendment to ensure that the agreement continues to meet the respective interests of the parties.

Community Scorecard

Resource developers are more sensitive to community perceptions about their social performance in the permitting and construction stages, when the project risks arising from the lack of community support are the highest. Over time, this sensitivity to community feedback and perception tends to wane, or the feedback loop tends to be distorted by unbalanced attention to "friendly voices" within the community. Company self-assessment of community perceptions is an unreliable foundation from which to understand and manage social risks. Dixon and Zandvliet's case study tells the story of how a company developed a simple mechanism that can be used over time for the community to rate the company's performance.

Dixon and Zandvliet analyze an approach that is disarmingly simple at first glance. Using handheld clickers, a mining company asks the community to rate how it is doing across five performance areas. The ratings are instant and shared. The aggregated data across a number of community forums is also public. Transparency tends to build trust. There is nothing quite as transparent as company personnel being given a "report card" by the community in real time with everyone in the same room. The community scorecard approach is in stark contrast to that of polling communities, which is usually undertaken by third parties, the feedback is neither immediate nor public, and there is little opportunity for dialogue between the company and the community about the community feedback.

Dixon and Zandvliet discuss the layers of this seemingly simple approach. What initially appears to be a point-in-time assessment of company performance is actually a structured conversation with the community, using the community's scoring and the company response as the springboard for discussion. The scoring at a particular point in time is far less relevant than the pattern of community feedback and company response, based around defined performance areas and agreed metrics, built up over time. The community scorecard is intended to be dynamic, with the performance areas and metrics adapting over time to what is important

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for the local community. Dixon and Zandvliet mention that even between the first two iterations of community scorecard, its format and metrics changed in response to community feedback.

One of the early lessons to come out of the community scorecard is that this simple technology is a leveler among loud voices and quiet participants at community meetings; they have equal weight in the scoring. Instant, anonymous feedback enables the silent majority to express its views, no matter the mood of the individuals with loud voices in the room. For this reason alone, the scorecard is an exceedingly valuable tool.

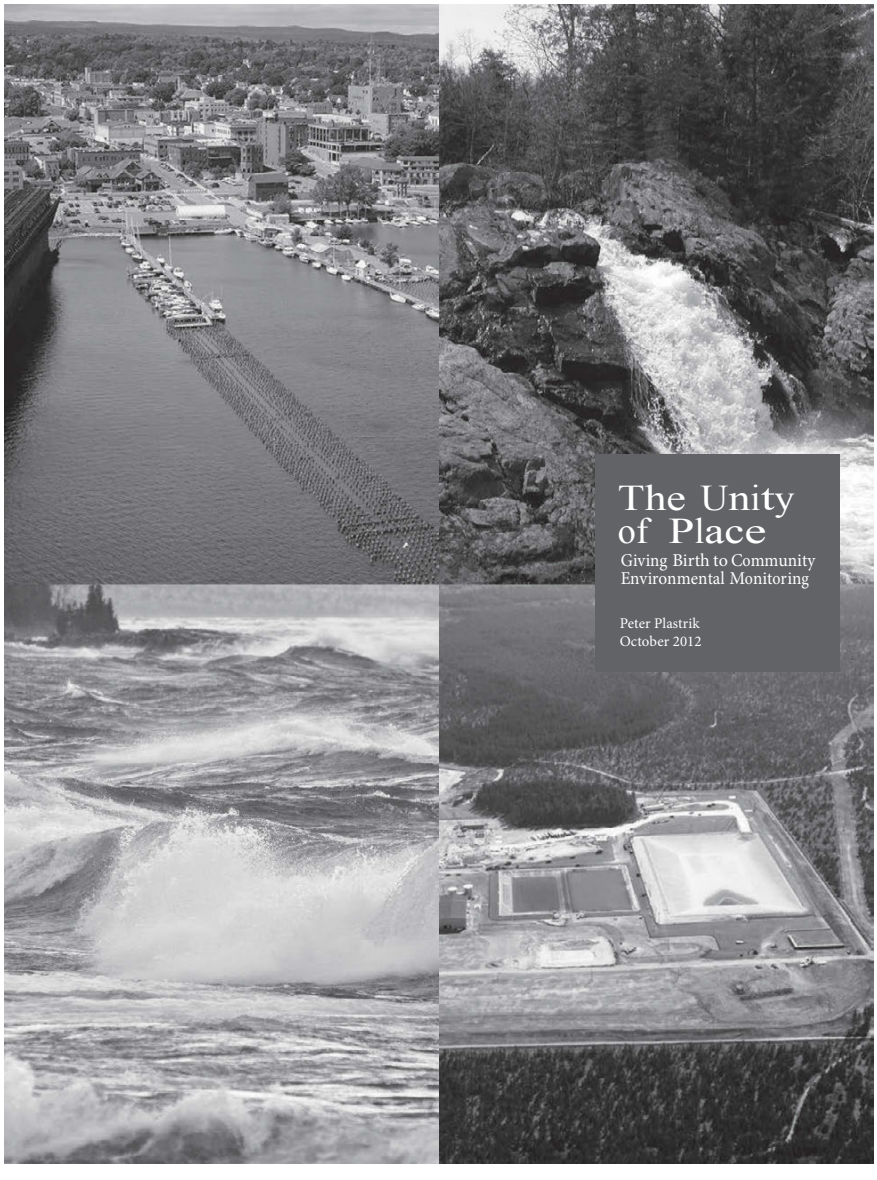
Dixon and Zandvliet describe the value of the scorecard in conveying community comments back into the business. The community scorecard provides both quantitative (the scoring) and qualitative (the points raised in discussion) data, which is rare for resource companies to acquire regularly and consistently. Employing the community scorecards at community meetings attended by personnel from functions across the company further enhances the linkages and the validity of the scorecard data back into the business. This has the additional benefit of taking pressure off community relations personnel who otherwise bear most of the weight of conveying community feedback into the business.

As with the community environmental monitoring, there is no one-size-fits-all here. The community scorecard approach may well be adapted to other contexts and in ways that are less challenging than asking the community to comprehensively rate a company's performance. For example, it could be applied at an early stage in project development to help define the matters of most concern to the community and the relative priority among those matters. It could be applied to get feedback on a narrower range of company performance, such the effectiveness of communication and engagement efforts.

Conclusion

Three things will hopefully arise from these case studies. First, the Eagle Mine CEMP and the community scorecard are in their early stages of implementation; they deserve evaluation to see how they develop and what can be learned from their application over time. Second, the value of these case studies is their identification of the underlying principles guiding each method and not advocating a cookie-cutter approach. It is hoped that these methodologies are applied to different contexts, in whole or in part, to help expand the range of what is possible in the relationship among resource companies and host communities. Finally, there is a great deal of innovation out there, generated by companies and communities alike, that is not shared when it deserves to be. Hopefully, these case studies will prompt others to share their innovative practices, from which we will all learn.

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RioTinto


Marquette County
community foundation
For good. For ever.

POSTSCRIPT: Rio Tinto has sold 100 percent interest in the Eagle Mine to Lundin Mining Corporation, effective July 18th, 2013. Lundin Mining fully supports the Eagle Mine Community Environmental Monitoring Program (CEMP) and will continue it.

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The main precondition to self-governance (and perhaps to global survival) is the simple, fundamental ability to communicate with each other across the barriers of individual differences in interests, nationalities, cultures, and frameworks for the purpose of setting common goals and strategies for achieving them.

—Daniel Yankelovich*

Unity of Place

This story is about people making up their minds, and even changing their minds, about something that threatened, disrupted, and divided their community. The people are the "solid citizens" you find in most places: a housewife, an accountant, a funeral home owner, a doctor, a lawyer, the head of a community-based organization, and others. The threat, too, is familiar—the coming to town of a big, distant corporation with plans for making money. In this case, the threat was intensified, because the company wanted to open up a nickel-copper mine, which poses risks for health, safety, and the environment. As you'd expect, the community fractured into sides—against the mine and for the mine.

The community is small and far from big cities. It is neither rich nor poor, but it has struggled and changed. Many residents are the descendants of people who came to work in mines dug in the 19th and 20th centuries, but those opportunities faded decades ago. Some are descendants of the Native Americans who also mined copper, long before the European influx. More recently, people young and old have been moving in to take advantage of the area's vast and relatively unspoiled natural bounty, the Great Outdoors.

This story is also about the people in that distant corporation and how they too have had to make up and even change their minds about how to act when they come into a community, this one and many others around the world, and then disrupt its life.

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Unity of Place

I. Fault Lines

Finally, this story is about an agreement, a genuine innovation hammered out between people in the community and people in the company that promises something unexpected and important about their future together. The choices they made will have consequences for the mine, still being dug out but with a projected lifespan of seven years or more, and for the community. Perhaps the agreement will reach even beyond this mine and this place. It set into motion a dynamic—within the community and within the company—that could reoccur when other mines are proposed in the vicinity by this or other businesses, as they surely will be. And perhaps what happened here will matter much further away, in other communities also located atop valuable minerals and also having to make up their minds.

I. Fault Lines

Maura Davenport knew exactly how she felt about having a new mine open up near the forestland she and her husband owned a short distance from their home in northern Michigan. She was dead-set against it. An environmentalist since her college days, now the mother of four adult children, she took an instant dislike to the mine owner, Rio Tinto Group. "We started to see drilling rigs and trucks and new signage. We didn't have any idea what was going on. When they finally announced they had purchased mineral rights for thousands of acres, that just got our ire up. They moved into the community, throwing their money around. We learned about this type of mining from groups opposing the mine, about cave-ins and sulfuric acid in the groundwater. From them we learned that Rio Tinto doesn't care about the community. They have a lot of money and start sponsoring every event and organization. They kind of take over and expect us to follow along. To their surprise, we didn't. We fought."

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Unity of Place

I. Fault Lines

Carl Lindquist opposed the mine. Twenty years earlier he'd moved into the region to be close to "wild country." For years he'd worked with state and federal officials, the Keweenaw Bay Indian Community, and others to raise $1 million and launch 20 projects to improve the Salmon Trout River's habitat and spawning areas for a dwindling population of coaster brook trout. "We started working there before there was a rumor of a mine. It's a unique place, the only place on Lake Superior's southern shore where there's naturally reproducing coasters; everywhere else they are being re-introduced." And the hard work has been paying off. Researchers reported the river had 70 percent more adult trout than a decade earlier. "I'm really proud of that. And then this mine issue came up, with the site right at the headwaters of the river." In 2007 Lindquist coauthored a management plan for the 31,000-acre Salmon Trout River watershed, its streams draining into Lake Superior, which warned that a mine posed a "significant threat to water quality." Page 33 spelled out an alarming scenario: "When the mineral or waste rock is brought to the surface and exposed to air, it oxidizes and creates sulfuric acid, commonly referred to as acid mine drainage. This acid can run off in rain or snow melt events and contaminate large areas of surface and ground water resulting in serious impacts to water quality and aquatic systems."

Fear of the unknown and the unexplained; distrust of a faceless corporation's motives and deep pockets; lack of faith in distant state and federal government regulators and their political masters; and a dismaying sense of powerlessness in the face of apparent threats to life, health, and property, to what one cherished, to the land, the waters, and the people: these feelings—natural responses—surged through Davenport, Cowell, and Lindquist and many of their neighbors in communities near the mine site. One hundred physicians bought a newspaper ad against

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Unity of Place

I. Fault Lines

the mine. The Keweenaw Bay tribe sued to stop the government from permitting the mine, as did others. Grassroots groups opposing the mine forced a township supervisor who supported it to face a recall election. "It was very frustrating," says Chantae Lessard, the mine's principal advisor for communities and social performance. "The folks who opposed mining were very well connected, very engaged, and resistant to talking to anybody from the company." In her previous assignment, "We had opposition, but they would come to the table and tell us what they didn't like and give us feedback. Here, everything that came out of my mouth was called a lie." The community fragmented along familiar lines: pro-mine, anti-mine, jobs versus nature. But the mine's plan won government approval, and the site construction and digging began.

Then something happened that Davenport, Cowell, Lindquist, and other members of the community hadn't imagined was possible. They got a measure of power over the mine. And it was Rio Tinto that gave it to them.

Chronology of Eagle Mine

2002	***Rio Tinto exploration discovers mineral deposit at future Eagle site***
2003-5	***Purchase of land and mineral rights by Rio Tinto***
2006	***Rio Tinto applies for government mining permits***
2007	***Permits approved***
2008	***Lawsuits challenging permit***
2009	***Permits upheld in court***
2010	***State permits finalized; mine surface construction begins***
2011	***Mine underground construction begins***
2014	***Estimated first production from mine***

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II. Guardian

In mid-May, 2012, Carl Lindquist received an intriguing email from Rio Tinto's Simon Nish, director of community, communications and external relations. Lindquist is executive director of the Superior Watershed Partnership, a regional nonprofit organization with a small board of directors—including Maura Davenport—and staff and an office in Marquette, Michigan. A self-assigned protector of natural resources, the Partnership stands at the intersection of the environment, economy, and community in Michigan's Upper Peninsula, along the southern shore of Lake Superior, the world's largest freshwater lake by surface area.

The "U.P.," as it's known, is Copper Country. Before French explorers arrived in the region in the 17th century, the indigenous people already there had been mining copper —digging pits—and trading it, as knives, axes, spearheads, needles and jewelry, with their neighbors. In 1841, geologist Douglas Houghton reported vast copper deposits in

Unity of Place
II. Guardian



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Unity of Place

II. Guardian

the region, which triggered America's first mineral rush, a migration of prospectors, East Coast financiers, speculators, and adventurers to the sparsely populated area. The mining of iron ore a few years later resulted in the development of Marquette, along the rocky Superior shore, from which ships carried the valuable minerals to mills and markets. For more than a century, mining and lumbering—removing natural resources and shipping them away for processing—drove U.P. economic life and communities. Volatile industries dependent on world commodity prices, they created commerce, employment, and wealth, but they also denuded the land and contaminated the water.

Today, Marquette is a city of about 22,000 people, nearly 40 percent of whom hold a college degree; it is the economic engine of a county with about 45,000 more people scattered in low-density towns and homeowner lots. The local culture is self-reliant, relishing the long, cold, and snowy winters and the isolation—the nearest "big city" of Green Bay (population 104,000) is more than a three-hour drive away. Several decades ago the region's copper mining came to a halt (although an iron mining company is the county's second largest employer), a legacy found only in historical museums or in family stories about why their ancestors' immigrated to the region. Marquette's dominant industries are professional enclaves: a state university, a regional hospital and health care system, and government agencies. A once-stagnant downtown is reviving thanks to an influx of people attracted to the area's vast natural bounty: the big lake, rivers and streams, endless woods, and abundant wildlife and the sailing, biking, fishing, hunting, and other recreational and spiritual opportunities they offer.

This has been fertile ground for the Superior Watershed Partnership, which grew into the region's most

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prominent community-based conservation entity, partnering with communities and Native American tribes and raising $1-2 million a year for its work. "As an organization," says Lindquist, "we focus on implementing projects that have tangible results. We don't shy away from taking a stand when we have the opportunity, but we tend to take the middle path on issues, because we work with everybody. As an example, two of our best partners are the City of Marquette, which supports the mine, and the tribe, which opposes it." Larger than local grassroots environmental organizations, the Partnership tackles a wide range of matters: Great Lakes pollution prevention, stream restoration and shoreline stabilization, invasive species removal, native plant reintroduction, youth education, climate-change adaptation, and more. Several times it took a stand against sulfide mining along the Salmon Trout River. Meanwhile Rio Tinto obtained the government permits it needed for Marquette's new Eagle Mine. It cleared and fenced in 120 acres and started to drill a mile-long tunnel to reach the ore, and reopened, cleaned up, and upgraded an off-site mill to separate mineral from rock, all just a short drive from the city.

The email Lindquist got from Simon Nish, after several conversations between the two men, suggested a new role for the Partnership.

III. Risk Management

By any measure Rio Tinto is a Goliath to the Marquette community's David. Started in London in 1873, when Marquette was still a small town, its payroll of 70,000 employees outnumbers the county population. Its 2011 revenue of $60 billion dwarfs the county's economic output. That year the company contributed $294 million to communities worldwide, while the Marquette County

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Unity of Place

III. Risk Management

Community Foundation issued some $400,000 in local grants. The fourth largest publicly traded mining company in the world, in the middle rank of the Fortune 500, Rio Tinto operates on six continents and in 2011 explored for copper and other commodities in 18 countries.

The hazards a mining company faces are well known. But in the past few decades Rio Tinto has had to acknowledge and adapt to a new problem: the feelings of the local community. That's where Simon Nish comes in. As Rio Tinto's director of communities, he arrived in Marquette in late 2011 to conduct an audit of the mine's relationship with the community, a process the company undertakes every three years at its operations. "I led the team," Nish says. "We interviewed community and company people about how the project was performing." He explains that the focus on community is a relatively new dimension for Rio Tinto, the result of a "long learning journey for the company" that started several decades ago and worlds away from Michigan.

In the 1970s in the newly formed nation of Papua New Guinea (PNG), Rio Tinto negotiated the Bougainville copper mining agreement with the national government. The prevailing view then was that companies could rely upon their legal license from the government. And companies and national governments also believed that local concerns, such as the distribution of revenues from resource projects and the influx of people into a region, were the business of government and not of corporations. "After a couple of years of mining," Nish says, "it was very clear that the locals were not very happy with both their share of the deal and the influx of people from other parts of PNG; they wanted to renegotiate the agreement. Tensions between the perceived role of national government and that of the local community escalated to the point of civil war and we exited

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the island under gunfire. There are senior people still in the company who went through that experience. This demonstrated to us that our social license to operate, earned from the local community, is just as important as our legal license to operate. We can never rely solely on a national or central government for our ability to operate. You have to have community support—or you are at risk of losing the mine."

In the 1990s, the Lassing Mine disaster in Austria, in which 10 people died, prompted Rio Tinto to replace its decentralized corporate model, which allowed free-wheeling subsidiaries to set their own standards for health, safety, and environmental programs, with a worldwide set of standards for every mine and control processes to assure that local mine managers met the criteria.

In parallel with these developments, Nish says, Rio Tinto officials noted a significant global trend: "Across continents and cultures, there was a weakening of the central state and an empowerment of the community and local organizations. You saw it in the western world in the massive street protests against world trade organizations. You see it in the linking up of environmental and community groups. You see it in the action that community groups are prepared to take now in determining their own affairs. There were people in the company smart enough to see that what could be described as singular events are actually linked up into a web of social change."

As a result, Nish explains, Rio Tinto decided it should approach communities where it wanted to mine in a new way that was neither corporate philanthropy nor corporate social responsibility. "It's about value exchange. In our minds, the value proposition is like this: The community says to us, if you treat us with respect and recognize our interests; if you operate in an open, transparent way;

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III. Risk Management

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Unity of Place

III. Risk Management

if you operate to the highest environmental standards; if you're going to create long-term economic development for us; and if you will clean up when you go—then we will consider supporting you being here. For Rio Tinto, the value exchange is that we do certain things in exchange for community support, which is highly valuable in dollar terms to us."

The Eagle Mine is a relatively small project for Rio Tinto, a "baby" in terms of its physical footprint, cost, and the volume of rock moved'. It's a cost-competitive project because of the high grade, the purity, of the estimated six-acre ore deposit (containing perhaps 550 million pounds of nickel and copper) some 1,000 feet below the surface. But compared to most Rio Tinto mines, that's not a great deal of ore and it will be removed in much less than the 40-50 year life span of a typical mine. When Rio Tinto's Adam Burley arrived in Marquette in July 2011 to take control of the mine project he recognized that, as he puts it, "Eagle is about more than just financial return. It's a sizeable business for the local area, and an important business for us, but even if we did the best we could financially, we are not in the same league as the major Rio Tinto projects. Eagle is an opportunity to build the company's reputation as a 'developer of choice.' In certain parts of the world many companies compete to access a particular deposit. There's a strategic advantage for the company if we can point to examples around the world and say, 'This is how we can develop, build, operate, and rehabilitate a mine in a responsible and sustainable way.'"

Burley, British and trained as a geologist, conducted explorations on several continents for Rio Tinto, worked extensively in Africa, and did an 18-month turn in the CEO's office before becoming president of the Eagle Mine business unit. He acknowledges that the company is already exploring

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for other potential sites in Michigan, Minnesota, and Ontario. "We're optimistic about the prospects. Geologically, all the indications are there. And if we develop those opportunities, we want to point to Eagle and say, 'We recognize this is an environmentally sensitive area and look how we've managed the environmental risk. Look how we've partnered with the community.'"

Particularly important in the Eagle Mine case, adds Nish, is the company's ability to work well with indigenous communities, an important factor in future U.S. mining because reservations of Indian tribes contain a great deal of mineral endowment. "The company's game plan is bigger than Eagle," Nish acknowledges. "What we do here could open doors elsewhere."

But as Nish and his community-audit team met with Marquette community members and company employees on site, it became clear that the community's "door" was far from open. "There was very intensive debate and conflict in the community. We'd been too slow off the start in this project; people who opposed the mine had a couple of years of free reign and they had shaped the story."

IV. Disturbance

Long before the Eagle Mine will produce nickel-copper and generate revenue for Rio Tinto it has already boosted the local economy and altered the landscape. Some 80 people are employed and hundreds of contractors supply goods and perform services. Some of them work at the mine site; others are in Rio Tinto offices in Marquette and nearby Humboldt. Company employees are renting and buying homes and filling local hotels and restaurants, while company funds have upgraded some of the local electricity grid and emergency medical equipment. Rio Tinto spent $30 million to install a state-of the-art water

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Unity of Place

IV. Disturbance

treatment plant, a centerpiece of its plan for environmental performance. Construction is about 45 percent complete and overall cost of the project so far is $225 million. The mine is due to be in production by late 2014, at which point employment is expected to reach 220 people.

The site has been cleared and engineered with roads, a truck-washing building and other facilities, and rock dumps and water-holding ponds, except for a fenced 9.5-acre outcropping of rock covered with thick forest, right beside the mine entrance. This is "Eagle Rock," left undisturbed by the company in response to the Keweenaw Bay Indian Community. A few minutes' drive from the site's office two wells pump groundwater to the mine area. A little further along, the dirt road crosses the upper portion of the Salmon Trout River, a small babbling brook, fed by groundwater. "Blink, and you'll miss it," jokes Bob Cowell, who is on his first tour of the mine, but knows this stretch of woods and stream well. (The lower Salmon Trout is more full-bodied and where the coaster trout live.) The river and surrounding woods are often described as "pristine," meaning unspoiled, but both have long histories of "human intervention." "It's been disturbed ground for many, many years," Cowell says. "The whole area was effectively a tree farm, logged and logged again and again. To say it's this pristine wilderness—the people who live around here think that's a total hoot." The watershed management plan that Lindquist helped to write noted that "human influence over the past 50 years has exacerbated" the river's worst environmental problem, sediment pollution, and identified "logging effects… [and] man-made barriers to migration" as factors reducing the coaster brook trout population.[†]

The company's regulatory permits address a range of potential environment impacts at the mine and the mill:

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contamination of the groundwater and streams; reductions or increases in groundwater levels and stream flows; dust and emissions in the air; damage to plants, wildlife, and habitats. Much of the focus is on the water. At the mine's water treatment plant, construction manager Adam Schultz, Australian with a degree in environmental science and previous Rio Tinto postings in Australia and Madagascar, says that up to 200,000 gallons a day are being treated and this can rise to 500,000 gallons daily under the mine's permits Almost all of this water is rain or snow melt that may have come into contact with mined ore. "There's a whole swag of criteria we have to meet" before water can be released back into the environment. "The water we discharge is cleaner than the water we pump out of the wells."

The company's confidence in the effectiveness of its environmental-impact plans and operations, however, met with continuing doubt and skepticism in the community. This is what Nish, with Burley's approval, set out to try to repair.

V. Alignment

The email Carl Lindquist received from Nish touched off an intense three-month, behind-the-scenes negotiation that eventually included a second local nonprofit institution, the Marquette County Community Foundation, and consultations with Rio Tinto officials worldwide. In a three-page attachment Nish had laid out the company's purpose and proposal. "The Eagle Mine wants to build public confidence in the environmental management and performance of the operations," declared the memo, proposing that the Partnership join with the company to establish "independent monitoring" of the mine's environmental performance. Rio Tinto offered to pay for the monitoring.

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Unity of Place

V. Alignment

In the prior months Nish had met twice with Lindquist, who he knew opposed the mine, and briefly mentioned the possibility of additional monitoring, beyond what government regulators had required. "What I heard from Carl was that this might reinforce the Partnership's role in environmental protection, a model for development in the Great Lakes region that protects water resources. It wouldn't just be a new way to hold our feet to the fire on environmental performance. I thought this was a nice intersection—we both had a bigger game than just the mine. There was mutual self-interest."

Lindquist liked Rio Tinto's idea. "The game had changed. They got their permit and they are moving forward. So what role would we play as an organization? Doesn't it make sense to have more monitoring and to have a local group doing it?" He shared Nish's note with Richard Anderson, the Partnership board chairman. Anderson, a consultant in business and community development and local resident for three decades, was intrigued by Rio Tinto's monitoring overture. He had heard from a trusted friend, a geologist, that mining in the U.P. could "be done the right way," and he had met Nish and concluded that "this is someone I could do business with; he's world class." But Anderson and other board members were deeply concerned about risks for the Partnership in associating in any way with Rio Tinto. "The board worried that working with Rio Tinto could be bad for our brand. The question was, is Rio Tinto attempting to acquire community standing by being affiliated with a highly respected local organization, or do they actually get that their standing long-term is best served by being affiliated with a truly independent mine monitoring process?" To negotiate with Rio Tinto, Anderson appointed a board subcommittee of three: himself; Jerry Maynard, a fly fisherman and attorney with a long career working for Fortune 500 corporations on envi-

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ronmental issues, and—"I wanted the board member who was the most concerned, or cynical, or against Rio Tinto"—Maura Davenport.

During the negotiations, Nish's sparse three-page "Draft Terms Sheet" mushroomed into a detailed 61-page "Community Environmental Monitoring Program Agreement." There was a lot to talk about and haggle over, word by word at times, but the most important discussions focused on several issues: What was the purpose of the effort, what would be monitored and, most critically, how independent would the monitoring really be? "There wasn't a sentence," Anderson says, "where the Partnership team wasn't examining how far we should go. But the balance of power in the negotiation always defaulted back to this question: Does it serve the purpose of our being independent? This could not be undermined. It was our lever."

The Partnership understood Rio Tinto's interest in building public confidence and trust in the mine operations, but that was not a goal it shared. "That's their hope, not ours," says Anderson. "Our job is to deliver on an independent monitoring program and do it in a way that the community can trust and use." The final agreement states that the joint purpose of the monitoring program is "to build a comprehensive and accurate picture of the Eagle Mine's environmental impacts… based on the highest scientific standards." Monitoring would cover Eagle's mining operations—"inside the fence"—the ore processing at the Humboldt Mill, stream crossings along the ore transport route, and air quality in Powell Township (the community closest to the mine). Monitoring could be done to verify Rio Tinto's own monitoring and to go "over and above" the company's government-required monitoring. In addition, community members could identify monitoring

Unity of Place

V. Alignment

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Unity of Place

V. Alignment

that they thought should occur, which the Partnership could choose to implement, and results of all monitoring under the agreement would be shared with the community.[g] Finally, the agreement requires that all data collected by the Partnership will be made public "in a way that is easily understood by the widest possible audience." (The first document posted at the Partnership's website was the agreement itself.)

The matter of the monitoring program's independence from the company required careful consideration by both the Partnership and Rio Tinto. The Partnership signaled that it would not accept money directly from Rio Tinto to conduct monitoring, because this could compromise its independence and the community's perception of its independence. The creative solution to this problem was to ask the 24-year-old Marquette County Community Foundation to step in as an intermediary to handle funds from Rio Tinto for monitoring— $1.2 million in the agreement's first three years—and pay them out according to the terms of the agreement. The foundation agreed to select a five-member oversight board— one from the foundation board, one appointed by the Keweenaw Bay tribe if and when it decided to participate, one with an environmental science background, one from mining, and the fifth from the community at large. This board would have final authority to settle any disputes between the Partnership and Rio Tinto over the monitoring agreement. Bob Cowell, the foundation's longest serving member, handled that organization's role in the negotiation: "The more I got into it, the more I realized how important this was. Both sides need it to work; they both have skin in this game." He likens the role of the oversight board the foundation will create to that of a "parent." If Rio Tinto and the Partnership "decide to fight, we put them in each corner, hear their stories, and then we decide."

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The Partnership also insisted on the right to monitor whatever environmental impacts it chose, period. This demand triggered serious discussions within the company. "It was, oh, this is really going to be independent!" Nish says. "The Partnership wanted ultimate discretion and the community foundation would be the umpire if there were disputes." This was not a simple decision. Nish was proposing something that created risk for the corporation, a "wild card" that it would not control: Rio Tinto would be agreeing to give the Partnership, and through it, the community, the power to decide what to monitor—and it would be paying for the monitoring. "Critics could say that we have manufactured risk that we don't have to have," Nish explains, "that with more monitoring any non-conformance to environmental standards will increase the likelihood of citizen action against the mine. But the answer to that is that the community monitoring horse has bolted out the door of the stable and is already galloping" because of the community's fears. "Additional monitoring will happen in one form or another. It will happen with people with plastic cups collecting water outside our gates or taking leaves off the trees and doing some sampling of them. The question is whether community monitoring happens in a scientific, managed way or happens in an unscientific chaotic way." Rio Tinto decided to embrace the wild card, once the Partnership agreed to a set of typical standards for science-based monitoring with defined baseline data.

The Partnership also took chances—risking its reputation because, some might say, it is "sleeping with the enemy"; committing to implement a multi-year monitoring program; and taking on what board member Jerry Maynard calls "the delicate and tough task" of communicating with the community—"our biggest risk." Rio Tinto shares the concern. "The numbers from the independent

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Unity of Place

V. Alignment

monitoring will be posted on line," explains Kristen Mariuzza, the mine's environmental and permitting manager. "There's a chance that people will see all these numbers and not know what they mean, and they can make anything out of it. The public outreach is critical so people understand the numbers."

In the end, though, the risk taking has been asymmetrical. Rio Tinto opened up the possibility of independent monitoring and agreed to most of the Partnership's requests, because it wanted to build community confidence in the company. The company gave an outside local entity, the Partnership, the power to conduct environmental monitoring that goes beyond what public regulators require and perform, and agreed that all monitoring results would be made public. It absorbed the cost of additional environmental monitoring—a roughly 30 percent increase over what had been planned—into the mine's cost of doing business. And it agreed to let another outside local entity, the community foundation, rule over any disputes between the company and the Partnership. In a nutshell, Rio Tinto gave the community some power over its work, because that was the best way to build confidence in the company. "Mining is disruptive and a new industry in town is disruptive," Nish says. "Part of what makes the community manage that disruption is a greater sense of control. This agreement gives people a greater sense of control over the thing they are most concerned about."

> "Under this agreement, Eagle Mine sets up a program of environmental monitoring that is independent of the company. This Community Environmental Monitoring Program is controlled and run by the community organizations that are committed to the environment of the region. The workings of the program and the information it generates are open to public view."
>
> From "Community Environmental Monitoring Program Agreement," page 4

Agreement clause 13 gives both parties the right to end the agreement, for any reason, with 60 days

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notice. But should either of the parties that have joined hands now and taken a vow in the presence of the entire community decide to back out of the agreement, it will be highly public and will trigger interpretation and speculation community wide about what went wrong and why. Surely that would damage any credibility that Rio Tinto had gained through the agreement. "If they pulled out," suggests the community foundation's Bob Cowell, "they would get slashed and burned all over the world, not just in Marquette."

VI. Journey

In mid-August 2012 the three organizations signed off on the monitoring agreement, which would take effect October 1. Adam Burley approved after consultations with other members of the Eagle Mine team, the company's senior counsel, and the Copper Group leadership.

At the community foundation's board meeting, Bob Cowell walked his colleagues through the agreement documents, explaining the role the organization would play—and why it should be involved. "Is there any better community group that could do this"—Cowell asks rhetorically—"that is relatively independent of most other influences?" Board chairman and funeral-home owner Mark Canale acknowledges that the organization is taking some risk: "But Rio Tinto is not going away and the Superior Partnership is known for its work. We had a chance to show the way a bit for the community, to lead. Hopefully the community will look at us as a truly neutral partner in the whole thing."

At the Partnership's board meeting, Carl Lindquist reminded his directors of the bigger stakes involved, showing them a 2009 map of the Lake Superior basin marked with more than 60 red dots for potential mineral explo-

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Unity of Place

VI. Journey

ration and mining. "This agreement's structure," says board chair Richard Anderson, "is an invention by the company and the community to build trust at a time that people distrust monitoring by the government and self-monitoring by the company." Board member Pete Zenti, a retired doctor and grandson of a miner, summarizes the agreement's value: "It's an open opportunity for the community to contribute and challenge."

A year or even a few months earlier, you could not have predicted that this convergence would occur. Too many unplanned things had to come together for it to happen. "Within Rio Tinto, the stars were in alignment," says Jim French, director of health, safety, and environment at the mine. "I can think of any number of my peers in the organization who would have put as much effort into fighting this as I did into supporting it. We just happened to have the right mix of people." Around the community, a web of trusting relationships—a local "social ecology"—had been built over the years and, when the independent-monitoring opportunity showed up, it quickly self-organized and delivered the competencies needed to work on the problem—environmentalists who knew the watershed and how to monitor; an attorney with experiences and skills in environmental regulation—and then influenced other decision makers in the community to buy into a risky, innovative approach.

All of this was unforeseen, but there was something of a pattern in how it unfolded, a general course by which people came to their converging judgments. "A learning journey," Simon Nish calls it—for the company and the community. It can be seen most clearly in the path taken by Maura Davenport, the Partnership board member who opposed the mine and who also sits on the community foundation board. Twice that week in August, in both

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board meetings, she advocated for the agreement and voted for it. "I've evolved from being in opposition to being educated on both sides and being part of a solution instead of fighting, fighting, fighting," she explains. "I'm working to make Rio Tinto a partner in the community, instead of being the big bad guy."

Jerry Maynard, the attorney on the Partnership board, reached a similar conclusion. As a member of the local chapter of Trout Unlimited he had been in intense meetings of mine opponents. "One was shortly after Rio Tinto said publicly it was willing to consider a community monitoring process. Everyone in that room—there were eight or nine organizations—said, no way in hell, we will never take a penny from Rio Tinto, because we know they are not sincere about this. It's just a fig leaf. It's just PR." Maynard wasn't against the mine—"I'm not anti-mine, I'm anti-bad mining. I'm an avid fly fisherman and I didn't like the idea of the mine going in there, but I can't say I'm against the mine if I'm using the products that use the met- als, and I do." His legal background and a Trout Unlimited study convinced him that Rio Tinto had the legal right to mine. "So right from the start, my attitude is, since there's going to be a mine, let's put our energy into seeing that it's done right." But he didn't know if Rio Tinto could be trusted to do that.

A part of the learning journey was to become open to receiving new information about the situation. When Simon Nish acknowledged publicly that the mine had not done a good job in its community relations, the confession impressed Davenport. "He said the mine wanted to change its relationship with the community, and I had a lot of respect for that." She visited the mine with other Partnership leaders and got a full-scale tour. "After visiting the mine and seeing how they operate," she says, "I think

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Unity of Place

VI. Journey

they want to make a real effort to be a partner in the community." Others also started to see Rio Tinto in a new light. "Going to the facility was an affirming experience," Anderson says. "It felt like a world-class mining facility. The place was pretty buttoned down and they had spared no expense doing it right." Lindquist had a similar impression: "It's definitely a state of the art, clean operation—but that doesn't put all my fears to rest."

Information and education were insufficient to resolve doubt and skepticism. At a certain point it became absolutely necessary to get to know the people involved—and judge their intentions and competence. As negotiations proceeded, Davenport liked what she found in the Rio Tinto team: "They have been listening to us. They respect our ideas, our opinions. It seems like they are sincere." She had watched Simon Nish in meetings and bumped into him on the street. "He's a mediator and he's very good. I want to believe what he says." And she noticed something else about "the other side"—"I feel they have more of a stake in our community than just making a mess and running away." Mark Canale met Rio Tinto management socially. "I've come to know them through parties in town and through some of my associates." He knows the husband of a Rio Tinto employee. "I have liked what I've seen and heard—the personalities of the people at Rio Tinto. They seem genuine and I enjoy being with them." Jerry Maynard negotiated long and hard with Rio Tinto leaders: "The mine's negotiating team has garnered my respect. For the first three or four meetings with them, I continued to have a high level of skepticism. But in a negotiation you develop a working relationship with the person sitting across the table, and we human beings are good at reading deceit in others. I could tell that Rio Tinto's people were being forthright with us, that was my personal read, and they were committed to the agreement."

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Simon Nish also found that his relationship building with community members helped pave the way for Rio Tinto's agreement to hard-to-swallow proposals. Once it was suggested that the community foundation serve as an independent steward for the agreement, Maura Davenport introduced him to the organization's leadership. "As we were wrestling with discomfort around the independent structure," Nish says, "we were building our confidence in the community foundation board and the reasonableness of that board."

When Nish realized that the Partnership negotiators were quite serious about reaching an agreement, he advised Adam Burley that it was time to get to know them. "I told him, this might happen. You'd better meet them and build your own confidence in them, which he did." Burley, who joined Rio Tinto straight out of college about 10 years ago and is a rising star, tells a story about how he had gained assurance about the company's intentions. Given a job in the CEO's office, he'd worked with senior executives. "Once I'd been exposed to them and witnessed the same ethics and practices and the focus on safety and transparency that the company espouses, that gave me a lot of confidence in the organization. I went in as a believer, but you don't really know until you get into those conversations behind closed doors."

As learning, relationship building, and trust took hold, the people involved began to reach new conclusions about what they might do together and how to do it. Then they took responsibility for what they were feeling and thinking, by agreeing to take risks, putting their institu- tions on the line, and making it all subject to the judgment of their neighbors. Will others in the community be open to the news of the agreement, to the surprise of a Rio Tinto-community organization convergence? Will others

Unity of Place

VI. Journey

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look at who's involved and decide they can be trusted, that they have acted in the community's best interest?

Unity of Place

VII. Adaptation

VII. Adaptation

Bob Cowell, the community foundation negotiator, has a vision of how success of the monitoring agreement could change the community, as well as ensure a well-run mine and mill. "If the agreement goes for the length of the mine's life, it will be a continuing reminder to the community that you can do things differently than just argue and fight. And you'll have a continuing pool of individuals from the community foundation, the Partnership, and the mine who are working together and can feed out their experience into other communities and other mines." But the agreement is set to end in three years, on December 31, 2015, according to Clause 12(a), unless the parties extend it. The agreement states that the parties intend the community environmental monitoring "to cover the life of Eagle Mine, from construction to mining as well as closure and rehabilitation" and may renew it for "additional three-year periods to cover the life of the mine."**

The hope, shared by Partnership and Rio Tinto principals, is that before three years pass parties, and the community, will want to stick with some version of the deal. But that probably won't be decided by the same people who built relationships and arrived at sufficient trust and alignment to embrace the original monitoring contract. Some—perhaps many—of them will be gone by then. Burley and Nish, for example, will certainly have moved on to other assignments with Rio Tinto. "Management changes," acknowledges the company's Chantae Lessard. "Right now we have the perfect line of managers who have the same mindset. We want to make sure that everything we've done here is integrated into the future." The mine itself will have

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moved out of the development stage into the production stage. Meanwhile, the leadership of nonprofits like the Partnership and community foundation, which rely heavily on volunteer board members like Anderson, Canale, Cowell, Davenport, and Maynard, may change as well. Eventually the underlying rationales and principles in the agreement must be internalized and accepted by institutions, not just the players who came together in 2012. The agreement has to become, much as Cowell envisions, a part of the culture of the community, of the way things are done around here.

As the agreement moves from words on paper to actions in the field, and leaves private discussions to enter the public realm, something new will be happening. "There will be road bumps," says Simon Nish. "We don't know what they are, but we know they will come." The big company and the little environmental group and the neutral foundation are in a relationship now, come what may.

Yet it seems safe to say that what's to come will look a lot like what's already been mastered once: there will be new information to take in, new people to get to know and trust, new choices to consider, new risks to take, and new responsibilities to shoulder.

For additional information:

Marquette Co. Community Foundation: www.marquettecountycommunityfoundation.org/

Superior Watershed Partnership: www.superiorwatersheds.org

Eagle Mine: http://eaglemine.com/

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Do you need a CEMP?

How your community and your company can design and implement a Community Environmental Monitoring Program

By Peter Plastrik
May 2013

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Peter Plastrik is a writer, consultant, and vice president of the Innovation Network for Communities. Co-author of Banishing Bureaucracy and The Reinventor's Fieldbook, he has written extensively about community-based innovations. This case study was jointly commissioned by Rio Tinto Group and the Superior Watershed Partnership.



Rio Tinto

POSTSCRIPT: *Rio Tinto has sold 100 percent interest in the Eagle Mine to Lundin Mining Corporation, effective July 18th, 2013. Lundin Mining fully supports the Eagle Mine Community Environmental Monitoring Program (CEMP) and will continue it.*

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Do you need a CEMP?

INTRODUCTION

In 2012 we unexpectedly started a journey together that led to the creation of a Community Environmental Monitoring Program (CEMP). We had very different starting points and purposes. We had very different backgrounds. Picture it: A long-time community-based environmentalist and a global mining company official. But we agreed on one thing: We wanted to find a way to empower the communities of Marquette County, Michigan—some 64,000 people—to understand and monitor a new mining operation's environmental impacts, going beyond any checking the company or governments had ordered. So we decided to have our organizations work together to try to find a way.

We took the journey's tentative first steps with little clarity about where we'd go next and no certainty of success. No one had a handy, off-the-shelf solution. We got others involved. We negotiated. We invented. And we finally came up with an agreement, the CEMP, of which we're quite proud and that's being implemented. We couldn't have done it without each other.

Now we're inviting you to learn about this innovation—what it is and does, how it might apply to your community or company, and how to do it yourself. A CEMP agreement can help to guard the environment from damage. It can help reduce the stress in a community seemingly faced with choosing between economic development and environmental protection. And it can enhance a company's efforts to earn the trust and support of the community. In this how-to booklet, authored by Peter Plastrik at our request, we offer step-by-step guidance for creating other CEMPs, adapted to fit your own needs and situation. The fact that we share a single voice in describing this to you, in spite of our differences, is something we could not have imagined when this journey started. It's also evidence that something new and different has happened, with exciting potential.

Simon Nish
Director of Communities, Communications and External Relations
Rio Tinto Eagle Mine

Carl Lindquist
Executive Director
Superior Watershed Partnership

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CONTENTS

Part I: Orientation **Page 1**
1.1 Every Solution Starts with a Problem
1.2 Origin of the CEMP
1.3 The CEMP At Work
1.4 What Is a Community Environmental Monitoring Program?
1.5 Benefits of a CEMP
1.6 The CEMP is a Model for Others to Use

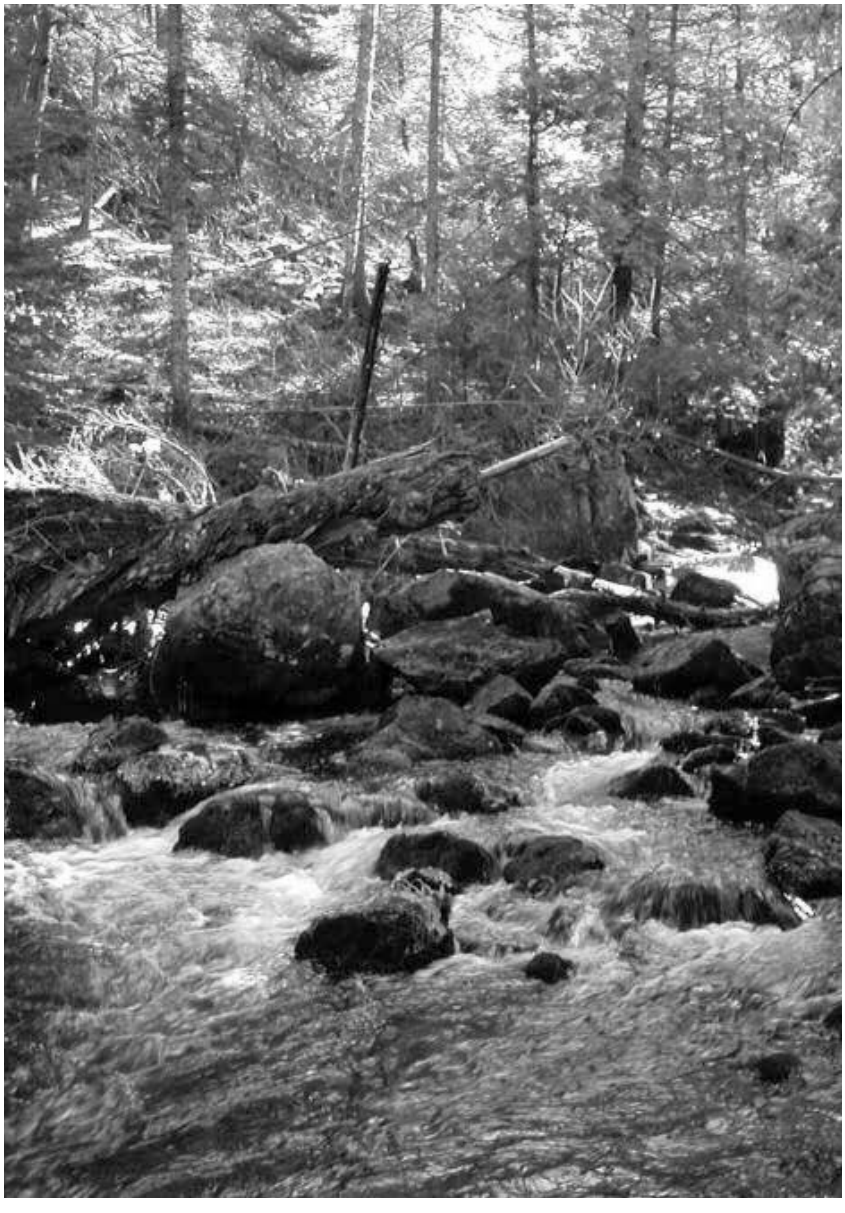
Part II: Step-By-Step Guidance for Designing a CEMP **Page 6**
2.1 Find Potential Partners
2.2 Build Trust
2.3 Identify Shared Goals for a CEMP
2.4 Identify Key Design Principles for a CEMP
2.5 Design Implementation Mechanisms

Part III: Implementation Mechanisms in the CEMP **Page 13**
3.1 The Written Agreement
3.2 CEMP Fund
3.3 CEMP Oversight Board
3.4 CEMP Annual Work plan
3.5 Data-Sharing and Monitoring Standards
3.6 Resolving Disagreements
3.7 SWP Community Outreach and Web Site

Part IV: Managing Initial Implementation **Page 20**
4.1 Organizing Operational Communications between the Parties
4.2 Setting up the CEMP Board
4.3 Bringing in the Public and the Press

Part V: Resources: Where to Find Them **Page 23**

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PART I: ORIENTATION

1.1 Every Solution Starts with a Problem

This booklet describes a new way that communities and companies can solve an old problem they share.

The problem is the risk to the environment created by certain economic activities and the public's anxiety about how well those risks are being monitored and managed. Even after a company's economic-development project has met all legal and government regulatory requirements, its potential negative impact on environmental quality and human health, should something go wrong, may distress people in the area. They simply may not trust the company to "do it right," because of the local history, the company's track record, or their suspicions about the company's motivations. They may not trust government officials to stay on top of what's happening at the development site, to blow the whistle if something is wrong, or to prevent a disaster from happening in the first place.

This sort of problem typically causes serious pain in a community. Many of its members divide into opposing camps: pro- and anti-development, pro-environment versus pro-economy. The battles can become fierce, personal, and endless—and spill over into other matters. Anxieties about the project's potential impact endure, further adding to community stress. Instead of the company's presence—its project, employees, contractors, everything about it—being a contribution to the community's well-being, it becomes a source of conflict within the community.

The company also suffers. The problem costs the company money and ill-will in the community, because it must fend off endless attacks and even lawsuits. Literally anything that happens at the project site, no matter how minor, can become a point of contention in the community and cause delay in the project. In some cases, determined community members may start their own ad hoc "monitoring" of the site, generating data that may or may not be valid but is sure to inflame community concerns. All of this can damage the company's reputation in other communities where it wants to operate and with customers in its markets.

Do you need a CEMP?

PART 1: ORIENTATION

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Do you need a CEMP?

PART 1: ORIENTATION

Anyone who has been through something like this knows how destructive it can be—and how hard it is to address. When community members don't trust the company and government regulators, who would they trust? When a company has complied with all legal and regulatory requirements, why should it go through additional effort and, yes, the cost of doing something to make the community feel better? What can really be done to reassure the community? Who would the company trust to do it?

1.2 Origin of the CEMP

The problem was in full bloom in Marquette County, Michigan in early 2012. A new nickel-copper mine was being constructed by a London-based corporation. The Rio Tinto Group had secured all necessary permits from state and federal government agencies. The mine was being built, hundreds of local contractors and employees were on the payroll, more than $30 million had been spent to build a state-of-the-art water treatment plant, and the company expected to spend at least $225 million on the site before generating any revenue.

But the community was disturbed. The mine site was located at the headwaters of a wild river that emptied into Lake Superior and contained a rare species of trout. Fear of the unknown and the unexplained; distrust of a corporation's motives and deep pockets; lack of faith in distant state and federal government regulators; and a dismaying sense of powerlessness in the face of apparent threats to the environment and health: as these feelings surged through the community, some began advocating for independent monitoring of the mine's environmental impacts.

The company concluded it had to find a way to build public confidence and trust in its operations. So in the spring of 2012 it decided to try a new approach, something it hadn't tried anywhere before. (For a detailed article about the process that led to the CEMP, see http://www.cempmonitoring.com/wp-content/themes/cemp/pdfs/RT_CEMP-The-Unity-of-Place.pdf).

1.3 The CEMP At Work

Fast forward about six months. It's the end of 2012; as winter descended on northern Michigan, staff members of the Superior Watershed Partnership, a regional conservation nonprofit, monitored the water and air quality at and around the new Eagle Mine,

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still under construction. They took water samples from the mine's water treatment plant, surface facilities, and groundwater monitoring wells, and sent them to a laboratory for testing. They set up a permanent air quality monitoring station west of Big Bay, the nearest town to the mine. They used hand-held devices to monitor the air quality around the mine. They assessed the mine's monitoring and data collection procedures to assure they will generate data representative of mine-site conditions. And they pored over the mine company's own environmental monitoring data and operations data, to check on its validity and the company's interpretation of what the data meant.

All of the Superior Watershed Partnership's monitoring was being done at its own discretion—it could even act on suggestions from the public—and went beyond what government permits required of the Eagle Mine operation. But it wasn't a secret or off-the-cuff operation. The mine owner, Rio Tinto, the world's second largest mining company, had agreed to give the Superior Watershed Partnership an independent hand in environmental monitoring, as long as it met scientific standards. Superior Watershed Partnership staff had complete access to the mine site, as well as its records.

This arrangement will continue for at least three years and could be renewed through the life of the mine. Under the agreement, the Superior Watershed Partnership will make public all of the results of its monitoring and checking and auditing of mine data as quickly as possible on its Web site. This, too, was agreed to by Rio Tinto.

All of the Superior Watershed Partnership's monitoring work is to be paid for by the company through its donations to the Marquette County Community Foundation, a fiscal-agent arrangement that ensures the Superior Watershed Partnership's independence from company influence. Other donors can add funding to provide for additional monitoring by the Superior Watershed Partnership.

Every bit of this—the scope and standards for monitoring that go beyond government requirements; the full and timely public disclosure of data; the funding from the company, above what it already will spend on environmental monitoring; and, most impor-

Do you need a CEMP?

PART 1: ORIENTATION

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tant, the Superior Watershed Partnership's independence to scrutinize the company's operation—was not just agreed to by Rio Tinto. The corporation had invited and embraced it. Indeed, it was Rio Tinto that initiated the discussions, early in 2012, that led to a formal, detailed monitoring agreement, known as the Community Environmental Monitoring Program, or CEMP.

Do you need a CEMP?

PART 1: ORIENTATION

1.4 What Is a Community Environmental Monitoring Program?

A CEMP is a voluntary agreement between an economic-project developer and one or more community-based organizations that empowers members of the community to monitor at their discretion the project's environmental impacts, based on scientific standards, and ensures public access to all monitoring information in a timely and understandable manner.

The agreement is a legally binding document that details the consents, commitments, and mutual obligations of the parties to the agreement. It guarantees that the community entities will have the independence, permission, access to company data, property, and personnel, as well as financial resources they need to determine and conduct monitoring. And it obligates the community entity to communicate to the public its monitoring findings.

All parties agree on what is to be accomplished under the pact: a program of independent environmental monitoring. The agreement controls the relationship between all of the parties. And it sets up a neutral, independent community-based board with the authority to approve all plans and budgets, enforce the agreement and resolve any disputes between the parties. A CEMP creates an additional layer of monitoring; it doesn't add regulations or change the accountability of the project developer for environmental management.

The agreement also institutionalizes the relationship between the community and the project, which provides some assurance that independent monitoring will not be affected by personnel changes within the community entities or the project management.

In Marquette County, the CEMP—officially called the "Rio Tinto Eagle Mine Community Environmental Monitoring Program"—is an agreement between three parties: Rio Tinto Eagle Mine, the Superior Watershed Partnership, and the Marquette

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County Community Foundation, which serves as both fiscal agent for the agreement and as community-based umpire to rule on any disagreements the other parties may have about implementing the agreement.



Press conference launching the CEMP: (From left to right: Simon Nish, Director of Community, Communications and External Relations Mark Canale, Chairman of the Board, Marquette County Community Foundation; Jerry Maynard, Director of the Superior Watershed Partnership; Carl Lindquist, Executive Director of Superior Watershed Partnership.

1.5 Benefits of a CEMP

A Community Environmental Monitoring Program may produce three distinct and important types of benefits:

- **Help to guard the environment from damage.** This was the driving motivation for the Superior Watershed Partnership.
- **Help the company to earn the community's trust and support for its operation.** A company that allows independent monitoring of its environmental impacts may gain a measure of respect in a community that has been troubled. Earning community trust and reducing the risk of future litigation were certainly uppermost on Rio Tinto's mind.
- **Help reduce the stress in a community faced with what it sees as the potential tradeoff between economic benefits and environmental quality.** This mattered to the Marquette County Community Foundation when it stepped up to assist Rio Tinto and the Superior Watershed Partnership in implementing the CEMP.

Do you need a CEMP?

PART 1: ORIENTATION

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Do you need a CEMP?

PART 2: STEP-BY STEP GUIDANCE

1.6 The CEMP as a Model for Others

The CEMP is more than a unique arrangement between a global mining company and an environmental organization in Michigan's remote Upper Peninsula. It's a potential model that other communities and companies in mining and other sectors can use to provide greater assurance that potential environmental impacts of any sort will be detected, revealed, and addressed. And it can be used for any type of project for which the community has abiding environmental concerns—a new development, a redevelopment, or even an existing situation.

There is no "one size fits all" for a CEMP agreement; each has to be tailored to the needs and contexts of the parties. This booklet is intended to help you do that, whatever your starting point.

PART II: STEP-BY-STEP GUIDANCE

2.1 Find Potential Partners

When it comes to creating a CEMP, it takes at least two to tango. A company may be interested in realizing the benefits of a CEMP, but it needs partner organizations in the community that can perform the tasks involved in a CEMP. A community-based environmental or civic organization may see the need for additional monitoring of a specific economic project, but it needs the company that owns the project to be a willing partner.

Whether a company or a community organization starts the process, it has to identify and engage potential partners willing to explore the possibility of an agreement. Remember, though, that the decision to dance should be voluntary. **No party should be forced into working on a CEMP agreement.** Discussions about creating a CEMP can even occur before a company has the necessary green lights for a project.

When a Company Starts the Process

For a company there are two ways to identify potential partner organizations in the community. One is to do a private "scan" of potential organizations—researching and contacting them to sound them out—and then select from those that seem most promising. Another way is for the company to issue a public Request for Proposals (RFP) to find out which, if any, organizations would

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be interested in and have the capabilities for conducting a monitoring program.

An RFP process is a useful tool for finding out which entities in the community might be interested in working to develop a CEMP and it allows the company to be public about what it's planning and how it intends to engage with community entities. But an RFP can also be a fairly slow process. It may pit community entities against each other, which is unhelpful. And it may lead community members to develop expectations—positive or negative—about what the company is up to long before there's any clarity about what might actually occur.

Whether a company uses a public RFP or a private scan to identify potential partners for a CEMP, it has to be clear about what it's looking for in a partner. Among the desired characteristics are:

- Credibility within the community.
- Capacity to negotiate and implement a CEMP.
- A track record of environmental monitoring and communicating with the community.
- A level-headed, reliable board of directors and top management.

When a Community-Based Organization Starts the Process

For a community organization that wants to engage a company in developing a CEMP there are several important aspects to approaching the company:

- Be clear about what you want and how it might be done. Your organization can use the example of the CEMP in Marquette County, and this booklet, to describe what a CEMP customized to your situation might look like.
- Consider how strong your organization's credibility within the community and capacity to implement a CEMP are—and what might be done to strengthen them.
- Consider how open minded the organization is to mining, without a strong predetermined bias about resource development.
- If you don't already have a relationship with top management in the company, instead of making a "cold call" on the company, identify someone in the community who

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might approach the company on your behalf, vouch for your organization's seriousness and standing in the community, and set up a first meeting with the right people in the company.
- Understand and be able to describe the potential benefits to the company in setting up independent community monitoring.

Do you need a CEMP?

PART 2: STEP-BY STEP GUIDANCE

2.2 Build Trust

The potential partners in a community environmental monitoring agreement must build enough trust between themselves so they can start to negotiate the details of a CEMP. In our experience, trust building involves at least three essential activities:
- Get to know each other as people.
- Clearly and candidly put your organization's motivations and "must haves" on the table.
- Build a relationship between the leaders of the community organization and company

Getting to Know Each Other

People get to know each other best by being with each other and doing things together. The negotiators for the Superior Watershed Partnership, Rio Tinto, and the Marquette County Community Foundation held frequent and long meetings, and side meetings, often over a meal. The Superior Watershed Partnership board of directors took a thorough visit to the mine site, which allowed it to assess the competencies and commitment of the mine's environmental managers. It also met with the mine president, Adam Burley, which gave it a chance to check on support for the CEMP higher up in the company.

Sharing Motivations and "Must Haves"

Each of the organizations that created the CEMP had different reasons for doing so. Being clear about each other's interests made it possible to look for areas of common ground. For instance, the Superior Watershed Partnership wanted to enhance environmental protection, while Rio Tinto wanted to build community trust in its environmental performance. SWP wanted to build a monitoring model that might be used elsewhere in the Great Lakes, while Rio Tinto wanted to create a model that would build its reputation for building new, modern mines. The convergence of these interests opened the door for designing a CEMP.

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It matters at the outset to make clear to the other parties what your motivations are and what your "must haves," your bottom lines, are. This allows each party to decide if it's willing to try to craft an agreement that satisfies the other parties' objectives. And it allows each party to think creatively about what a solution must look like if it will respond to all parties' motivations.

2.3 Identify Shared Goals for a CEMP

The purpose of the CEMP, built right into the agreement is "to build a comprehensive and accurate picture of Eagle Mine's environmental impacts." Period. This is the shared goal agreed to by Rio Tinto, the Superior Watershed Partnership, and the Marquette County Community Foundation. This goal is not the same thing as the motivations that each party started with. It was by developing the shared goal of creating a comprehensive and accurate picture of the mine's environmental impacts that each party was able to achieve its own objective.

Although the CEMP covered all potential environmental impacts, that was a choice made by the parties. It's possible, instead, to focus on a particular type of environmental impact—groundwater quality, or air quality, or soil quality, for instance—depending on the type of development project underway and the concerns of the community.

2.4 Identify Key Design Principles for a CEMP

On the way to creating the CEMP, the negotiating parties agreed on a set of principles that had to be addressed in implementation. Some principles were more important to one party than another. Some were difficult to agree to, some were not. All of the principles were used to develop the CEMP's implementation mechanisms.

In all, six key principles are embedded in the CEMP, each one reflecting key questions that the parties in a CEMP negotiation will likely have to work through. The answers that the CEMP negotiators reached may provide guidance for others.

1. ***The agreement supports community participation in determining what will be monitored, but all monitoring must meet scientific standards.***

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Do you need a CEMP?

PART 2: STEP-BY STEP GUIDANCE

The agreement adds community-determined monitoring to the monitoring required by government regulatory agencies granting the permit to operate. The community participates in determining monitoring in two ways: (a) through monitoring that the community-based monitoring entity (the Superior Watershed Partnership in the case of the CEMP) has embedded in the CEMP agreement with the consent of the other parties and (b) through additional suggestions made by community members, which the monitoring entity will consider for implementation.

However, any monitoring by the monitoring entity must meet scientific standards for monitoring as defined in the agreement. The CEMP embraces the "highest scientific standards" and this is further defined and illustrated. For instance, the agreement states that "the way that sampling and testing is done…must ensure that results can be easily compared with results from earlier samples and tests."

In the case of the CEMP the parties will use monitoring standards of the U.S. Environmental Protection Agency and the State of Michigan Department of Environmental Quality. And they will establish "baseline data," measurements of the current state of the environment—based on existing data or new data to be collected—against which future states can be compared. This baseline data must meet scientific standards.

2. ***The agreement ensures the independence of the community monitoring entity, both in fact and in perception by the community.***

Nothing in the agreement may compromise the independence of the community-based organization conducting the monitoring, in fact or in the community's perception. The scope of monitoring—what and when to monitor—is solely up to the monitoring entity without restriction except—and this was crucial to Rio Tinto-the requirement to meet scientific standards in monitoring methodology. The Superior Watershed Partnership's independence was constrained, but not compromised, by the condition that all monitoring meet scientific standards; this established a balance between both parties' interests.

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The CEMP assures that the Superior Watershed Partnership "will be independent in the way it runs the CEMP, although it must do so within the rules of the agreements and agreed monitoring standards." The Superior Watershed Partnership has "final say" on where monitoring data will be collected; which subcontractors will do monitoring work; which laboratories will do testing; how to approach additional monitoring; which baseline data will be used; and more.

A particular concern that had to be addressed in the CEMP negotiation was how—what mechanism would be used—to ensure the Superior Watershed Partnership's independence when Rio Tinto was paying for monitoring the Superior Watershed Partnership would do.

3. ***The agreement requires that disputes between the parties be resolved by a neutral, independent community-based umpire.***

The agreement must ensure that neither party has the power to violate the terms of the agreement and that any disputes that arise between the parties will be resolved fairly. It's not hard to anticipate that there might be some differences between the parties in interpreting what the agreement permits and requires. This meant that the power to enforce the agreement and to resolve arguments had to reside outside of the Superior Watershed Partnership and Rio Tinto, with a third party. Accordingly, the agreement created a community-based "referee," the CEMP Board, an implementation mechanism established by the Marquette County Community Foundation. (More on the CEMP Board in Section 3.2).

4. ***The agreement provides for complete and timely data sharing with the monitoring entity and for maximum transparency with and outreach to the public.***

The agreement establishes the processes and timelines for sharing of all data from all environmental monitoring of the project (including monitoring required by government permits and the project's own monitoring). It also ensures that the community will be able to see the agreements that established monitoring, how the monitoring is funded, and all of the information collected by mon-

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Do you need a CEMP?

PART 2: STEP-BY STEP GUIDANCE

itoring. Since, even if there were no CEMP, much of the mine's monitoring data would be made public, the most important value that will be added by the Superior Watershed Partnership is in helping the community make sense of what the monitoring data means. This is particularly important when it comes to translating the technical data from environmental monitoring into information that community members can understand and use to assess the mine's environmental impact.

The agreement requires that community outreach efforts include community meetings and presentations, as well as information online.

5. ***The agreement has funding committed at the outset sufficient for implementation and should be open to additional funders for additional monitoring.***

The agreement includes an initial funding commitment, provided by the party that will benefit financially from the project, which covers the estimated cost of monitoring for the life of the agreement. But additional funding can be provided by others not already a part of the agreement, as long as it will support monitoring that meets the conditions in the agreement.

The CEMP specifies an annual financial payment—a donation to the Community Foundation—by Rio Tinto. The amount was determined in negotiations between the company and the Superior Watershed Partnership. The financial exposure of Rio Tinto is capped, but unexpended funds could be spent in subsequent years.

6. ***The agreement is open to renewal, updating, and improvement.***

The agreement has a fixed term, but can be renewed by the parties. The parties to the agreement can revise the agreement by mutual consent to adapt to changes in the project's realities. This was especially important because it was the first time any of the parties had entered into such an agreement, so it made sense to assume that during implementation they would find ways in which the agreement could be improved. Having a renewal point also allows the parties to take stock of how well the agreement is working and, together, to devise improvements.

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In the CEMP, the agreement is set to last three years, a term that made sense to the negotiating parties because of the phasing of the mine's life. And the parties expressed the intention to go longer: "The CEMP agreements are intended to cover the life of Eagle mine, from construction to mining as well as closure and rehabilitation. Eagle Mine and SWP may agree to renew this agreement for additional three year periods to cover the life of the mine."

2.5 Design Implementation Mechanisms

Agreeing on the design principles for a CEMP was a prelude to agreeing on the mechanisms—the rules, standards, procedures, financial commitments, organizational structures and authority, as well as the operative documents—that would be used to make the CEMP happen. This step, too, involved a give-and-take negotiation and it required more invention than anticipated, particularly the design of a CEMP Oversight Board. Until all of the mechanisms were spelled out in detail in the CEMP agreement, there could be no final pact. During this process lawyers also got into the act, to ensure their party was not agreeing to something it wouldn't be able to live with when it was implemented.

A complication that occurred: what had started as a two-party negotiation between Rio Tinto and the Superior Watershed Partnership morphed to some extent into a three-party negotiation with the addition of the Marquette County Community Foundation, which was to serve in a fiscal and oversight capacity, but had its own objectives and "must haves." As a result, the CEMP is made up of two interacting agreements: the monitoring agreement between Rio Tinto and the Superior Watershed Partnership, and a funding agreement that also includes the Community Foundation. Each agreement includes the other agreement.

Part III: IMPLEMENTATION MECHANISMS IN THE CEMP

3.1 The Written Agreement

The CEMP Agreement was signed by the chief executives of the Superior Watershed Partnership and Rio Tinto Eagle Mine, and is legally binding.

Do you need a CEMP?

PART 2: STEP-BY STEP GUIDANCE

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It is a 16-page document that covers 19 topics, with 46 additional pages for nine attachments that provide detail about some of the implementation mechanisms. While that may seem extraordinarily long, it was necessary to cover the many details in a ground-breaking agreement. But every page was written in plain English, not legalese. This was to make good on the principle of maximizing transparency with the public, as was the decision to make the agreement available at the Superior Watershed Partnership's Web site (http://www.cempmonitoring.com/).

Do you need a CEMP?

PART 3: IMPLEMENTATION MECHANISMS

3.2 CEMP Fund

The CEMP agreement specifies that Rio Tinto will provide up to $300,000 per year (for three years), plus an additional one-time contribution of $300,ooo to cover the Superior Watershed Partnership's set-up costs, including the purchase of monitoring equipment and setting up of an air-monitoring station and a Web-based communication platform for the CEMP. The exact annual amount will be determined by a budget that the Superior Watershed Partnership will include in the annual work plan.

The Marquette County Community Foundation provided the mechanism for funding the CEMP's work by the Superior Watershed Superior Watershed Partnership. As a Community Foundation it can accept donations for charitable purposes—and community-based environmental monitoring fits the government's definition of charitable purpose. Rio Tinto can and will contribute into the foundation's fund for CEMP implementation—and so can any other organization or individual. Non-Rio Tinto funds can be used for additional monitoring or to continue monitoring that was supposed to end because of other priorities in the Superior Watershed Partnership's work plan. However, additional monitoring must meet monitoring standards established in the agreement and must be conducted by the Superior Watershed Partnership or its approved subcontractor.

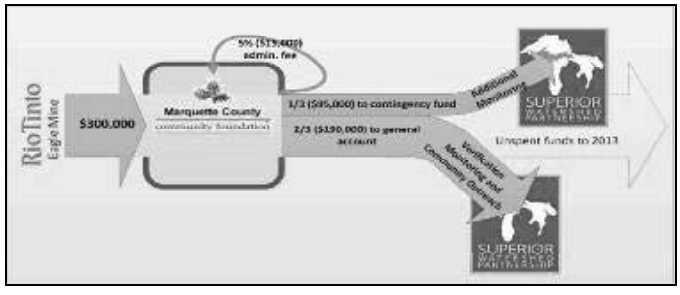
Technically, the foundation and Rio Tinto Eagle Mine created a "non-endowed" fund that would accept donations from Rio Tinto and pass them on to the Superior Watershed Partnership for doing monitoring work. The fund is the foundation's property and all donations are irrevocable; Rio Tinto can't get its money back under any circumstances, even if the CEMP were to be terminated.

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This funding mechanism ensured that Rio Tinto's funding would go to a neutral third party rather than directly to the Superior Watershed Partnership, and that spending of the funds would only be guided by the terms of the CEMP agreement. This preserved the Superior Watershed Partnership's independence from Rio Tinto influence, in fact and community perception. At the same time, it made it possible for others within or even outside of the community to contribute to CEMP implementation, thus expanding the community's potential engagement with the CEMP.

Do you need a CEMP?

PART 3: IMPLEMENTATION MECHANISMS



3.3 CEMP Oversight Board

The Marquette County Community Foundation created a Board of independent community members (volunteers) to oversee the CEMP Fund; ensure that the parties implement the CEMP in accord with the agreement's requirements, standards, and procedures; and resolve any disputes between the parties. Designing the CEMP Board's functions and membership was absolutely critical to forging the CEMP agreement because it ensured that a neutral, independent, community-based third party would oversee implementation. The Board must approve all Superior Watershed Partnership plans and budgets for monitoring. To be clear: the Board does not run the CEMP. That's up to the parties in the agreement.

The CEMP specified that the Board would have five members, four selected by the foundation in accordance with general characteristics spelled out in detail in the agreement—one each from the environmental science sector, mining sector, community at large

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and the Community Foundation board of directors--and one selected by the Keweenaw Bay Indian Community, representing the Anishinabe Nations. The foundation, which is governed by community volunteers, used a local personnel consulting firm to identify potential candidates for the sector-based seats on the Board. This ensured that the candidate-selection process would not be politicized, and would remain credible in the eyes of the community.

Do you need a CEMP?

PART 3: IMPLEMENTATION MECHANISMS

3.4 CEMP Annual Work Plan

The CEMP requires the Superior Watershed Partnership to develop an annual work plan that describes the activities it intends to take, a timeline for the activities, and a budget. The work plan will be made available to the public. Rio Tinto may raise with the CEMP Oversight Board any concerns it has about the proposed work plan, and the Board has final approval of the plan.

The work plan should cover the following topics in detail:

- Community environmental monitoring objectives
- Risk assessment (of potential impacts on the environment)
- Annual monitoring objectives, including sampling sites and facilities monitoring
- Publication/communication plan
- Community outreach
- Annual budget

(Much greater detail is available in Attachment B of the CEMP agreement, a table of contents for the work plan.)

3.5 Data-Sharing and Monitoring Standards

Data Sharing: The CEMP's rules about data sharing are concise and clear: "Eagle Mine will share all the data from its environmental programs with SWP (the Superior Watershed Partnership). SWP will make this data public." Eagle Mine must share all data within 14 days of it coming to hand, with two important exceptions:

- *Serious risks:* "Eagle Mine and SWP will tell each other, by phone or email, of any data that suggests a danger to community health or the environment, as soon as they become aware of the risk." And SWP will release this information to the community "as soon as possible."
- *Breaches of permits:* "Any data that shows that Eagle Mine has breached its regulations or permit conditions will be shared verbally within 24 hours of discovery." That has

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to be followed up by written communication within 14 days. This data will also be made public.

Monitoring: The CEMP agreement devotes seven pages—Attachments D, E, and F—to describing standards and methodologies for community monitoring, including identification of the pollutants whose presence is being checked, baseline data that will be used, and frequency of monitoring. These cover two categories of monitoring:

- *Verification* monitoring checks on Rio Tinto's existing monitoring of mine facilities, groundwater, surface water, flora/fauna, and air quality.
- *Additional* monitoring is at the discretion of the Superior Watershed Partnership and, from the outset of the agreement, identified additional monitoring of air quality and of new transportation routes for moving ore from the mine to a processing facility.

Additional Monitoring: Although under the agreement the Superior Watershed Partnership "may decide on its own" to do additional monitoring to better understand how the Eagle Mine is affecting the environment, there are some rules about how the Superior Watershed Partnership must proceed in doing this. First, it must develop a plan saying how it will do the monitoring, describing the baseline data and standards that will be used. It must give the plan and budget to Rio Tinto Eagle Mine for comment. Eagle Mine has 28 days to provide comments and if the Superior Watershed Partnership does not agree with the comments it must give its reasons to Eagle Mine in writing. At that point, if Eagle Mine objects to the additional monitoring, the issue goes to the CEMP Board for a decision. While the dispute is being resolved the Superior Watershed Partnership may start the additional monitoring, but it must stop immediately if the dispute process finds the additional monitoring will not help to understand the impacts of Eagle Mine.

3.6 Resolving Disagreements

The CEMP identifies two types of disagreements that may arise between the Superior Watershed Partnership and Rio Tinto—technical/scientific disagreements and non-technical disagreements about interpretation of the CEMP agreement—and establishes different processes for resolving each.

Do you need a CEMP?

PART 3: IMPLEMENTATION MECHANISMS

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Do you need a CEMP?

PART 3: IMPLEMENTATION MECHANISMS

Technical disagreements—including about monitoring standards, interpretation of monitoring results, a need for additional monitoring—will be resolved through a peer review process. Either party can initiate a peer review process. A peer reviewer must be a scientific expert in the area of the disagreement. If the Superior Watershed Partnership and Rio Tinto cannot agree on a peer reviewer, then the Oversight Board has the authority to select a peer reviewer and determine the scope of the review. Both parties must abide by the peer reviewer's findings. The findings must be made public.

Non-technical disagreements will be submitted directly to the Oversight Board for a decision. Both the Superior Watershed Partnership and Eagle Mine must abide by the Board's decision.

3.7 SWP Community Outreach and Web Site

The CEMP agreement commits to community outreach, which "aims to make sure that the results of the monitoring program are available and understood by the community," and lays out some initial understanding of what such outreach, mostly run by the Superior Watershed Superior Watershed Partnership, would look like:

- All CEMP agreements (including the funding agreement with Marquette County Community Foundation, work plans, and budgets will be made public.
- SWP "will own any of the data it collects and will provide the data to the community in a way that is easily understood by the widest possible audience. Data will be made available on the Internet and SWP will decide when and how this is done."
- "Community outreach will include, at least, community meetings, presentations and on-line information."
- SWP "will ask the community for suggestions about the work of the CEMP. This will be done as part of the community outreach program. It is up to SWP to decide if it adopts these suggestions, but it must respond in writing to each one detailing the technical or scientific reasons for its decision. These responses will be open and available to the community."
- SWP "will develop a community outreach plan as part of the CEMP Work Plan. The community outreach plan will be updated each year along with the update of the Work

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Plan. An initial education campaign will include information on environmental monitoring currently done at Eagle Mine and monitoring that will be undertaken by SWP as part of the CEMP."

- "The community outreach plan will include annual community forums… on the outcomes of monitoring as well as presentations, brochures and website information. It will also include data for the Eagle Mine Community Scorecard. A schedule of community meetings and activities will be developed annually and included in the plan."

Even as the CEMP was being launched, the Superior Watershed Partnership set up a part of its Website (http://www.cempmonitoring.com/) to handle a large amount of the community outreach. This is where all relevant documents are posted and where monitoring results will be made public in a Scorecard. It's also where anyone can send a suggestion or comment to the Superior Watershed Partnership's staff.

Do you need a CEMP?

PART 3: IMPLEMENTATION MECHANISMS



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Do you need a CEMP?

PART 4: MANAGING INITIAL IMPLEMENTATION

PART IV: MANAGING INITIAL IMPLEMENTATION PROCESSES

The CEMP was just starting to be implemented as this booklet was being written. As verification and additional monitoring commenced, three implementation processes were underway:

- Organizing regular, reliable communications between the three parties: Rio Tinto Eagle Mine, Superior Watershed Partnership, and, for the first time, the CEMP Board appointed by the Marquette County Community Foundation.
- Setting up the CEMP Board.
- Bringing in the public—initiating community outreach using the local media and community forums.

4. 1 Organizing Operational Communications between the Parties

With a CEMP agreement in place, it's up to the parties to decide how the agreement's details will be implemented. Rio Tinto, the Superior Watershed Partnership, and the Community Foundation established a set of protocols about the steps their interaction would follow. At the same time, Rio Tinto and the Superior Watershed Partnership set up a technical group, which meets every few weeks to hammer out detailed implementation procedures for the organizations. Since it's likely that initial procedures will have to be revised as the organizations gain experience with implementing the CEMP, ongoing communication is a must.

4.2 Setting up the CEMP Board

When a CEMP Board first convenes, it has important work to do in preparation for addressing any disagreements that may arise between the parties. The Board must:

- *Understand its role and responsibilities.* This requires careful study of the CEMP agreement and, probably, some discussions with the parties to the agreement. It's essential for the Board to recognize that it is not for or against the development project (e.g., mining), but is focused on monitoring of the project. The Board also needs to be clear about what may not be in the agreement but is still being worked out by the parties, such as procedures the parties will use to notify each other of findings from monitoring.

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In the case of CEMP, it was important for the Board to understand that it had to keep the Community Foundation, which appointed it, informed of its activities.

- *Get to know the parties*. Meeting with them allows the Board to understand each of the players and their roles, and also lets the players get to know the Board members.
- *Get to know the members of the Board*. This is important, because the Board members will have to be able to work together to resolve disagreements among the parties. Time together and discussions help to build relationships and expectations.
- *Establish clear recruitment procedures*. Clear and public selection criteria for the Chair and the Board Members sets out the basis of their recruitment to the Board. Having a clear conflict of interest policy will be more important for smaller communities.
- *Establish operating procedures*. There are decisions to make: Setting up a regular meeting schedule. Determining whether meetings will be private or public. (The CEMP Board meets privately.) Determining what will be communicated to the public and how it will be done.

4.3 Bringing in the Public and the Press

It's critical to make sure that the local community, as well as the press (newspapers, television and radio news shows), understand what the CEMP is about and what to expect as it is implemented. This involves more than just issuing a press release, because community monitoring of the sort in the CEMP is a new way of doing things and the technical information involved in environmental monitoring can be quite difficult to understand. In addition, community engagement in the CEMP involves more than just receiving information; community members are asked to submit their ideas about what should be monitored.

In addition to a press conference to publicly launch the CEMP, the Superior Watershed Superior Watershed Partnership held a set of community town halls—in four communities—to inform the community about the CEMP and to start to gather feedback. It distributed information about other ways people could engage with the CEMP, such a hot line phone number and the Web site URL. Some community members praised the CEMP, others criticized it, but overall the basic facts about the CEMP were broadly

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Do you need a CEMP?

PART 4: MANAGING INITIAL IMPLEMENTATION

communicated. (The Superior Watershed Partnership intends to hold additional town hall meetings quarterly in 2013 to report to the public and seek additional input.)

At the same time, the Superior Watershed Partnership, Community Foundation, and Rio Tinto were briefing the news media (reporters, editorial boards) about the CEMP, and distributing a Frequently Asked Questions sheet. They anticipated that a key question from the press would be about just how independent the Superior Watershed Partnership really was in determining what to monitor and what to tell the public. For the region's largest news source, the *Marquette Mining Journal*, the proof was in the doing. On April 15, 2013, the newspaper applauded the Superior Watershed Partnership's recent demonstration of independence:

> *"Two recent issues addressed by the Lake Superior Watershed Superior Watershed Partnership have demonstrated greatly desired independence in the group's Community Environmental Monitoring of Rio Tinto's mining activities in Marquette County.*
>
> *"Despite the program's indirect funding by the mining company—which many people have been critical of—recent Superior Watershed Partnership commentary on an amendment to Rio Tinto's air quality permit and the group's detection and reporting of concentrations of uranium found in water samples at the bottom of a rock storage area at the Eagle Mine show the Superior Watershed Partnership is taking its role as an environmental watchdog over Rio Tinto's mining activities seriously.*
>
> *"This is a positive step, which should help transform at least a few critics into supporters…*
>
> *"All of the results of the partnership's community environmental monitoring are available online to keep the public informed. The group's involvement in testing and reporting—with the independence now demonstrated—should go a long way toward proving the monitoring program is what it was intended to be—a valuable community asset gauging the success of the mining company's mining, milling and transportation operations."*

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PART V: RESOURCES... where to find them

CEMP Agreement and Attachments
http://www.cempmonitoring.com/documents/

"The Unity of Place: Giving Birth to Community Environmental Monitoring"
http://www.cempmonitoring.com/wp-content/themes/cemp/pdfs/RT_CEMP-The-Unity-of-Place.pdf

CEMP Monitoring Scorecard
http://www.cempmonitoring.com/

History of Superior Watershed Superior Watershed Partnership activities in Salmon Trout watershed
http://www.cempmonitoring.com/history/

Eagle Mine Web site
http://riotintoeagle.com/operations/eagle-mine/

Mine website page on CEMP
http://riotintoeagle.com/approach/community/community-environmental-monitoring-program/

Do you need a CEMP?

PART 5: RESOURCES... WHERE TO FIND THEM

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TRIPLE R ALLIANCE

Walking the Talk:
Community Rating of Eagle's Social Performance



Larry Dixon and Luc Zandvliet [1]

July 2013

[1] Larry Dixon is an independent consultant with Triple R Alliance (TRA) and Luc Zandvliet is Director of TRA. TRA (www.tripleralliance.ca) supports companies in their efforts to establish positive and constructive relations with local communities, NGOs, and authorities.

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I. INTRODUCTION AND CONTEXT

The idea that a community can judge a company's social performance, and is even encouraged to do so by that same company, is a world upside down to many mine managers. Sure, consulting with stakeholders, informing them about company plans, even involving communities in company operational decisions, such as closure plans, are increasingly a best practice in the industry. But to be held publicly accountable on an ongoing basis is unchartered territory. Certainly in situations where trust levels between the company and the community are poor, it would seem counterintuitive for a company to leave itself exposed to public opinion, and potentially to scrutiny and criticism. And yet Rio Tinto's Eagle Mine chooses to do just that.

Eagle Mine (Eagle) is located on Michigan's Upper Peninsula (U.P.) and is the first greenfields operation permitted by Rio Tinto in the US in decades. It is located in an area known for its outdoor lifestyle, with a population that includes many well-informed stakeholders who are cautious of outsiders, especially large mining companies. Many simply do not trust the global mining giant's environmental record and practices.

Against this background, Eagle developed the Community Scorecard, an interactive tool that enables the community to rate the company's performance and provides the company with a way to respond to the community's concerns around corporate impacts, especially as they relate to the environment, safety, transparency and the economy. The Community Scorecard tracks and measures company performance in areas of importance to both the company and the community. By being transparent and responsive to community concerns, the company aims to demonstrate it genuinely listens to the community, understands its concerns, and is willing to make changes, thereby building trust and improving business practice.

Moreover, although the Scorecard was designed for Eagle in particular, the circumstances surrounding that operation are not unique to Michigan's Upper Peninsula, or to the mining industry. There are lessons that can be drawn from Eagle's experiences that are relevant to other extractive and non-extractive companies alike.

The "Yoopers"

Michigan's Upper Peninsula (U.P.) makes up almost a third of the state's land area but is home to only 300,000 people, or 3% of the total population. Residents refer to themselves as "Yoopers". They have a strong sense of independence and pride in a unique culture that comes, at least in part, from both the early settlement of the area by mostly Nordic populations some 200 years ago, and from a thriving Native American population.

For most of the last two centuries the regional economy has been based on natural resources. This includes a long history of timber and mineral extraction, which laid the foundation for the

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turn-of-the-century facades that dot the region's communities. In recent years however, the region has experienced growth in tourism based on outdoor activities—most people in the U.P. have a passion for hiking, fishing, hunting, watersports, skiing, and snowmobiling. Wealthy urbanites own second homes there, while retirees and residents who appreciate the outdoors treasure the natural beauty and historic richness of the region. Like most rural regions in the US experiencing the cyclical nature of the natural resource sector, the area is transitioning into service and tourism for an increasingly aging population. However, with a continuously high global demand for mineral commodities, the region has seen an increase in exploration activities.

The Eagle Operations

Rio Tinto's Eagle Mine (Eagle) consists of an underground nickel and copper mine, and the refurbished offsite Humboldt Mill, both located in Marquette County. This area makes up the primary impact area of the overall operation. The company has mineral rights throughout the mid-continental rift in North America, including Michigan and Minnesota in the US, and Ontario in Canada. It has explored the area for over two decades. In 2002 these efforts led to the discovery of Eagle, which is estimated to produce 350 million pounds of nickel and 250 million pounds of copper over its eight-year expected life.

Halfway through the construction phase, the project has a staff of around 70. This is expected to grow to roughly 230 once it is fully operational.

II. LIFE PRIOR TO THE SCORECARD: EAGLE AND THE COMMUNITY

Not unlike other mining operations, Eagle initially faced communities reluctant to embrace the company, and in particular its potential environmental impacts. Making this more difficult was the fact Eagle was a new operation and that Rio Tinto had to develop new relationships with regional authorities, regulators, and the community, all of whom had no prior direct experience with the company.

Recognition that stakeholder engagement was weak

In 2011, a number of challenges became apparent to Eagle management. First, it noted that the company did not communicate well. The population that makes up the region surrounding Eagle is well-informed and aware of the environmental impacts of mining, not the least of which was the potential risks of sulfide mining on water resources. Reports found on the Internet about Rio Tinto's environmental and economic performance at some other sites instilled concern amongst some in the community. People wanted to be better informed and educated on known and unknown environmental risks associated with natural resource extraction. They needed Eagle to recognize, respect, and address those risks. The community also wanted to make sure that they were being listened to. Eagle had previously not found an effective way to do so, hurting its credibility in the community.

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Adam Burley, President and CEO of Eagle, noted he was surprised at the lack of company trust and credibility in the community, especially on environmental issues. *"It was a shock to me when I went to community meetings and could see the genuine emotion and concern the community had, when really we are committed to best practice and being a world class operation. If only they could see what we are really doing."*

"People here want to be guardians of the environment, and especially of water. Many of us are concerned about climate change and the demands it will put on our water resources. I think Rio Tinto thought they had a 'sleeper' community here and could build a mine unopposed."

- Resident from the Eagle impact area.

Secondly, Eagle is the first project to develop under Michigan's new non-ferrous mining law that was passed in 2004. It was clear that some in the community perceived that regulatory monitoring was inadequate. Throughout planning, design, and construction, Eagle assured the community that the company was committed to the toughest environmental safety standards and that it would follow government laws and regulations. However, many in the community were unclear about the details of these regulations and did not understand which regulatory bodies were responsible, and accountable, for monitoring Eagle's progress in managing environmental risks. With regulatory budget cuts over the past decade, others questioned the capacity of government agencies to monitor Eagle. This sentiment became even more intense after the 2010 BP Oil Spill of the Deepwater Horizon in the Gulf of Mexico.

Thirdly, Eagle management recognized that its business strategy was not fully articulated, affecting both the company and community. Unlike Eagle, Rio Tinto tends to operate mines that consist of very large deposits, are low cost to operate and have a long life of mine expectancy. Some staff perceived the Eagle project to be of less importance to the larger organization since it did not fit into the typical Rio Tinto profile. In addition, Eagle's business strategy was not well communicated internally. The project found it difficult to retain staff: from 2008 to 2011 Eagle experienced high staff turnover including three different CEOs, increasing the perception in the community and among some staff that the project was adrift.

Fourth, community feedback was not fully integrated into the business. The team dealing with local stakeholders was operating on its own little island, detached from the rest of the organization. The insights gained from engaging with the community were not being included in decision-making processes, which meant that social-risk identification, as well as the development of options to do better from a social performance perspective, were both missed.

Using an unlikely tool

By the summer of 2011, a new Eagle CEO was in place and the management team set out to review all aspects of the business. A business strategy for Eagle was clearly defined: "To build a world class, modern nickel-copper mine that we are all proud of". They considered the tools available to them and made a counterintuitive move. Few managers like to be assessed by their corporate office. However every three years Rio Tinto requires all business units to conduct a Communities Site Managed Assessment (SMA), a process akin to an internal audit. The

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objective of an SMA is to evaluate operational site compliance against its Communities Policy and Communities Standards and make recommendations for future directions. To capitalize on the expertise available within the larger Rio Tinto organization, the Eagle Team requested that the corporate office fast track the SMA for Eagle, which was conducted in the fall of 2011, a full year earlier than required. Instead of being a reluctant subject to the corporate assurance process, Eagle proactively used it as a tool to gather ideas on how to address its challenges.

The SMA identified areas where Eagle excelled, summarized challenges it faced, and provided a comprehensive and integrated set of recommendations outlining the need for Eagle to understand and better respond to the community's concerns around mining. It also recommended better integration of community feedback into business decisions, with the aim of becoming a world-class operation.

Turning a weakness into an opportunity

The Management Team realized that Eagle provided opportunities for Rio Tinto to "open doors" in North America as a new project. As a new operation in a new area, there were local laws to apply, different communities with their own values and perspectives, and regulators that had not worked with the company. Many new relationships needed to be built. Eagle's behavior would go a long way in whether it would be perceived as a good partner and neighbor…. or not. Also, Rio Tinto is in the process of exploring for minerals throughout Michigan, Minnesota, and Ontario. Eagle wanted to design leading practices that would set it apart, and that could be replicated at other Rio Tinto sites. Eagle recognized that if it is going to open the door for new mining in North America and be the developer of choice, it needed to be - and be seen as – listening, and responding, to local stakeholder perceptions. And because company-community relations were strained already, Eagle recognized it had to go the extra mile to demonstrate its intentions were genuine.

> *"If you want to be innovative and help Rio Tinto become the developer of choice, this is the place to be."*
>
> - Eagle Management Team Member

Eagle didn't set out to create a Community Scorecard. But as a new project in a new region, the management team knew it needed to establish its relations "the right way," so communities would accept mining activities in their area and, moreover, would choose Rio Tinto over other companies. The team knew the company needed to have a dialogue with these communities to first understand their concerns, and second, address them in a way that could be recorded and tracked objectively. In this manner, even if some in the community still did not agree with mining, they could at least see whether Eagle was doing what it said it would do on the issues they cared about.

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III. THE SCORECARD

By the end of 2011 Eagle took the bull by the horns. It began by making two changes that would pave the way for Scorecard development and improve social performance.

Gearing up for transparency and accountability

Internally, Eagle integrated Communities, Communications and External Relations activities into one functional department and created a new Director-level position as part of the Management Team. By doing so, it provided the department with equal standing in the organization relative to other functional departments. This created a much-needed gateway to address community concerns at a senior management level.

Externally, to respond to community concerns about environmental impacts and a lack of trust in existing regulatory monitoring, Eagle initiated the Community Environmental Monitoring Program (CEMP).[2] This program allows the community to independently monitor company environmental impacts. Two trusted community organizations—the Marquette County Community Foundation (MCCF) and the Superior Watershed Partnership (SWP)—oversee funding and monitor Eagle's environmental performance, reporting back to the community. Testing Eagle's seriousness, the community demanded that through the SWP, they determine what is being monitored and when. Eagle's Management Team agreed. This not only addressed a lack of trust in regulatory capacity and existing monitoring, but it also strengthened Eagle's reputation in the community as a company that aims to walk the talk.

Establishing the CEMP early on helped many in the community view the Scorecard as a credible and legitimate effort to respect the community and 'put Eagle's money where its mouth is.' One community member explained that the Scorecard and Forums are a good way to be informed and give feedback, and that "things changed with the announcement of independent monitoring and I felt hopeful."

There were other efforts that reinforced the level of transparency initiated by the establishment of the CEMP. For example, Eagle made mine tours more accessible to the general public, demonstrating that it had nothing to hide and that the public could go see Eagle activities for themselves. An information center was opened in downtown Marquette in 2010, providing a storefront presence for the business in the largest population center. The project was turning from a "what it might be" to a "this is actually what it is" approach.

By both reorganizing internally and allowing the community to familiarize itself with its activities, Eagle formalized the way it integrated community concerns and social data into its decision-making process. Addressing community concerns became the responsibility of the entire Eagle management team, rather than only the Communities function. This enabled Eagle

[2] For more on the CEMP, go to http://www.cempmonitoring.com , or see the case study, "The Unity of Place: Giving Birth to Community Environmental Monitoring" by Peter Plastrik.

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to think outside the box and to try new, innovative ways to address community concerns, such as through the CEMP.

Looking for Ways to stay Abreast of Perceptions and Expectations

But "seeing for itself" was just the beginning. Eagle needed active feedback. To be responsive and transparent, it needed a dialogue. And with the new integrated approach, it saw an opportunity to enable the community to measure, rate, and track how the company was doing in areas that both community and company alike identified as important.

The problem was … there were few examples of exactly how to do this. No other mining operation had ever been this willing to be publicly assessed on an ongoing basis. In its quest for benchmarks in other sectors, including government, Eagle did not find anything that was simple or that would fit the U.P. context.

A local design firm was contracted to work with the Eagle Team to develop a Scorecard. It was a lengthy and repetitious process with more than 20 different versions developed over five months. Although Eagle clearly knew what it wanted the Scorecard to achieve, there was no blueprint and only a strong sense of its aim drove the process through the many draft versions until it was finalized and introduced in September 2012.

How the Community Scorecard Works

The Community Scorecard is more than just a 'report card.' It is helpful to think of the Community Scorecard as a process made up of four components:

- Performance Areas consist of the topics that are assessed using metrics – analytical yardsticks, if you will – to measure trends
- Community Forums are the public meetings where the Performance Areas and Metrics are presented and where scoring takes place
- A Community Scoring procedure measures the degree to which Eagle is, or is not, meeting people's expectations
- Improvement Plans explain the way in which Eagle will change or adapt in response to Forum feedback

In use, the Scorecard creates an opportunity for discussion, clarification of expectations, and enables the community to hold the company accountable. A more detailed description of the key components that make up the Scorecard gives a better sense of how it actually works in practice.

"We won't change the minds of our opponents, but others in the community are open and want to have their concerns answered. The Community Scorecard is a tool for a conversation between the company and the community."

- Eagle Management Team Member

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1. The Areas that are Measured

The Scorecard is made up of five Performance Areas, or areas of greatest community concern, based on a series of community focus group discussions that took place in 2010 and 2012. It is written with straightforward language, using multiple colors and fonts for easy use, as well as several icons to represent the specific Performance Areas. The Scorecard uses data that is comparable to industry-wide reporting criteria, such as the Global Reporting Initiative (GRI). The five Performance Areas are:

- **Environmental Performance**. Originally there were two parts to measuring Environmental Performance. Eagle reported on its Mine and Mill permit violations while findings from the independent community-monitoring program were part of the Environmental Performance metrics. In response to community feedback during the first round of forums, Eagle now also reports on environmental "events" which are defined as any event that requires further investigation to determine if there is any risk to the community or the environment.
- **Local Hires**. Eagle's goal is to fill at least 75% of its operation with local hires (both direct and contractor). Although the target is for the Operations phase, Eagle is already tracking and reporting on this halfway through construction. The company defines "local" as being recruited from one of three tiers: tier 1) Baraga and Marquette Counties; tier 2) the rest of the U.P. and Northern Wisconsin counties, and tier 3) Lower Michigan. For each six-month period, the percentage of local hires is reported.
- **Safety**. The company has set a target of zero injuries for all employees and contractors at the mine and mill. Total Injuries are reported for the previous six months along with a description of the nature of the injury, if there are any, so that the community can assess their severity. Many families have relatives working in the construction or mining industry and are very safety aware. Figure 1 below shows how Safety Performance appears on the Scorecard.
- **Transparency and Communication**. Information-sharing metrics include reporting on the number of community events attended by Eagle, the number of Community Forum participants, mine tour attendance, and the number of Information Center visitors. Media-communication metrics consist of the number of radio spots, Eagle print ads, Eagle website hits, and email updates.
- **Leave More Wood in the Woodpile**. One of Eagle's objectives is to leave the region better off than when it arrived. This Performance Area includes three sets of metrics.
  - The growth of new and existing businesses, measured by the number of new jobs and businesses created outside of mining; increases in income for existing businesses, and the number of individual contacts seeking to utilize 'Accelerate UP' - an enterprise facilitation program initiated by Eagle.
  - Amount of land set aside, tracked by the number of acres reserved for biodiversity, recreation, and cultural use.
  - Infrastructure, measured by the mileage of new and improved roads and new power lines.

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Figure 1: Safety Performance Area and Improvement Plan from the Scorecard



2. Community Forums: More than Just a Meeting

Community Forums are where it all happens. The Forums are town-hall style meetings open to the public that serve as the platform for scoring Eagle's performance. They are held every six months in six different locations across Marquette and Baraga counties, and are advertised both in print media and on radio.

Forums are led by Eagle's Communities Department accompanied by managers and staff from other departments. This provides community stakeholders with direct access to decision makers, which is key for participants to feel their opinion is being taken seriously.

The Forums typically start off with an informal period prior to the meeting where participants can ask questions of Eagle staff to better understand the mining process and address concerns they may have with the appropriate company expert. The bulk of the meeting however, is spent

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informing the community of recent activities, reviewing Eagle's Performance Areas, scoring the company on those Areas, and giving the community an opportunity to ask questions and provide feedback to the company.

Forums may include participants who are not from the impacted area. To avoid the problem of "stacking a forum" with company proponents or opponents and skewing Community Scoring, a few rules exist. For example, only residents are invited to score. Eagle staff and contractors cannot participate in scoring. Also, people who have already scored the company in the current round of Community Forums are requested to not do so again.

Although some people choose to come to multiple forums and make comments at them, they can only score the company once per round of Community Forums. Scoring relies on the honor system—there is no residential verification, other than participants serving as a check on whether someone is a resident or not.

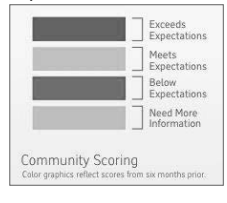
A Community Forum in 2013



3. How Communities Score Eagle's Performance

During the Community Forum, each Performance Area is presented with an explanation of the change in metrics compared to the previous scoring session. Then, residents of the impact area are invited to rate Eagle's performance through electronic Community Scoring. Using handheld remote

Figure 2: Community Scoring Graphic from the Scorecard



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units synched to a computer and projector, residents score the company with "exceeds expectations," "meets expectations," "below expectations," or "need more information." Scores are then projected on a screen for everyone to see. During the first Community Forum "need more information" was not included as a scoring option. However, participants felt unable to score some areas without more input, so it was added as an option as indicated in Figure 2.

Because it is done electronically, scoring is fast, confidential, appears live on screen, and can only be done once per metric. The Scoring mechanism ensures that each participant, no matter how loud or quiet, can score the company's performance, rendering all voices in the room equal.

4. Improvement Plans

After a Performance Area is reviewed and scored, comments are taken to determine where the community expects to see improvement, or to express where the company has excelled. As comments are made they are projected on a screen, which helps participants feel they are listened to. Eagle subsequently takes this information and develops improvement plans or adapts the way it operates in response to the feedback. These changes are fed back to the community via the Eagle website as well as during the next round of Community Forums. All scoring data and metrics are housed on its website for the public to view.[3] An example of the type of feedback that Eagle provides is in Figure 1 above under the heading "Our Response to Community Feedback." This level of transparency with impacted stakeholders is unique in the industry.

> *"Improvement Plans will be developed in the same way the whole Scorecard has, through the Management Team, with senior leaders having ownership on the different areas of the Improvement Plan to lead the process and make the needed changes."*
>
> - Eagle Management Team Member

IV. EARLY RESULTS: COMMUNITY AND COMPANY FEEDBACK

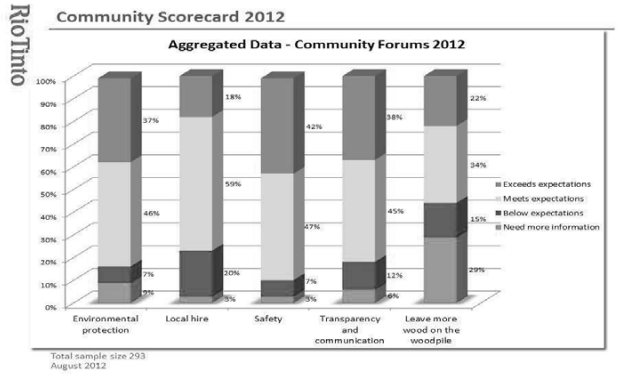
Scorecard Results

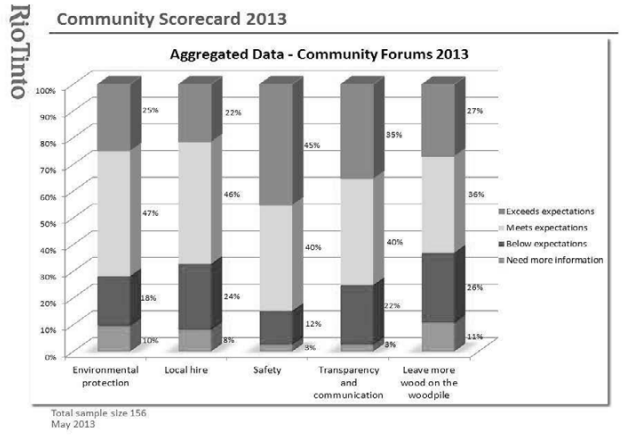
During the first round of Community Forums, a total of 293 community members scored Eagle's performance, whereas the second round saw 156 community members scoring. Although the small sample size makes it difficult to provide definitive results on how the community perceives the company, it does already provide valuable information as is displayed in Figure 3.

[3] See, http://riotintoeagle.com/approach/community/community-scorecard/

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Figure 3: Community Scoring Result





A comparison between data aggregated in the fall of 2012 and the spring of 2013 makes it possible to identify some early trends:

1. Of those who have participated in the Community Forums and scored Eagle, the vast majority feel the company meets or exceeds their expectations on the five Performance Areas.

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2. Compared to 2012, more people feel Eagle “exceeds expectations” for Local Hire, Safety, and Leave More Wood on the Woodpile.

3. At the same time, there is also an increase in “below expectations” scores for all Performance Areas.

4. There is a marked decline in the number of people attending the Forums.

5. There is a decrease in “need more information”, showing that even though around half the participants in each forum during the second round were new to the Community Forums, fewer people felt they needed more information to rate Eagle’s performance.

So what is behind these scores and how should they be interpreted? For example, should the drop in attendance rates be seen as a success factor, or a sign that people do not support the approach? Although Eagle will continue to explore the facts behind the figures, initial feedback from community members suggests that lower attendance rates can at least partly be attributed to an increased overall comfort level amongst communities with how Eagle is performing. Some community members who only attended the first round of Forums explain that the combination of the CEMP along with heightened media awareness for possible environmental incidents provides them with trust levels sufficient that “we no longer feel we have to watch over your shoulder.”

However, increased transparency comes with its own risks. Lower attendance rates of those that are satisfied with the company performance also mean that project opponents have a relatively larger impact on scoring patterns. Some NGOs opposing the project now use Facebook to urge their members to attend Forums. Another reason for the “below expectations” scores are due to legacy issues that have generated mistrust in the past and continue to influence Scorecard results.

Equally important, and not told by the figures, is the atmosphere during the Forums. For example, Eagle staff perceive that the tone of the discussion in the Forums has changed positively over the two rounds. People behave more respectfully and less confrontationally towards each other and are also starting to hold each other more accountable for their public behavior.

To increase the sample size and validity of the scoring, Eagle plans to run the Scorecard with an expected 350 people who join one of the public mines tours that the company will organize during the summer months.

Community Reaction

Many in the community recognize the Scorecard as an effort by the company to be more transparent and responsive, and it is fair to say that most participants see it as a good step by Eagle to listen, understand community concerns, and make changes. Even those who do not

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support mining activities still appreciate the company effort to provide a venue to keep people informed on what is happening at the mine and a place where interaction can take place.

> *"I don't support the mine, but I recognize that if we are going to be neighbors, I want to be informed."*
>
> - Community Forum Participant

> *"Just because you meet my expectations doesn't mean that I trust you!"*
>
> - Community Forum Participant

Some in the community explain that people don't want to "rub your neighbor the wrong way," so many welcome the act of confidentially scoring the company, as it allows them to register their opinion in a low-risk manner, especially with a vocal opposition present. Even those who oppose mining and say they don't trust the company say they take the anonymous scoring seriously. Many participants say they like seeing the scoring results immediately, compared to the company taking the data away to publish at some later point. This immediate feedback instills a heightened sense of trust in the system – it would be hard for the company to manipulate the figures, if it would ever contemplate doing so. Some also acknowledge that Eagle is going above and beyond what is required by state and federal regulators by enabling the community to score its performance.

However, even with this hopeful new start, mistrust still exists. Some groups in the community are skeptical the Community Scorecard process will lead to real improvements. They feel that the information presented is, as one Forum participant said, a "PR-blitz", and argue the exercise should be more substantive so participants can be more informed to score Eagle. Others question whether the Performance Areas and metrics fully reflect the community's concerns, and note they look more relevant to industry standards than to community interest. Also, several people have posed questions that do not fit the framework of the Forums, and some groups have not yet chosen to participate in the Scorecard exercise all together. This underscores the need for Eagle to maintain its other ongoing community engagement efforts and to highlight how the Scorecard fits in with that engagement.

But in general, people throughout the impact area are intrigued by Eagle's efforts to be more transparent, and although skepticism exists, many are encouraged and expect to see the company make changes identified at the Community Forums. Eagle realizes it needs to deliver and develop Improvement Plans that reflect these changes. The Scorecard must continue to evolve to fully reflect the community's concerns, whittle away skepticism, increase participation and fortify trust.

Company Reaction

From a company perspective, all Eagle staff are aware of the Scorecard and are proud of what it means to Eagle and the community. Internally there is little skepticism for how effective and useful the Scorecard will be, yet staff and management at Eagle note reluctance and apprehension from some colleagues at other mining sites who question why they would want

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to engage the community so intimately and intensively. Regardless, the management team sees the Scorecard both as a means to improve Eagle's business practices and community relationships and possibly serve as a precursor of how community-company relations throughout the mining sector and other industries will evolve in years to come.

One element the Eagle team appreciates in particular is how the Scorecard makes feedback from the community useful through track-able metrics. While some senior managers admit they initially were "a little scared" of allowing the community to score company performance, utilizing meaningful and accurate metrics made it easier to support Community Scorecard development. Also, since several aspects of the Scorecard are already tracked through Rio Tinto's Corporate Social Performance reporting to regulators and investors, putting this information into a format that the community understands is not a big leap. Rather, the big leap has been to ask the community to regularly rate the company's performance against those metrics. The team understands that to be effective, the Scorecard needs to evolve and be dynamic in order for it to truly be responsive to community concerns.

"We need to do some fine tuning to make the Scorecard more responsive to what the community wants, and we need to allow it to evolve."

- Eagle Management Team Member

V. ANALYSIS AND LESSONS: SCORECARD AS LEADING PRACTICE

Although still in the process of fine-tuning its design, the development and early stages of implementation provide a solid foundation and a good working model for integrating community concerns into project planning and development. Eagle's Scorecard provides an example of effective and meaningful community engagement and provides lessons learned from which other mining companies, and impacted communities, could benefit.

Lesson 1: Combine leadership commitment with technical expertise

The primary factor that enabled the Scorecard to develop was Eagle's management team. Elevating the importance of the Communities Department to the level where it had a seat at the table of the management team enabled it to influence planning and strategy development. But gaining a corporate commitment to take a more transparent and engaging approach was only half the work. Bringing in the right level of technical expertise and background to the Communities Department work was also essential to making the change in the stakeholder engagement approach. The confidence displayed by the Communities function to "make it work" made it easier for other functional departments to appropriately respond to community concerns. Without this team effort, it is difficult to see how Eagle could have created the Community Environmental Monitoring Program or the Community Scorecard.

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Lesson 2: The Forums serve as an early warning system accessible to Eagle's Management

The management team understood how community concerns lead to social risk and therefore developed the Scorecard as an early-warning tool. The Eagle team however, realized that it needed better access to the community to understand its concerns. By attending Community Forums and hearing those concerns first-hand, the management team could relate to these concerns as members living in the community themselves. Directly seeing and hearing people discuss their concerns and fears made it more personable to the team, and moved them to act.

Lesson 3: Internal assessments can serve as positive catalysts for change

At Eagle, social performance is not just the function of one department, but of the entire organization. The management team understood the power of moving beyond compliance with corporate social performance standards. Eagle used the Rio Tinto Communities Policy and Communities Standards as a framework for addressing the challenges they found at Eagle, and then contextualized those findings to create their Scorecard. Although the Communities SMA never specifically recommended creating a Scorecard, it did point out the more fundamental weaknesses of the project and outlined areas where Eagle needed to improve its Social Performance. The management team then brought in the guidance it needed to develop something new that would address social risk, conform to standards, and address their challenges. The Scorecard was the outcome of that process.

Lesson 4: The Scorecard creates a safe venue for community members to provide meaningful feedback to the company

People want to be aware of what companies are doing in their community, and how corporate activities impact their lives. But communities also want to be sure that companies are listening to them and understand what they are worried about. They want to communicate that "worry" is not always necessarily the same as "opposition."

The design of the Scorecard provides a safe place for people by:

- Enabling the "silent majority" at Community Forums to be heard, giving a sense of where everyone is on a particular issue, including those not comfortable speaking out publicly.
- Making it possible for opponents of mining to express that the company meets their expectations on certain objective areas and measures, without approving of mining.
- Allowing community members to express where they think Eagle does not meet their expectations in a way that won't damage their relationship with the company.

Discussions with participants why they scored the company the way they did creates meaningful feedback from the community on how Eagle can improve its performance. However, while scoring is done anonymously and puts participants at ease to rate the company's efforts as they see fit, comments have to be made openly in front of other participants. Some in the community feel this set-up may hinder participant feedback in a place

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where it is the norm to not offend your neighbor. Others explained that they are apprehensive about speaking up in front of other Forum participants who oppose the company. Eagle is considering alternative ways for participants to provide comments—such as through written note cards — to ensure a more robust, representative sample from the community beyond those who self-select by attending Community Forums.

Lesson 5: Design the tool in a way that leaves room for it to be adapted.

The Scorecard makes it possible to revise and change Performance Areas, as was done by adding the "event" category to Environmental Performance. Some in the community question whether the Performance Areas and metrics necessarily capture the intent of the Performance Area. For example, some participants at Community Forums question whether the metrics under Transparency and Communication are appropriate, noting that the use of media might indicate communication, but since Eagle pays for the spots they might not indicate transparency. Eagle has only had two series of Community Forums so far, and they realize that further changes will need to be made. The company notes that over time the areas and metrics will evolve based on community comments from the Forum.

Lesson 6: Company changes in response to community concerns improve relationships and business operations

The Scorecard aims to demonstrate that the company can be trusted. It also allows the community to verify if the company is able to keep its commitments. The Performance Areas and Metrics demonstrate good faith to provide information that the community desires, update them on the performance of the mine, and help to facilitate the type of performance the community expects from Eagle.

However, good intentions will not satisfy the community unless they lead to changes by Eagle. The Scorecard creates Improvement Plans that enable the company to respond to community feedback in a structured, formal way and make changes to improve company performance. These plans codify company changes and are at the core of how the community influences Eagle's performance.

As more Community Forums are held and Scoring conducted, Performance Areas and Metrics will change based on improvements the company makes. This dynamic, adaptability, makes the Scorecard responsive to community concerns. As improvements happen, they will foster greater transparency, accountability, and responsiveness to the community, as well as help to mitigate social risk.

Lesson 7: Credible community engagement does not develop in a vacuum — trust-building activities must reinforce each other

Often, communities do not trust environmental data gathered by companies themselves, and do not have the technical background to fully understand the scientific process and results.

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Many times they don't have access to the money or resources needed to hire an independent researcher to do this on their behalf.

Eagle provided resources to establish the CEMP, under which the community utilizes an independent, trusted organization, the Superior Watershed Partnership (SWP), to verify Eagle's monitoring and conduct additional monitoring of its own. Additionally, the SWP conducts its own meetings and forums to gather community input on monitoring and set priorities. These monitoring arrangements are invaluable to the community, providing an extra layer of accountability on environmental issues. The community appreciates the CEMP, and its establishment has helped the community overcome some of its mistrust of Eagle, while increasing the legitimacy of the Scorecard by involving two highly respected independent organizations. People now feel that the company allows them to hold it accountable.

VI. CONCLUSION

Only 18 months ago, internal assessments pointed out some serious weaknesses in Eagle's community-engagement approach. The response was to meet the problem head-on, by developing an innovative Scorecard approach which is the first of its kind in the mining industry and significantly raises the bar in terms of transparency and accountability in company-community relations. For this, both the company as well as local stakeholders deserve a great deal of credit.

And although this journey is relatively new and has yet to mature, it is an initiative that is already being watched closely by other companies and civil society groups. Regardless of the outcome of the Scorecard approach at Eagle, the genie is out of the bottle, in particular due to the public nature of the approach. The jury may still be out on how transparency, accountability, mine development and constructive engagement all come together at the Eagle project. However, in terms of company-community engagement, Eagle and the communities of Marquette and Baraga counties are actively developing a next-generation approach that will be replicable far beyond the Upper Peninsula of Michigan.

To view Eagle's Community Scorecard visit:
http://riotintoeagle.com/approach/community/community-scorecard/

Postscript: Rio Tinto announced a binding agreement with Canadian based Lundin Mining Corporation to purchase 100 percent interest in the Eagle Mine. Lundin Mining has stated that it supports the Eagle Mine Community Scorecard and will continue it.

This case was written to profile Eagle's Community Scorecard and document lessons learned as a contribution to the broader field of corporate-community engagement. TRA did receive financial compensation for its development but had final authority over the writing, contents and editing process of this document.

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CHAPTER 7

Evaluating the Science of Environmental Assessments with Aboriginal Groups

Bruce R. Muir

INTRODUCTION

Northern environments in Canada are home to numerous Aboriginal groups who face substantial challenges due to the potential broadening of renewable and non-renewable economic development activities. Whether industrial proliferation will adversely impact the ecological integrity of territories that sustain cultural traditions, customs, and practices is of serious concern. There has been, perhaps not surprisingly, mounting pressure to ensure that environmental impact assessments (EIAs) adequately integrate Aboriginal cultural values with the goal of protecting them for future generations. EIAs must properly consider the procedural rights of Aboriginal groups to participate in decision-making processes and their substantive rights to the land and natural resources that could be adversely impacted by a project proposal. Such cultural rights are recognized in section 35(1) of Canada's *Constitution Act*, 1982 and therefore cannot be unreasonably infringed or extinguished at the pleasure of federal and/or provincial governments (collectively, the "colonial governments").

This chapter explores the experiences of Aboriginal groups in their pursuit of sustainable development, specifically how several groups in northeast British Columbia (BC), Canada, are overcoming barriers of evaluating the scientific technocracy of EIAs. Through a case study of the experiences of West Moberly First Nations, the chapter examines the development and implementation of the First Nations Independent Technical Review (FNITR) process and its application to the EIA for the Quintette coal mine project (the "Quintette mine"). The corollary

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of the Aboriginal-generated framework and its successes, challenges, and opportunities are discussed, in addition to possible future application of the process.

THE FIRST NATIONS INDEPENDENT TECHNICAL REVIEW PROCESS

Origins and Initiation

Like many community initiatives dealing with potential threats to the sustainability of local environments, the FNITR process was born out of necessity. In this case, the impetus was the scale and diversity of industrial activities within the territories of several Aboriginal groups in northeast British Columbia. Much of the economic development was occurring without the proper environmental planning and management systems in place to balance industrial projects with cultural uses of land and natural resources. As a response, leaders from two Aboriginal groups, specifically Saulteau First Nations and West Moberly First Nations, collaborated in 2003–2004 to identify issues that threatened their traditional modes of life and began developing the approach for the FNITR. McLeod Lake Indian Band, another Aboriginal group that began to participate in the FNITR process, played an important role a few years later by ensuring that the Aboriginal perspective was a more pronounced consideration during the scoping and evaluation process, which has since become a core principle of the FNITR process.

Aboriginal groups observed that their traditional knowledge was inadequately represented in the studies that made up impact assessments, and in many cases, the cultural means of decision making were marginalized because EIA processes did not accommodate the approaches used by the groups. Technical documents were thus viewed as a considerable impediment to effective participation in EIAs and, even more so, when attempting to determine which projects were likely to be sustainable. Working as a collective, the groups requested funds from proponents to evaluate the scientific efficacy of proposals from a cultural perspective.

Application and Scope

Designed as an instrument to engage with proponents, the FNITR process has been considered appropriate when participating Aboriginal groups are asked to review technical information as part of a consultation process. However, when Aboriginal groups receive thousands of proposals containing technical information on an annual basis, few proposals are selected to undergo an FNITR. Each group is limited in time and resources irrespective of the provision of sufficient capacity, a deficiency largely attributable to timelines found within colonial laws and interpretive policies that do not necessarily align with the traditional decision-making protocols of each group or with their workloads from the plethora of consultation requests. Project proposals are thus appraised on a case-by-case basis. Scientific investigations (e.g., population surveys of ungulates, socioeconomic assessments),

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submissions from proponents for various land tenures (e.g., bulk sampling of coal), plans for land use and natural resource management (e.g., water use management plans, licenses to cut forests), and the EIAs for a full mine operation are examples of activities that could be subject to an FNITR. Large-scale industrial proposals, however, are often given priority due to the propensity of such developments to cause project-specific impacts and cumulative effects. Importantly, an EIA process pursuant to BC's Environmental Assessment Act (EAA) and/or Canada's Canadian Environmental Assessment Act (CEAA) is not, however, a prerequisite for an FNITR. Impact assessments, and therefore the application and scope of the FNITR, may take many forms to ensure adequate inclusion and consideration of traditional knowledge when determining what is environmentally and culturally sustainable for future generations.

Guiding Principles

Aboriginal architects of the FNITR believed that the evaluation of technical documents ought to be based on Indigenous *and* Eurocentric worldviews. They determined that the approach should be guided by the following fundamental principles: representatives from the proponent of the project proposal and the groups should be responsive to Aboriginal values; scientific rigor should be applied to evaluations (Glynn 2004; Lawrence 2003); and the process should embrace collaborative problem solving. Interactions within the FNITR setting, similar to the observations of Waiten (1981), are perhaps best "characterized by the consensus nature of native society in which the exchange of ideas and information occurs in an unstructured manner and by the opportunities for mutual education and the sharing of knowledge." These fundamental principles have come to form the philosophical character of the engagement process for the FNITR.

Participants and Their Roles

Membership of the FNITR consists of representatives from a proponent and the Aboriginal groups that could potentially be adversely impacted by a project proposal. Each party also has its own team of external specialists from various scientific disciplines (the "technical team"), which functions in the manner of "a resource person and facilitator" (Waiten 1981) providing technical advice and completing tasks as necessary for the review. Representatives of both the proponent and the affected groups, which oversee the engagement activities and ensure their progress, make decisions jointly whenever possible. In situations where consensus cannot be reached, the responsibility to resolve the conflict is elevated to the leadership level of each party. Neither the British Columbia Environmental Assessment Office (BCEAO) (provincial level) nor the Canadian Environmental Assessment Agency (federal level), which are responsible for legislated EIAs on large-scale project proposals, are invited to participate in the process at this time.

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Interactions and Communications

Meetings (gatherings) play an important role in the FNITR process with respect to the exchange of information. Not only do these gatherings serve as the primary means by which an Aboriginal group gains a more comprehensive understanding of the potential consequences of a project proposal, but they also provide an opportunity for the proponent and scientists to better understand the substance behind the concerns reflected in the scope of an evaluation and the issues that are identified. Seemingly an innocuous consideration, but indeed essential, is the location and setting of certain meetings as part of the FNITR. Initially, gatherings took place in the communities of the participating groups. These locations at first seemed more fitting from a traditional perspective, as the evaluation process was made more accessible to community members and respected that discussions about the land ought to take place on such land. This approach, however, became less effective in some ways. When meetings are held in a community, for example, representatives from the Aboriginal groups are regularly pulled away from FNITR meetings to attend to other matters, which is reflective of their considerable workloads.

In addition, and perhaps most important from a technical and learning perspective, the extent to which Aboriginal representatives interacted with specialists was greatly diminished when the majority of meetings occurred in the Aboriginal communities. The cost of travel for 10–40 specialists by commercial air from southern British Columbia to northern, remote Aboriginal communities was prohibitive. Interactions were therefore limited to less meaningful formats, such as teleconferences, instead of the face-to-face meetings that are culturally preferred and generally more effective. While Aboriginal representatives' attendance at meetings in southern British Columbia addressed both issues of cost and effectiveness, balancing these issues with cultural protocols was often a consideration when evaluating the underlying purpose of a particular meeting and its location.

Various procedures have been used as "checks and balances" to ensure that the interactions between the technical teams and others remain focused, reasonable, and ethically responsive to the values of the Aboriginal groups. Communications among parties are expected to remain open and transparent when technicians are working together. E-mails, memoranda, and letters that are sent from one technician to another are copied to representatives of the proponent and the groups. Meetings, whether face-to-face or via teleconference/videoconference, always include an open invitation for representatives of the parties to participate in or monitor the discussions that take place. Also, in recognition that the outcome of the FNITR will likely be used by a proponent to reflect an important element of its procedural obligations to the groups with respect to the legal requirements pertaining to consultation, the manner by which the proponent and the groups communicate with colonial governments is done collaboratively. This is not to say, however, that the proponent and/or one or more of the groups cannot communicate

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with a colonial government during an FNITR process. All parties will likely be required to meet individually or collectively with regulators to some degree on other matters as well.

Capacity

Determining the level of capacity that would sufficiently fund an FNITR is based on the circumstances of a project proposal and is established by the Aboriginal groups (e.g., through a needs assessment). Several factors are considered, including the type of project, ecological and cultural settings, the needs of each group in order to participate effectively in a collaborative environment, cultural traditions and customs, and the statutory processes that are likely to occur concurrently and/or subsequently. In broad terms, the amount of funding required from a proponent to properly conduct the FNITR for an EIA of a mining development has traditionally been between $200,000 and $500,000 in Canadian currency. These funds cover various items such as the hiring of a qualified consulting firm (i.e., the technical team) to evaluate scientific information, which can take approximately 700 to 1,500 hours depending on the quality of the EIA and the willingness of the proponent to work collaboratively. Expenses incurred by the technical team include professional time, meetings, travel and accommodations, and the production and printing of reports and materials. Funding from mining proponents also covers the costs of Aboriginal groups to participate in the review process, which may include items such as travel and accommodation, meetings, the professional fees of a representative when lack of internal resources deems one necessary, and the application of various cultural protocols. FNITR funding does not, however, include the costs that a proponent would likely incur while participating in the process. Expenditures may fluctuate depending on the project, and such fluctuations are often based on the willingness of a proponent to meaningfully embrace working within an Aboriginal context.

The FNITR Process

The evaluation of an EIA centers on its technical adequacy. Reviews focus on whether the potential impacts on valued components for the participating Aboriginal groups were properly determined and (if appropriate in the sense that the project is legally justifiable) addressed in the follow-up plan. Within the context of an EIA regarding a mining project, the FNITR will generally respect the five stages delineated in the following sections.

Stage 1: Process Initiation

Aboriginal groups begin by screening project proposals that are received from proponents through various consultation processes. Selection criteria are used to guide the process of identifying which proposal should be subject to a technical evaluation.

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These may vary to some extent, but they typically include the geographic location and characteristics of a proposal, existing or potential environmental cumulative effects, and whether the physical and/or meaningful exercising of traditions, customs, and practices of the Aboriginal cultures would be negatively influenced. Secondary selection criteria have included the performance history of a proponent and its respect for traditional governance, self-determination, and treaty rights, including the quality of its relations with Aboriginal groups from other regions.

In most cases, the technocratic nature of an EIA for a coal mine is such that Aboriginal groups require external sources to conduct and manage the reviews. This creates a dependence on consulting firms to form the technical team. Procuring a qualified, proficient consulting firm is critical to the success of the review. Because impact assessment is a discipline of disciplines, focus should be placed on whether a firm, including its network if applicable, consists of the necessary multi-disciplinary experts to evaluate a particular EIA. Noble (2009) suggests a number of criteria to appraise the expertise of an individual or members of a technical team, particularly the following: experience managing or leading scientific assessments, a minimum of 10 years of experience/education in the related discipline, and academic/professional achievements (e.g., research published in peer-reviewed journals). Also relevant is an individual's level of experience in conducting cultural and/or scientific studies for Aboriginal groups, as opposed to doing studies on such groups. The overall ability of a consulting firm to conduct a scientifically rigorous review is equally as important as its ability to build a relationship with the groups and to appreciate/integrate the cultural substance and sensitivity of the issues and concerns that each group may have in relation to a proposal.

The scope of the evaluation is also important for the efficacy of the review with regard to identifying issues. With the understanding that an objective of the review is to evaluate the aspects of an EIA that could impact the cultural values of Aboriginal groups, establishing the scope from the outset and reviewing it periodically during the process are purposeful though difficult tasks. Groups must contemplate their cultures in space and time while considering the pathways in which project components may possibly intersect, directly or indirectly, with their values, including the likelihood of cumulative effects to such values.

Determining the scope of the evaluation has been accomplished in two ways. First, a community-based approach (as opposed to an external expert-drive approach) has been the most common. With this approach, each representative of the FNITR meets individually with the members of his or her group. In some cases, a collective workshop is held as well. In rare cases, such as when the members of a group are unable to meet either individually or collectively (e.g., when they are inundated with consultation requests, the timing of cultural activities overlaps with the process, or an unforeseen event occurs), representatives on the FNITR will set an interim scope that is subsequently revisited during the process with members

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of each Aboriginal community. Second, expert advice is sought during the scoping exercise in relation to highly specialized disciplines, such as geochemistry. Most scopes consist of the biophysical components of the EIA.

Like the interdisciplinary approach that should be used to conduct an EIA (Canter 1996), the review process should also include technicians who mirror the select disciplines of an EIA. Assistance from roughly 10 to 15 scientific disciplines—including air quality, aquatic resources, fish and fish habitat, geochemistry, groundwater, hydrology, reclamation, selenium, soils and terrain, vegetation, wetlands, and wildlife—is often needed to review an EIA for a mine. Aside from health risks (e.g., wildlife becoming contaminated via industrial applications and the possibility of impacts to humans from use), human components of the EIA that relate to social and cultural impacts, including archaeology and traditional/cultural land uses, are typically excluded from the scope. The reason for doing so is based on the expectation that the Aboriginal groups, not the proponent, conduct the impact assessment relating to these components. In the event that a proponent does not work collaboratively with individual Aboriginal groups or provide adequate capacity for such studies, the human components of an EIA would likely be included in the scope. Explicitly excluded from the FNITR is an assessment of impacts to the rights and interests of the participating Aboriginal groups, which is a matter that has remained entirely within the purview of each group.

Stage 2: Evaluation of Technical Documents

A conceptual diagram of Stage 1 and Stage 2 of the FNITR process is provided in Figure 7.1. In Stage 2, reviewers from each discipline are provided with relevant technical documents based on the scope. Because the evaluation is designed to be independent of direct input from Aboriginal groups, reviewers are expected to take an approach that is grounded in impact assessment science (Glynn 2004). Reviewers are also expected to use, for example, the most up-to-date scientific approaches and best practices within the respective industries, in addition to the precautionary and uncertainty principles (IAIA 2003). Issues identified by each reviewer are categorized based on the scientific discipline. When a commonality and/or duplication occurs in the list of issues (a frequent occurrence given the integrative nature of many EIAs), the issue is categorized according to the discipline that is most germane to the underlining values outlined in the scope. Once separated by discipline, the issues are then organized into various groupings, a process that generates a road map to address the shortcomings and limitations of a project proposal. Reviews involving mines have typically included the following groupings of issues (Rescan Environmental Services 2012b):

- Administrative and organizational
- Scope of valued components
- Spatial and temporal scopes

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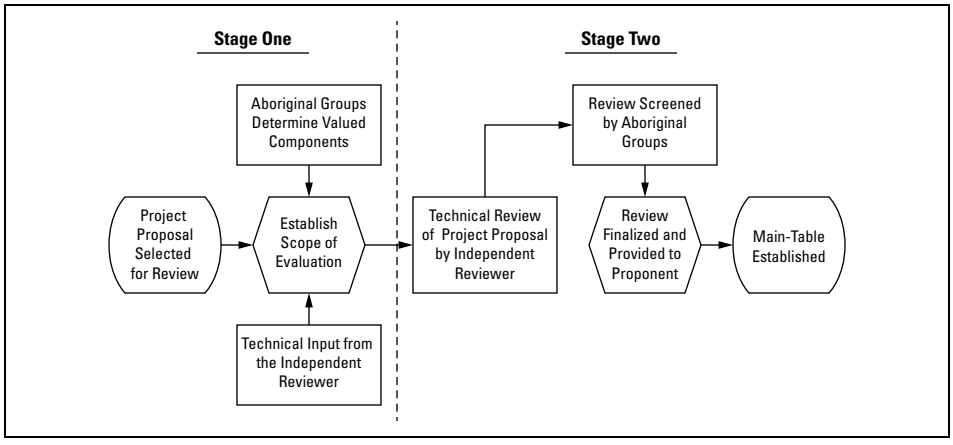


Figure 7.1 Conceptual diagram of Stage 1 and Stage 2 of the FNITR process

- Baseline (historical reference point)
- Methodologies
- Effects characterization
- Cumulative effects assessment
- Significance
- Follow-up (mitigation, monitoring, and management)

Each grouping encompasses the issues from the various disciplines. Additional groupings have been used in the FNITR process as a means to reflect instances where multiple issues emerge during evaluations with similar characteristics. These have included, for example, data sufficiency, language, and explanation. Less frequently used, but important for Aboriginal groups to consider in detail, is the consultation record that proponents and/or colonial governments generate to sequentially track the qualitative information derived from the procedures used to engage with the groups. Because of the litigious nature of procedural components of EIAs, however, the adequacies of nontechnical components (e.g., whether a consultation record is accurate) are often excluded from the scope of the FNITR, and instead such matters are left in the hands of each group.

As the quantity of issues identified during FNITRs have varied considerably, ranging anywhere from approximately 50 to more than 1,000, each issue is delineated as "key" or "general" after being placed into a grouping. Key issues, which represent a "significant gap" that needs to be sufficiently addressed for an EIA to be regarded as scientifically sound, are set apart from general issues (Rescan 2012b). This distinction is important from an efficiency perspective. Reviews that have generated more than 80 issues have caused proponents to focus on the quantity of issues rather than on the substance found within each technical comment. This

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is not to say, however, that general issues are less important. With the identification of a key issue relating to the scope of a valued component, additional general (and possibly key) issues would likely emerge in the areas of spatial and temporal boundaries, collection of baseline data, effects assessment, determination of significance, and in the follow-up plan (e.g., the mitigation and management plans). The interconnectedness of an EIA does not preclude the possibility that a particular issue could be unique in the sense that it stands alone from other issues; however, a key or general issue that has been identified at one point suggests the likelihood of one or more additional issues elsewhere in the EIA.

The first substantive output of the FNITR is a report that articulates the findings of the evaluation. It is drafted by the technical team and provided to representatives of the Aboriginal groups for review and comment. Specialists from the technical team are expected to present the issues to the groups and explain why each issue was identified, its importance to the discipline and the EIA overall, and most importantly, preliminary potential solution(s) or starting points from which remedies could be developed. Following this, the technical team and the groups finalize the report and provide it to the proponent. It is important for the proponent to have sufficient time to review the FNITR report, likely with the assistance of its technical team. When all parties are available, the Main-Table, which includes representatives from the proponent and the Aboriginal groups, is called together so that parties may begin to discuss the evaluation in depth, along with expectations of each other and their technical teams, including timelines, and next steps.

Stage 3: Technician-to-Technician Discussions

Not all technical issues identified by reviewers are substantive in nature. Many are likely straightforward, such as clarifying assumptions, terminology, background data, and references. Issues such as these are more efficiently dealt with on a technician-to-technician level rather than during the Main-Table workshops. Discussions among the technical teams focus largely on general issues, but they may also include key items. Technicians work collaboratively on discussing the particulars of the issues via conference calls and videoconferencing. When possible, face-to-face meetings are encouraged in situations where the technicians are in close geographic proximity to one another. Other parties are invited to partake in the technical discussions as well. In many cases, however, representatives of the parties choose to participate only intermittently or abstain completely, in part due to workloads from myriad consultative processes. Results from the discussions (in the form of recommendations) among the technical teams are tracked and presented to the Main-Table for review and comment. A conceptual diagram of Stage 3 of the FNITR process is shown in Figure 7.2.

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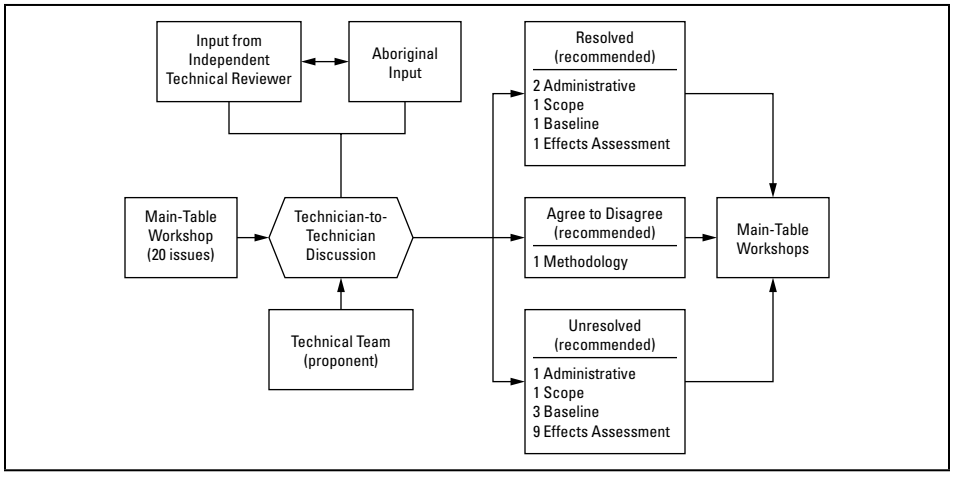


Figure 7.2 Conceptual diagram of Stage 3 of the FNITR process

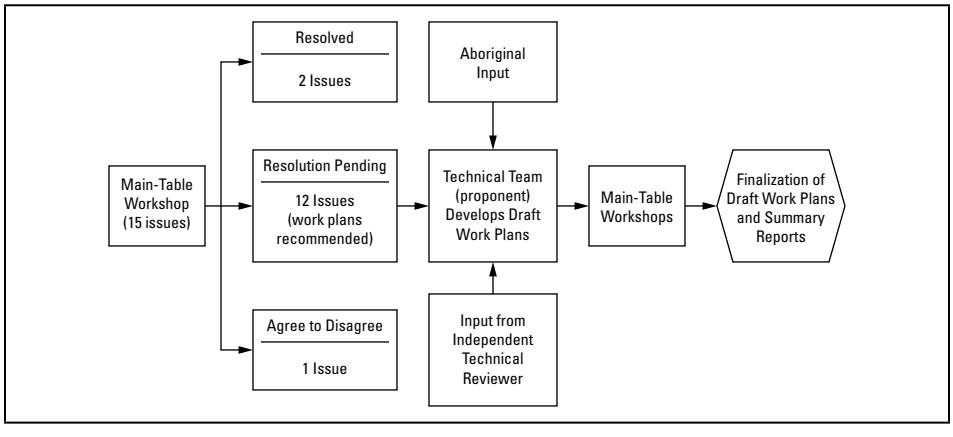


Figure 7.3 Conceptual diagram of Stage 4 of the FNITR process

Stage 4: Main-Table Workshops

A conceptual diagram of Stage 4 of the FNITR process is shown in Figure 7.3. Building on the work that has already been completed by the technical teams, the parties begin the Main-Table workshops to thoroughly discuss outstanding issues. Face-to-face meetings are preferred for these discussions. The discussions are focused on finding solutions that are collaborative and inclusive of an Aboriginal perspective of sustainability. Listening and learning from one another is thus an essential aspect of the workshops. Although proponents are not asked to atone for the missteps of others per se, lessons from previous EIAs and FNITR processes provide an important backdrop for ways to move forward and are necessary for knowing which areas of the evaluation have the potential to be contentious for

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the mining industry. Proponents should also be familiar with the region where the project proposal is situated. Even when operating within the same political jurisdiction, the manner in which regulators apply discretionary power may vary considerably, particularly in the case of the constitutional rights of each group. An understanding of the relationship between the mining industry and Aboriginal groups (in terms of expectations and disappointments, as well as the relationships between the groups and colonial governments) provides a basis from which a proponent may work. In other words, a best practice for a mining proponent is to first focus on the relationship it is building with an Aboriginal group and, second, to identify on the efficiencies that could be available. Such an approach is likely to generate an increase in transactive effectiveness for the proponent during all stages of development.

Most mining proponents in northeast British Columbia, in the absence of receiving direction via the FNITR, have applied various standard mitigation measures, which, on the surface at least, seems appropriate. Regarding legal expectations, however, the substantive rights of Aboriginal groups to environmental components call for more than what is owed to mainstream society. The general public, for the most part, does not have substantive rights to environmental components (e.g., a harvestable surplus of a species), whereas an Aboriginal group likely does. This includes the proper characterization of cultural valued components and the assertive tackling of adverse impacts on those values, including the proper consideration of historic (i.e., cumulative) effects (*West Moberly First Nations v. British Columbia [Chief Inspector of Mines]* 2011). Cultural values (Aboriginal and treaty rights) should not be construed so broadly that the important particulars of traditions, customs, and practices are rendered perfunctory. Hunting values (e.g., preferred locations, settings, and species), for example, are dependent on the mode of life of each Aboriginal culture, including the traditional seasonal round (*West Moberly First Nations v. British Columbia [Chief Inspector of Mines]* 2010). Moreover, the process of assessing the impacts on such values and then surveying potential remedies "is not to be narrowly interpreted as the mitigation of adverse effects on Aboriginal rights and/or title"; rather, the goal is reconciliation between the colonial and Aboriginal governments (*Dene Tha' First Nation v. Canada [Minister of Environment]* 2006).

Without prearranged limits, the parties must ultimately decide at which point this stage has reached its analytical conclusion. Based on previous FNITR processes, the surveying of potential solutions for each issue typically takes anywhere from 2 months to 1 year. The duration of this stage is mostly contingent on the substance, rather than the quantity, of the issues that have been identified. Another factor relating to the timelines has been the proficiency of the proponent and its technical team. There has been significant resistance to using subjective criteria (e.g., counting the number of meetings that have occurred on a particular issue

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and the establishment of arbitrary timelines for commenting and responding) as determining factors—an approach that is characteristic of processes managed by colonial governments. The groups, along with the proponents, have been successful in appraising each circumstance individually and determining if the substantive qualities of a specific issue and the investigation into the possible remedies have been exhausted reasonably and collaboratively. Whether or not the workshops are able to produce a consensus, representatives from the parties at the end of this stage must nevertheless consign each issue to one of the following classes:

- *Resolved:* The parties agree on a provisional remedy to the issue.
- *Agree-to-disagree:* The parties agree that a technical remedy cannot be reached and that neither considers the issue to be serious in the context of potential adverse effects to valued components.
- *Referred:* The parties agree that a provisional remedy cannot be developed due to an external entity and/or process.
- *Unresolved:* The parties do not agree on a provisional remedy.

Before the Main-Table is dissolved, a summary report is prepared that includes the primary elements of the FNITR, procedures that were used, state of relations among parties, and the assigned class for each issue. The summary report should clearly show how the concerns of the Aboriginal groups noted in the scope (and possibly articulated in the evaluation report as issues) were "seriously considered" and "demonstrably integrated" into the project proposal (*Halfway River First Nation v. British Columbia* 1999) through remedies and/or other commitments made by the proponent.

Stage 5: Community Verification

With the Aboriginal groups' values serving as the lens through which the sustainability of a project proposal is ascertained, the final stage of the process includes an engagement process with members and decision makers from each community. The summary report functions as a launching point for internal engagement, but there is not a prescribed approach for collecting feedback. The protocols of each community guide each subsequent step(s). There are, however, some generalities that exist due to the extensive amount of information in the summary report. These need to be communicated in ways that members may understand and critically evaluate in order to articulate their views on provisional remedies. Meetings with decision makers, specifically the Chief and Councils and, if applicable, traditional authorities (e.g., trapline holders or a headman), would typically include a brief review of the project proposal and a step-by-step overview of the FNITR process, with particular attention to the provisional remedies. In many cases, the information from the FNITR process is directly communicated to the membership of the groups through various social gatherings. Techniques akin to an "open house" style of disseminating and collecting information are avoided whenever possible due to

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Figure 7.4 Quintette coal mine and open pits in the foothills of the Rocky Mountains

their propensity to discourage interactions and the exchange of information among representatives and traditional knowledge holders within Aboriginal communities. Productive approaches include working one-on-one or in small groups with community Elders as well as hosting dinners with traditional units (e.g., houses, clans, families) and feasts at the community level.

Although the process carried out by the proponent to confirm the provisional remedies is not formally part of the FNITR process, the results are presumably presented and explained to the appropriate internal decision makers. Such communication is important because if the project proposal were to be approved, there is an expectation that resolutions become terms and conditions within authorizations from regulators and/or contractual commitments on the part of the proponent. Most often, these understandings form the building blocks for a relationship among the parties moving forward, which may then be structured in the form of an Impact Benefit Agreement or other instrument.

CASE STUDY: THE QUINTETTE COAL MINE PROJECT

Project Proposal

The tenure area of the Quintette mine is located southeast of the municipality of Tumbler Ridge, British Columbia, in the foothills of the Rocky Mountains. Figure 7.4 shows the site of the Quintette coal mine and open pits. While an approval from the BC government in 1982 allowed the proponent to construct and begin extracting coal, the mine was closed prematurely around the year 2000 because of low global coal prices. As a result, activities at the mine site were more or less quiescent for more than a decade.

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In 2012, a project proposal was submitted to once again extract coal from the tenure area of the Quintette mine site. Production was proposed to include the extraction of up to 3 million tons of "steelmaking coal" on an annual basis (Teck Coal Limited 2011). In this case, an added economic benefit of the proposal for the proponent was that much of the infrastructure and physical disturbances of the original mine were not decommissioned, reclaimed, or otherwise ecologically restored. This included, for example, access roads, load-out facilities, administration buildings, and the processing plant. The project proposal submitted to BC regulators included the additional construction and maintenance of a number of components, including the following:

- General access and haul roads
- Additional pits and spoil areas
- Expansion of spoils and coarse core reject areas
- Conveyor to transport coal from pits to processing plant
- Sediment ponds and drainage ditches
- Transmission lines to new facilities
- Maintenance and explosive facilities
- Wells, reservoirs, and seepage collection (Teck Coal Limited 2012)

These components were predicted to account for approximately 3,300 acres of new physical disturbance, which was in addition to the 9,100 acres disturbed previously (Rescan 2012a). Development activities were not characterized as being part of a new project per se. Instead, the proposal was described as a "restart" of an existing project (Teck Coal Limited 2012), and the existing infrastructure would be "reused whenever possible" (Teck Coal Limited 2011). The description of the proposal was an important consideration in the determination of the regulatory path.

Regulatory Process

Mining activities are generally considered socially acceptable in the region of Tumbler Ridge, British Columbia, provided that such proposals and developments do not unreasonably infringe upon the cultural rights of one or more of the Aboriginal groups. Project proposals for a full mine operation, which are adjudicated differently than the majority of authorizations equated with exploration (e.g., license to clear land of timber), are considered in one of two ways. The first is through the Regional Mine Development Review Committee (RMDRC), which, in addition to reviewing general proposals for exploration (Ministry of Energy, Mines and Petroleum Resources 2010b), is responsible for examining applications from proponents for small mines (i.e., less than 250,000 tons of coal mined annually) or expansions/amendments to existing mines. The second way to extract coal resources in the region is by proposing a large-scale mine, which triggers BC's EAA if the proposal plans for more than 250,000 tons of coal to be mined annually, and possibly Canada's CEAA when, for example, federal permits are required. Section 6(1)

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of the EAA provides decision makers with the discretionary power to more or less define any development activity as reviewable, and it is therefore possible that exploration activities requiring regulator authorizations, small mine projects, or amendments might each have to undergo a formal EIA. This is, however, unlikely because it diverges from policy direction.

Whether this particular adaptation of the Quintette mine was to undergo an EIA pursuant to the EAA or the RMDRC process was a point of contention. Some believe it was reasonable and in the public interest to subject the mine proposal to all the requirements of EIA laws. In part, this is because regulatory approvals in the 1980s were not informed by a formal EIA, because laws governing the assessment of impacts of large-scale projects (along with an agency to oversee such processes) were not established in British Columbia until 1994 with the enactment of the EAA and the subsequent establishment of the BCEAO (Haddock 2010). Moreover, a great deal has changed since the Quintette mine was first authorized. In the past 30 years, for example, scientific methods for impact assessment and knowledge of the environment have improved immensely, in addition to the escalation of cumulative effects in the region (see, for example, Lee and Hanneman 2012; Nitschke 2008). Also, caribou (*Rangifer tarandus*) that reside on the mine site are now considered a threatened species in Canada (Government of Canada 2002).

Despite the history of the Quintette mine, the BCEAO determined that the project proposal should be exempted from the requirements of EIA laws, a decision that was made without adequately consulting with potentially affected Aboriginal groups (as required by law). The groups attempted to trigger a meaningful consultation process with the BCEAO on numerous occasions, specifically to determine which regulatory process would be most appropriate for the mine and with respect to their cultural rights. They were unsuccessful. Although the EIA for the Quintette mine was subject to the RMDRC process, the project proposal was nevertheless considered by the proponent to be "a comprehensive effects assessment" that purportedly addressed the shortcomings of the original Quintette mine plan (Teck Coal Limited 2012).

British Columbia's decision to use the RMDRC process as a substitute for a formal EIA appeared to correspond with its plan "to develop and implement a faster and simplified approach" for approving project proposals for mines (Ministry of Energy and Mines 2005). Normally this process coordinates reviews of those regulatory decision makers who are responsible for "any authorizations required for mining proposals." These reviews purport to include construction, operation, and closure and reclamation plans, as well as "follow-up and monitoring plans," with a focus on "statutory permitting requirements" (Ministry of Energy, Mines and Petroleum Resources 2010b). Implicit within the direction provided to the RMDRC is the fundamental purpose of developing recommendations for the "terms and conditions of mine approval" (Ministry of Energy, Mines and Petroleum Resources 2010b), all but explicitly closing the door on rejecting a project proposal

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so long as the dissenting view is captured in the final report (Ministry of Energy, Mines and Petroleum Resources 2010a).

Results of the FNITR Process

The Quintette mine proposal review involved a technical team of 31 scientists of varying specialties to evaluate the technical information contained within the EIA (identified by the scope). These individuals had either a professional designation (e.g., professional engineer: P. Eng.) and/or master's/doctorate degrees with publications in peer-reviewed journals. The aggregate time that was required to evaluate the technical documents (Stage 2 of the FNITR) was "in excess of 1,100 hours" (Rescan 2012a). The technical team identified approximately 897 issues that spanned 12 scientific disciplines, with 120 issues characterized as key to be resolved before the Quintette mine proposal could be considered a potential candidate for sustainable development. To put this into perspective, these results were roughly triple the highest amount of issues ever identified during an FNITR. Many issues related to the "quantity and quality" of data and information (Rescan 2012a). Importantly, as noted in the evaluation report, the "issues and concerns identified… [did] not necessarily reflect the views or positions, in whole or in part, of the First Nations, either individually or collectively" (Rescan 2012a).

Based on the evaluation, the review concluded that the EIA did "not provide sufficient and credible information to allow for a proper evaluation of the Quintette Mine Project's potential environmental effects" (Rescan 2012a). Additional information was therefore required for the technical team working with the Aboriginal groups to determine whether the assessment and the suggested measures to mitigate and manage the potential effects were adequate.

Conditions and Commitments: A Path Toward Development

The parties to the FNITR of the Quintette mine mutually agreed to conclude Stage 4 of the process after approximately 5 months of discussions. Perhaps the most surprising outcome, given the amount of issues identified, was that the overall process was a success, both procedurally and substantively. The majority of the issues were thoroughly discussed and resolved, notwithstanding a number of issues relating to caribou and their habitat classified as *referred*, because some of the Aboriginal groups and the Government of Canada as represented by the Canadian Wildlife Service disputed the scientific validity and cultural acceptability of the recovery plan for the species that the BC government had developed. For the purpose of ensuring clarity and comfort among the parties moving forward, the substantive outputs of the FNITR were incorporated into either authorizations issued by regulators or contractual agreements. Select outputs considered important in the context of sustainability during the review process are discussed in the following sections.

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Work Plans

Most frequently used to resolve an issue are work plans that articulate potential remedies. The Main-Table proposed nearly 50 work plans to be carried out within approximately 1 year. These plans included actions that could be taken relatively soon to provide the necessary information to determine the adequacy of the Quintette mine proposal. Examples of such work plans include the following:

- Preparing wildlife habitat feature surveys
- Surveying of amphibians, ungulates, and breeding birds
- Determining links between species and explanation of scientific models
- Constructing grizzly bear denning and summer habitat models
- Fabricating moose winter habitat model
- Determining the impact of pine beetle kill on marten habitat
- Developing wildlife protection and monitoring plans
- Demonstrating the interactions of the local predator–prey relationships
- Confirming and analyzing hydrology model
- Surveying and monitoring of fish and fish habitat
- Updating groundwater reports and models
- Determining metal concentrations in soils, vegetation, and large mammals, and consumption through traditional land-use activities
- Comparing reclamation before and after disturbance
- Evaluating dust loading on soil
- Preparing rare plant survey and vegetation predisturbance study

The majority of work plans incorporated multiple key and general issues. Each plan identified the relevant shortcomings of the EIA, the methodology used, expected deliverables, and timelines. The technical team assisting the Aboriginal groups reviewed and commented on the work plans and, in a few cases, developed work plans in concert with the groups that were then submitted to the proponent for consideration. Results from the work plans were jointly reviewed and integrated into the EIA system. Whenever possible, the parties cooperatively executed the actions of the work plans with the integration of traditional ecological knowledge (TEK). The reliance on the technical teams by both parties was to be reduced significantly and, if appropriate, designed to end eventually through initiating training programs for members of the groups and mine personnel.

Cumulative Effects Assessment and Management

Few were surprised during the Quintette mine FNITR that the Aboriginal groups raised a concern over cumulative effects, because these effects are perhaps the longest outstanding land-use planning and natural resource management concern in the region. These cumulative effects were first documented during the impact

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assessment process of the proposed Alaskan Pipeline project, which took place nearly four decades ago (Mair 1980). With the absence of a cumulative effects management framework, which is implemented in similar jurisdictions (e.g., the province of Alberta, Canada), the substantive issue carries forward into each and every EIA regarding mining proposals. More problematic is the extent to which industrial development continues to occur without the proper mechanism in place to adequately protect cultural rights, such as analysis of cumulative effects on valued components of the Aboriginal cultures as required by case law in Canada (*West Moberly First Nations v. British Columbia [Chief Inspector of Mines]* 2011). Individual proponents have therefore been compelled to grapple with a problem that is caused by multiple proponents from numerous industries, which is challenging given the diversity and scale of development activities. However, because cumulative effects cannot be adequately resolved at the site-specific level, the BC regulators' lack of implementation of an appropriate landscape-level strategy not only threatens the general sustainability of the region but also jeopardizes the efficiency of projects that would otherwise be considered sustainable developments.

Reviewers of the Quintette mine EIA identified numerous issues related to the proper assessment of project-specific effects that needed to be addressed before the cumulative effects could be evaluated. Many issues related to how the baseline conditions were characterized. Instead of using a historic reference point to establish the baseline conditions for valued components, the project proposal used current conditions (circa 2010) for the assessment. Examples of key issues identified during the FNITR include the following:

- Key Issue No. 24: "Extensive baseline studies were not conducted for a suite of biological indicator species. Instead, the Application relies on historic literature reviews as a basis for environmental assessment. The use of historic literature information as a surrogate for baseline studies on abundance and distribution can be misleading. Without current information, it is unclear how impacts to wildlife can be measured or monitored, or what types of changes will trigger adaptive management measures."
- Key Issue No. 34: "Thresholds are relative to natural conditions. Given this Application is for a reopening of an existing mine, thresholds should be calculated and assessed against baseline conditions from over 30 years ago when the mine was first developed."
- Key Issue No. 37: "Calculation of the significance of habitat loss to caribou only considers new loss. Substantial loss has occurred as a result of past development, and this should be considered in the assessment. This historic loss combined with new losses may indicate that the threshold of 35% has already been exceeded." (Rescan 2012a)

Due to the number of issues identified, which included varying elements of cumulative effects and follow-up, the FNITR for the Quintette mine developed

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a strategic, coalesced remedy, as "cumulative effects require cumulative solutions" (Canter and Ross 2013). It was determined that a "pre-disturbance baseline scenario" would be used moving forward. Work plans were developed where, from a cumulative perspective, the valued components were re-scoped. Spatial and temporal boundaries were also adjusted to account for a regional assessment area that included surrounding anthropogenic activities, the collection of adequate data to establish baseline conditions, and the reassessment of potential effects on valued components.

Using a 2010 temporal boundary to establish the baseline condition, which essentially represented the current conditions of certain valued components, the EIA had concluded that there were no significant effects to valued wildlife species that were of concern to the Aboriginal groups. However, when a predisturbance (i.e., the historical reference point) was used to establish the baseline conditions of the valued components, the cumulative effects assessment produced considerably different results. The reanalysis demonstrated that there were, indeed, significant adverse impacts to culturally important species such as caribou, martens, grizzly bears, mountain goats, northern goshawks, and forest songbirds (Stantec Consulting 2013). These results directly contradicted the analysis of the EIA and further demonstrate why a proper delineation of baseline conditions is required for an impact assessment to credibly determine the potential effects of a project proposal on valued components.

Due to the substantial threats to the sustainability of several species and habitats that were discovered during the FNITR, management plans were modified accordingly and implemented to mitigate project-based effects to the extent possible. Furthermore, and with regard to "ecosystem impacts that cannot be fully mitigated or rehabilitated," strategies were developed to offset such impacts whereby the Quintette mine "would contribute to creating a net positive impact in the greater area of influence within northeast British Columbia" (Stantec Consulting 2013).

Lastly, and to address the absence of a cumulative effects management system in the region, the parties agreed to jointly develop a work plan to review various approaches in other jurisdictions. This was to be followed by a second work plan that would introduce a preliminary cumulative effects management framework with an initial focus on fish and water quality within the Pine River watershed, a spatial unit that could ecologically manage direct and measurable effects. The watershed also includes other operating mines that expressed an interest in participating. The goal was to eventually expand the framework to include additional aquatic and terrestrial valued components (including fowl) as well as proponents from other industries.

Perhaps the most problematic consideration in advancing this initiative was whether to include the colonial governments. Although the parties agreed that the

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Figure 7.5 Conveyor belt used to transport coal from open pits in the alpine to the site of the processing plant in the river valley

solution to cumulative effects included a role for certain regulators, the extent to which they should be included and what they might bring to the table was unclear at the time. The hesitation to include colonial governments likely stemmed from the general breakdown of relations between them and the Aboriginal groups in the northeast with respect to mining and EIAs, as noted by Booth and Skelton (2011), in addition to the history of colonial indifference toward cultural rights being impacted cumulatively by industrial development.

Conveyor Belt and Wildlife: "Over, Not Under"

In addition to the issues identified during the evaluation of the EIA, the Aboriginal groups identified other concerns that were incorporated into the review process and discussed at the Main-Table workshops. Of particular concern was the conveyor used at the old mine site to transport coal from open pits in the alpine ridges to the coal washing plant in the river valley, a distance of approximately 8 miles, shown in Figure 7.5. The conveyor was not decommissioned despite a mine closure of more than a decade. The issue of the conveyor had implications to the ecological integrity of the area. While hunting in the area, community members of West Moberly First Nations observed that the conveyor obstructed the movement patterns of ungulate species, including elk and likely caribou. Changes to wildlife patterns due to anthropogenic activities are problematic from an Aboriginal perspective because, among other things, the TEK of hunters operates based on the functions of ecosystems. Impaired ecosystems correlate to unsuccessful hunting, which is an adverse impact to the cultural mode of life. Although several underpasses were constructed along the conveyor, which were likely designed to accommodate wildlife movements, the mitigation measure appeared to be largely ineffective.

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Several new measures were put into place to address the issue. The first was to decommission the infrastructure at the old mine site and to restore ecological functions to the extent possible. The second step, which incorporated the Aboriginal groups' observations, was to design the conveyor at the new mine site to include overpasses rather than underpasses to reduce the disruption of wildlife movements. The third and final step was to ensure that the overpasses were monitored with cameras during operations to determine whether the design and surroundings (e.g., trees and embankments) effectively accommodated the preferences of valued species. Part of the monitoring program involved the training of Aboriginal group members and mine personnel to jointly implement the plan.

Follow-up: Monitoring, Management Plans, and Implementation Committees

An environmentally sustainable mine in a region where land and natural resources are foundations of cultural subsistence, as articulated during the FNITR process, begins with ensuring that the population and distribution of species are maintained. Access to cultural rights has been defined as more than the physical ability to hunt, gather, trap, fish, or otherwise rely on the environment for cultural purposes—the cultural meaning of carrying out such practices is equally as important as physically exercising the practices themselves. In several instances, the EIA and the subsequent discussion of issues revealed problematic interactions between potential project effects and traditional land-use patterns. However, these interactions could not be properly addressed via a typical work plan. Because cultural data were not part of the EIA, and the follow-up of potential impacts to social and cultural valued components is not legally mandated under Canadian EIA laws as it is for biophysical components (Storey and Noble 2005), the parties were forced to commit to the further investigation of the potential interactions between cultural practices and mining activities during the operational stage of development.

The appropriate mechanism in this case was the Joint Management Advisory Committee set up under the Impact Benefit Agreement among the parties. Not only would the committee follow up on various substantive components of the EIA and continuous studies (e.g., the work plans), but it would also investigate cultural phenomenon, like culture camps—the traditional Aboriginal practice of using land and natural resources for a few weeks to a month for the purpose of hunting, fishing, gathering, spiritual ceremonies, and teaching youth the traditions, customs, and practices of the culture, which occur in addition to the land-use activities associated with the traditional seasonal round. When a culture camp is situated within the general area of the mine and/or mining activities, the respective parties were to identify and discuss the potential ways in which mining activities could negatively influence traditional land uses associated with the practice. Noise from blasting activities, for example, was identified as a likely adverse impact. Advice provided to the committee if a culture camp were to be placed in the vicinity of the

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Quintette mine was to examine the situation, in relation to the mining activities themselves (e.g., zone of detectable noise and blasting schedule alongside scheduled cultural activities), by taking into account the following:

- The location of the site for the camp (e.g., river valley, alpine lake)
- The spatial unit that supports the cultural activities of the camp (e.g., watershed, complex of ridges and mountains)
- The timing of the camp (e.g., winter or summer), including the during of the preparation and the activities at the camp itself
- Cultural activities that are expected to occur (e.g., foci species and preferred settings) in relation to the mining activities themselves (e.g., zone of detectable noise and blasting schedule alongside scheduled cultural activities)

As each cultural use of land and natural resources is governed by distinct timelines, and locations as planned in accordance with the traditional seasonal round that is distinct for each Aboriginal group, the impact of noise could be mitigated to a moderate extent. It was determined that the mine could adapt its operational and management plans. For example, it was suggested that the mine could refrain from blasting before and during the scheduled camp to minimize the ecological and cultural impacts. Limitations to mitigating such impacts were also identified, as the measures would not necessarily address significant impacts to valued components such as the power of medicines, spiritual ceremonies, and the meaning of land-use practices that may also be part of the culture camp experience. Further interaction with knowledge holders within the Aboriginal groups, the sharing of information, and the exploring of hypotheses were needed to study and potentially develop additional mitigation measures that could be studied and monitored.

Unplanned Closures

Project activities and operations of the mining industry are not immune to the influence of externalities, as demonstrated by the Quintette mine's closure in 2000 when coal prices dropped. Such unforeseen events increase the potential for degradation of the terrestrial and aquatic environments, which may result in "significant effects" (Nyamekye 2000). But seldom, if at all, is the possible closure of a project considered seriously during the assessment of potential impacts.

This issue, however, became a key issue during the discussions of the EIA for the Quintette mine, considering its history of closure and the recent closure of coal extraction activities at the Willow Creek mine in the region, also due to market conditions. As this issue remained hypothetical in nature, the recommended solution was to provide the Aboriginal groups with a detailed plan of the mine's "care and maintenance program," which is typically requested by regulators and constitutes the mechanism by which to address a temporary, premature closure. The commitment included engagement obligations that would be triggered before

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a decision was made by the proponent to close the Quintette mine to ensure that the plan would adequately address the substantive concerns of the groups.

SHARED LESSONS

The FNITR process allowed the parties to collaboratively work through technical issues on a level playing field, with the provision of adequate capacity and the implementation of a culturally responsive process. As a result, the adversarial atmosphere that was once the norm in consultation processes has largely been replaced with one that is more collegial in nature. Important aspects of the FNITR have been adopted, modified, and in some cases deleted based on the feedback received from proponents and technical teams. Such a setting, as Sinclair and Diduck (2005) point out, provides an opportunity for the parties involved to identify and understand each other's values and effectively use information that makes up local, scientific, and traditional knowledge systems, all of which is valuable for enhancing sustainable development. The FNITR has in this way provided a structure from which elements of TEK may be integrated into a project proposal at the discretion of each group. This has noticeably mitigated several deficiencies in the ways EIAs are currently practiced in British Columbia. As a result, some of the cultural traditions, customs, and practices have been incorporated into the technicalities of the impact assessment. The FNITR has also improved the quality of EIAs before regulators make decisions based on them.

The FNITR process has evolved, in some respects, since its conception. Initially developed to deal with the technocracy of science associated with project proposals, the process has also begun to function as an important tool for Aboriginal decision makers in managing their respective territories. The review of the Quintette mine, for example, included several community gatherings during which the content of the summary report was made available through cultural methods of processing and discussing information that were unique to West Moberly First Nations. These gatherings dovetailed with the spirit and intent of the Custom Code of Governance used by the First Nations. Taken as a whole, the FNITR process and its outcomes were considered by some within the community to be a fundamental step in acquiring their "free, prior and informed consent," as suggested by the United Nations (UN 2008; Newman 2009). Future iterations of the FNITR should ensure that this community expectation is properly accounted for in the framework.

Adequate funding is essential for the success of the FNITR; however, when the administrative and operational privileges were removed from BCEAO, the funding it provided (albeit limited) for the review of formal EIAs ceased as well. Under the current funding model, the Aboriginal groups' ability to implement the FNITR is entirely dependent on whether the proponent of a specific project proposal considers the engagement opportunities and the potential outcomes valuable, and therefore

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agrees to provide the necessary funding. The initial response to requests for capacity to review technical documents has been positive, as no industry proponent has refused to provide capacity funding to date. Proponents have recognized that they benefit from the "economies of scale" by working with the groups as a collective.

But some problems have emerged. Several proponents have noted that the necessary funds were unavailable when requested, as the associated costs of the FNITR were not anticipated. This is because the task of thoroughly consulting with Aboriginal groups on the technical aspects of a proposal are not typically incorporated into the initial budget. This oversight has caused internal delays when a proponent agrees to the FINITR, as additional time is needed for budgets to be revised accordingly. To some extent this has impeded the initiation of the FNITR process, resulting in a need to modify the stages to varying degrees in addition to steps and expectations of the groups.

Integrating the TEK of Aboriginal groups into the FNITR, including information about the environment, its use, values, and knowledge system (Usher 2000)—while also integrating preferences such as location, setting, season, and valued component to ensure that meaning behind these knowledge systems is considered—remains the most problematic obstacle in the FNITR process. More often than not, it is not a question of whether TEK *can* be incorporated into a project proposal, but instead whether there is access to the resources (e.g., adequate capacity from the proponent, availability of knowledge from a group) and the time necessary to collect the information. Proponents' limitations, such as internal obligations and the timelines of colonial processes, are usually acknowledged, but this same acknowledgment is rarely afforded to the Aboriginal groups. This is a problem given that TEK cannot be collected and disseminated in a convenient (Eurocentric) fashion. Cultural protocols do not fit effectively (or respectfully) within, for example, the generic procedural components of EIAs. While these challenges presumably vary from culture to culture, what is likely generalizable is the need to respect a knowledge holder's pedagogy, the proprietary nature of the knowledge, and the cultural responsibilities that come with being provided such knowledge.

FUTURE APPLICATION

Although most FNITR processes have been limited to the evaluation of EIAs, the participating Aboriginal groups and mining proponents have a mutual interest in broadening the application and scope of the FNITR. More specifically, as the evaluation of the EIA for the Quintette mine demonstrated, ensuring the early inclusion of Aboriginal values and perspectives in the impact assessment process would likely have alleviated or noticeably reduced the quantity and substance of the issues that were identified. Implementation of an engagement strategy with Aboriginal groups, which includes the FNITR during the planning, exploration, construction, operations, and closure stages, is likely to increase the transactive

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effectiveness of the overall development of projects. Strategic engagement of the FNITR process may include the following elements of an EIA that are typically omitted: (1) evaluation of potential locations to apply for tenures to acquire rights to subsurface resources; (2) development of the impact assessment scope (e.g., valued components, spatial and temporal boundaries); (3) advancement of parameters for establishing baseline conditions (i.e., historical reference point) as well as current and future conditions; (4) development of follow-up programs that contain cultural components; and (5) progression toward a cumulative effects framework ensuring that the development of a mine remains sustainable.

Improvements in these areas of engagement provide the groundwork from which proponents may demonstrate that Aboriginal groups' values, perspective, issues, and concerns have been integrated into development plans. Furthermore, and perhaps most importantly from the perspective of a proponent, knowing that a project proposal is situated within a culturally sensitive area (i.e., a no-development zone) before financial investments are made is beneficial, as the initial proposal could be discontinued and efforts refocused on potential opportunities elsewhere within the territory. Balancing the traditional economy (i.e., the cultural land uses) of Aboriginal groups with modern economic activities (e.g., construction of a mine) is an important condition when pursing sustainable development (Berger and Mackenzie Valley Pipeline Inquiry 1988).

CONCLUSION

Aboriginal cultures and the broader values of the Canadian community have been at odds many times over the years. Some have described the climate as fostering an "irreconcilable collision course" between the differing values systems unless fundamental changes are made to regulatory approaches (Devlin et al. 2012). While an EIA is not likely the most appropriate mechanism to adequately satisfy Canada's legal obligations to reconcile with Aboriginal groups, the processes nonetheless provide opportunities to ensure that project proposals are sound from a scientific perspective, which is an important element of sustainable development. Technically sound project proposals make it possible to begin the assessment of potential impacts on the cultural rights of groups likely to be affected. The FNITR plays an integral role in blending the values of differing worldviews, albeit by excluding colonial governments. Engagement of this fashion has gone a long way in restoring tenuous relations between the mining industry and Aboriginal groups. Fundamental to the success of the FNITR has been the willingness of mining proponents and the Aboriginal groups to work collaboratively, as demonstrated by leadership displayed during the evaluation of the EIA for the Quintette mine. Direct and organized engagement has provided the foundation for the serious consideration of Aboriginal issues and concerns. The integration of culturally based philosophies and information has improved the decision-making process

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and, optimistically speaking, the potential for approved projects to be sustainable. Future implementation and refinements to the FNITR process are likely to further the Aboriginal groups' goal to protect the ecological integrity on which their cultural modes of life are based.

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PART III

BIODIVERSITY AND CONSERVATION MANAGEMENT

Daniel Jones

Biodiversity is an ecological concept that refers to the abundance, distribution, and variability of organisms within habitats at a variety of physical and temporal scales. In simpler terms, biodiversity is an inventory of which species are found in an area, and an understanding of how they interact in that space over time. Biodiversity is important because biologically diverse systems are resilient to change.

Biodiversity assessments characterize the abundance and distribution of sensitive biological resources. Biologists and ecologists use field surveys, geographic information system databases, genetic methods, and biometric statistical analysis to inventory and analyze sensitive vegetation and wildlife. For mining projects, biodiversity assessment can play an important role throughout the life of the mine. Preconstruction biodiversity assessments can inform mine planners, regulators, and other stakeholders of the baseline abundance and distribution of species at the site. This information aids mine planning to minimize effects on sensitive species, and supports environmental approvals and permit applications. Biodiversity assessments during mine operations can monitor the impacts of mining activities on sensitive species and establish compliance with environmental regulations. Finally, biodiversity assessments can guide postclosure restoration.

Biodiversity assessments are particularly valuable as tools to facilitate collaborative planning among mining companies, regulatory agencies, and other stakeholders, from initial mine development through long-term reclamation. A common theme in the three chapters presented in this section is the use of field

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biological surveys to develop management strategies that accommodate both conservation of sensitive species and habitats, and continued mine development.

Chapter 8 presents a case study on the collaboration between Cliffs Natural Resources and the Western Australia Department of Environment and Conservation to gather the biological resource data needed to manage natural resources in the northern Yilgarn region. The resulting management plan provides a pathway for continued mine development while reinforcing natural resource conservation. It also resulted in training and jobs for Indigenous people to help implement the management program. This case study illustrates two key points about the value of biodiversity assessments for mining projects. First, proactive investment in biological surveys can identify environmental issues early and avoid disruptive 11th-hour discoveries of natural resource complications. Biological surveys early in project planning can be costly, but those costs are offset by an enhanced understanding of potential mine impacts on natural resources in the region. Early surveys support better strategic planning for mining operations and improved conservation planning through expanded natural resources data. Second, collaboration among agencies and the mining industry can make standard mitigation processes step beyond the project limits and improve biodiversity and other environmental values over a larger region.

Chapter 9 describes how a biodiversity assessment conducted for a proposed mining project used intensive field biological resource survey methods to determine the actual distribution and abundance of a species that was thought to be rare. In the Yilgarn region of Western Australia, a particular species of trapdoor spider was considered a high-priority rare species. Regulators believed that the spider occurred only in unique, sparsely distributed, disjunct habitat that the authors refer to as "islands of biodiversity." A mining company with ongoing operations in the region wanted to develop a new mine in the documented range of the trapdoor spider, so the company asked a local biological resources firm to examine whether the spider species was "rare or just poorly understood." Biologists used intensive field surveys and genetic studies to determine that the spider was more abundant and more broadly distributed in the region than had been previously thought. The researchers were also able to develop methods for translocating the trapdoor spider species, further mitigating potential project impacts. The study's finding that the trapdoor spider species was in fact not as rare as previously believed led to an adjustment of the species' regulatory conservation status and its removal from Western Australia's Specially Protected Fauna list. The adjustment of the species' conservation status helps the resource agency and the project proponent by allowing them to redirect their efforts on protection of species in the region that are actually rare and potentially affected by mining.

Finally, the case study provided in Chapter 10 illustrates the use of biodiversity assessment as a tool to facilitate collaboration among industry, government, and

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nonprofit natural resource organizations. In this case, habitat for several rare plant species and for desert bighorn sheep overlaps economically important limestone mining operations in the San Bernardino Mountains of California. A multi-stakeholder process that included agencies, industry, and nonprofit organizations drafted a habitat management plan that recognizes the need to conserve critical habitat for sensitive species while allowing for continued economic development through mining. The plan makes monitoring of the desert bighorn sheep populations and habitat a joint effort among state agencies, mine employees, and the nonprofit organization. The habitat management plan also created a habitat reserve and provides guidance for locating future mining operations.

These case studies underscore the value of obtaining comprehensive biological resource information at an early stage in project development. The chapters also demonstrate the shared positive outcomes that can result from collaborative planning among agencies, local stakeholders, and the mining industry. In all three cases, a planning approach that incorporated conservation of biological resources resulted in continued and expanded mining operations, better understanding of regional biodiversity, more effective mitigation strategies, and enhanced protection of natural resources at a regional scale.

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CHAPTER 8

Joint Land Management Project in the Northern Yilgarn, Western Australia*

Robert K. Howard

INTRODUCTION

In late 2009, Cliffs Asia Pacific Iron Ore (Cliffs) entered into a voluntary joint land management project with the Western Australia Department of Environment and Conservation (DEC). The project aimed to cooperatively address biodiversity knowledge gaps and to build land management capacity in the relatively remote Yilgarn area of Western Australia. The project area possesses high conservation values as well as valuable iron ore deposits, with a high potential for conflict to arise in the mine permitting process, particularly as a result of limited information around the distribution of native species.

Cliffs Koolyanobbing Operations

Cliffs operates an iron ore mining operation in the Yilgarn region of Western Australia. Cliffs' operations are based at Koolyanobbing, 50 km north of the town of Southern Cross (Figure 8.1).

Iron ore mining in the Koolyanobbing area dates back to 1950. A BHP mine at Koolyanobbing was active from 1960 to 1983. Portman Iron Ore Limited recommenced mining in 1994 at an initial rate of 1.5 million metric tons per annum (Mtpa). Production from the Koolyanobbing operations has progressively increased to reach 11 Mtpa in 2012. In 2009, the Portman operations were acquired by Cliffs Natural Resources. The Koolyanobbing mines are now operated by Cliffs Asia Pacific Iron Ore Pty Ltd.

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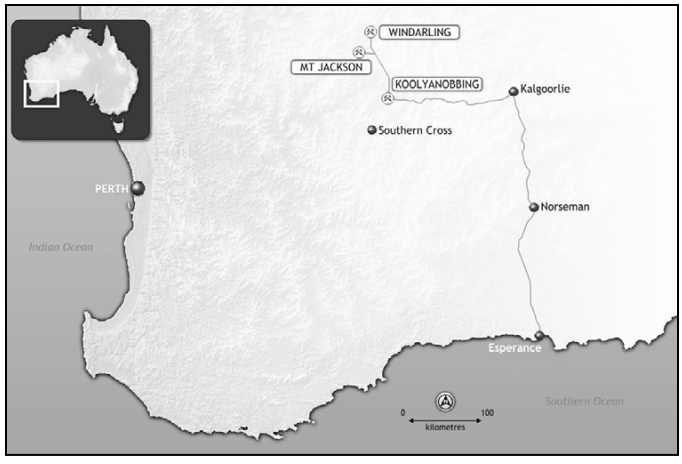


Figure 8.1 Location of the Cliffs mining operations and the transport route to the port of Esperance

Mining uses conventional open pit mining methods, with the ore being hauled by road train from the northern mines to a crushing plant and railhead at Koolyanobbing. The ore is transported by rail from Koolyanobbing to Esperance (via Kalgoorlie) from where it is shipped to steel mills in China and Japan. Multiple, separate ore bodies are mined concurrently. The ore product is of a high grade and requires no processing other than crushing. However, ore from the various deposits does vary in the content of iron and minor elements such as phosphorus and sulfur. A sophisticated process of blending must be applied to achieve the product specifications required by customers.

Cliffs' Koolyanobbing operations are located in a region of notable biodiversity and wilderness value. This area, lying between the agricultural zone to the west and the inland deserts to the east, is the largest intact woodland landscape remaining in temperate Australia, and it is receiving increasing attention for its global biodiversity significance (Watson et al. 2008).

The Yilgarn region is relatively flat, geologically ancient, and semi-arid. Ore bodies are typically associated with low-outcropping, banded iron formations, or BIFs (Figure 8.2). Such features are scattered across the region, forming "islands" of biodiversity where the vegetation often contains groupings and species that differ from one range to the next. This isolation and divergence of populations is thought to arise from the spatial separation of the ranges combined with a very long period of geological stability. In some cases, species of flora are known from single populations at only one location. This presents particular challenges for mining projects as a result of the potential for ore bodies to overlap with the distributions of rare flora.

ORIGINS OF THE JOINT PROJECT

When Portman Iron Ore recommenced mining at Koolyanobbing in the 1990s, the environmental assessment and approvals for mining were relatively straightforward

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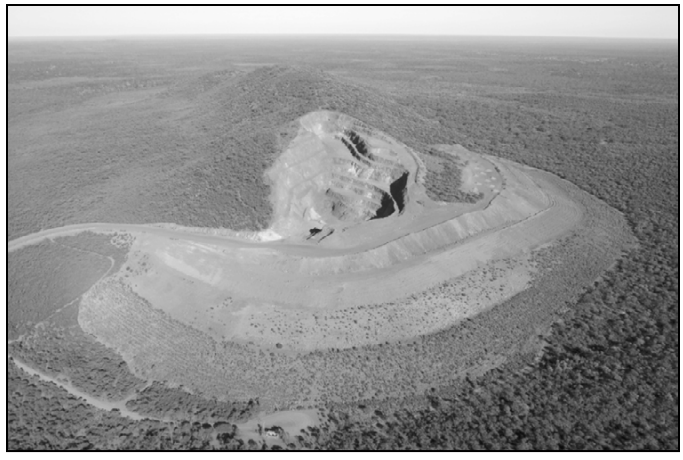


Figure 8.2 Mining is based on multiple small ore bodies that are typically located on or adjacent to banded iron formation ranges

as a result of the mining footprint being largely restricted to areas that had been disturbed during the previous mining operations. The opening up of new mining areas further north at Windarling and Mt. Jackson 10 years later was a different matter, however. These deposits were located in areas that had not been subject to previous mining, and baseline environmental surveys revealed the presence of flora species whose distributions appeared to be restricted solely to these ranges.

Three such species, which were subsequently given the status of Declared Rare Flora (DRF) under state legislation, were identified. *Tetratheca paynterae* (subspecies *paynterae*) is one of two species at Windarling that are classified as DRF (see Figure 8.3). *T. paynterae* occupies a highly specialized habitat, growing only in the rock crevices of BIF outcrops. The other species of DRF occurring at Windarling is *Ricinocarpos brevis*.

At Windarling, the location of the major ore deposit coincided closely with the distribution of *T. paynterae* ssp. *paynterae*. Mining of the whole of the ore body would have resulted in the removal of around 90% of the 7,500 individuals recorded.

During the environmental assessment and approvals process for the Windarling and Mt. Jackson mines, the Environmental Protection Authority initially recommended against approving the Windarling component of the project on the basis of the impact on *T. paynterae* ssp. *paynterae*. Ultimately, however, the Minister for the Environment approved a modified version of the proposal that excluded mining from defined areas, such that a minimum of 50% of the population would be retained.

For any mining development, the environmental impact management strategy follows a hierarchy of avoid → minimize → mitigate. Avoidance is always preferable if it can be achieved, but this was clearly not possible at Windarling if its valuable iron ore deposits were to be accessed. In this case, a government decision was required

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Figure 8.3 ***Tetratheca paynterae*** **ssp.** ***paynterae*** **occurs on exposed banded iron outcrops at Windarling where it establishes a root system within rock crevices**

to define an acceptable balance between economic value and the impact on the *Tetratheca* population (Figure 8.4). The proportion of the original population that was subsequently retained at Windarling was estimated to be 73%. In achieving this result, access to potential ore worth around $800 million, in today's terms, was foregone.

Cliffs takes the viewpoint that, in gaining access to mineral resources, it accepts an obligation in terms of managing its direct environmental impacts and in making a positive contribution to social development and conservation outcomes more broadly. There were a number of important issues arising out of Cliffs' experience in developing iron ore operations in the northern Yilgarn that provided the impetus for the development of the Cliffs–DEC joint project.

The first concern relates to a deficiency in the typical process that leads to mine development, whereby major environmental issues can potentially emerge at the "11th hour." Detailed biological surveys are time-consuming and costly, and mining companies rarely undertake such work until there is a high degree of confidence that they have a viable ore deposit. In some cases, this can mean that the presence of rare flora or fauna is not known until project plans are well developed and large investments have been made in proving up mineral resources. From the point of view of both Cliffs and the government, a proactive investment in regional biological surveys is a means of addressing this issue, and it is particularly relevant in the BIF setting. Improved biological information would provide a better understanding of the impacts of mining proposals in the regional context and support a more strategic approach to the planning of future mining operations.

The other main driver for the joint project was the recognition that opportunities existed for Cliffs to make an effective contribution to conservation and biodiversity management beyond the boundaries of the company's mining

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Figure 8.4 The Windarling site showing the W3/5 pit in the foreground. The unmined portion of the Windarling range containing 73% of the original population of *T. paynterae* extends west (right) from the pit.

tenements. Normal statutory approvals processes for mining proposals must necessarily focus on the avoidance and mitigation of environmental impacts directly associated with the proposal and associated infrastructure. They do not address the broader issues that pose the major threats to environmental values across the region. For example, the impacts of feral animals, weeds, and fire are considered to represent the major threats to conservation values across the broader region (DEC 2010). Effective management of these issues requires a regional approach underpinned by significantly increased land management capacity, and this was an area where Cliffs believed it could make a valuable contribution in partnership with the DEC.

In late 2008, discussions were initiated between Cliffs and the DEC to explore such opportunities, and the components of a collaborative land management project were refined during 2009. In November 2009, Cliffs entered into an agreement with the DEC to commence a joint project to improve the information base and on-ground capacity to manage the natural environment in the Northern Yilgarn region of Western Australia (Figure 8.5).

SCOPE

The joint project covered four key areas:

1. **Indigenous training and employment.** This involved a 3-year training and employment program for four local Indigenous people. The Indigenous training and employment component operated under an existing DEC program structure—the Mentored Aboriginal Training and Employment Scheme (MATES). The training program was managed by the DEC and included on-the-job training with DEC and Cliffs. This program would

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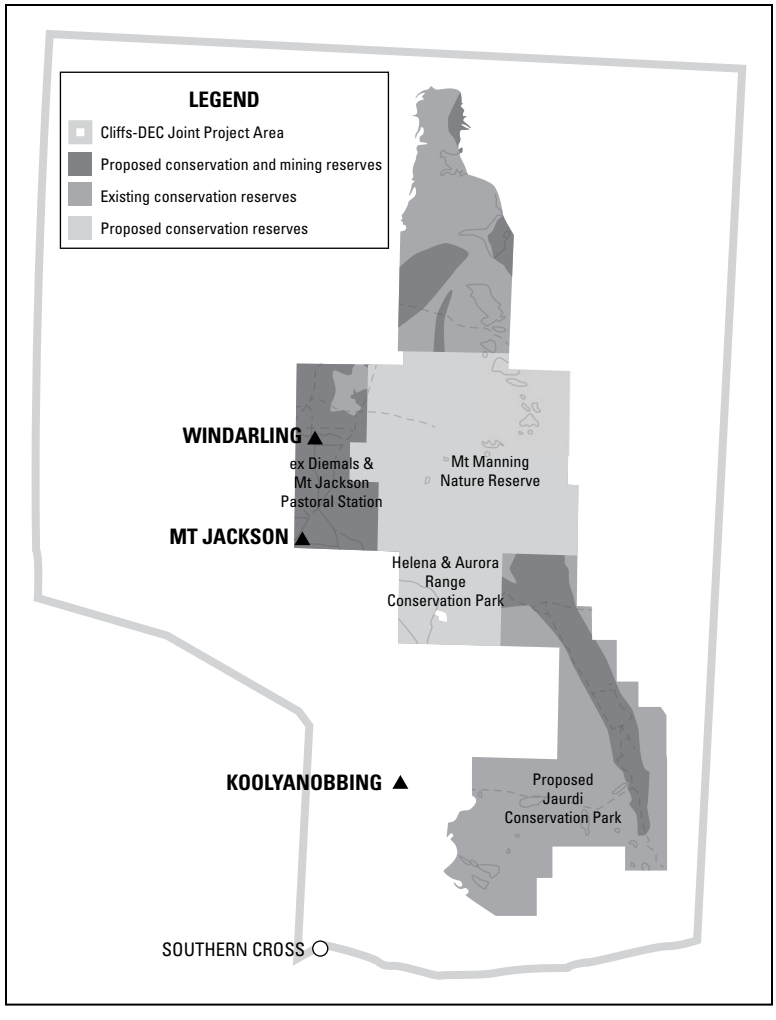


Figure 8.5 Map showing the approximate boundaries of the Cliffs–DEC joint project area in relation to mining operations and existing and proposed conservation reserves

also provide for progress toward permanent employment either with Cliffs or the DEC.

2. **Flora.** The flora component involved field surveys of flora of conservation significance. The surveys were conducted on a regional basis—and incorporated areas outside Cliffs' tenement boundaries.
3. **Fauna.** The fauna component involved targeted research and regional surveys aimed at improving the knowledge base for species whose distribution and abundance was poorly understood.
4. **Fire.** The fire component involved developing a fire management plan for the area based on a wildfire threat analysis.

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Cliffs' contribution consisted of funding of AU$2.5 million plus staff time and in-kind assistance over a 3-year period.

Governance

A project steering committee, made up of representatives from Cliffs, the DEC, and a nongovernmental organization (Great Western Woodlands Collaboration), provided general oversight of the project. Technical working groups, comprised of Cliffs and DEC staff, with advice from other experts as needed, managed the work programs and provided recommendations to the steering committee regarding the allocation of discretionary funding.

OUTCOMES

Indigenous Employment and Training Program

This program operated under the structure of a preexisting DEC Indigenous training scheme (MATES), albeit modified to incorporate exposure to mine-site-related environmental and land management aspects (Figures 8.6 and 8.7). The program involved formal studies in land management (Certificates II and III in Conservation and Land Management) in combination with field-based learning skills.

A key challenge for the program was to prepare the trainees for full-time employment. The trainees initially underwent a "work ready" preparation phase that involved full-time work, mentoring, basic training, and securing driving licenses. This served to prepare them for the transition into the full-time traineeships within the DEC regional team. There were also challenges in keeping trainees on the program. Retention rates for Indigenous trainees in similar programs have typically been less than 50%. This aspect was managed through close supervision, support, and mentoring.

The training and on-the-job work program included the management and development of recreation sites, work on former pastoral stations, building and infrastructure management, biological survey, fire control and prescribed burning, cultural site management, and conservation reserve management. Three of the four original trainees were able to successfully complete the 3-year traineeship. One of the graduates subsequently accepted a position with Cliffs, and a second was employed by the DEC.

Fire Management

Frequent wildfires represent a major threat to biodiversity, human beings, and assets in the region (Figure 8.8). The fire management aspect of the project aimed to develop a fire management plan for the project area. The project area included unallocated crown land and DEC-managed reserves such as nature reserves, national parks, conservation parks, and former pastoral leaseholds.

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Courtesy of *The Kalgoorlie Miner*.
Figure 8.6 Indigenous trainees from Cliffs–DEC joint land management project



Figure 8.7 Indigenous trainees setting up Cliffs rehabilitation trials for rare flora at the Windarling mine site

The initial task involved completion of a wildfire threat analysis. The threat analysis used fire risk mapping based on assets, fire history, and vegetation types across the project area. This information was then used to determine appropriate fire mitigation works for locations potentially at risk.

The fire management plan focused on four key fire management factors:

1. The likelihood of a fire starting and spreading
2. The potential fire behavior under severe summer conditions in each major vegetation type

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Figure 8.8 Frequent wildfires pose a threat to the region

3. The threat to life, property, community assets, and biological and environmental values
4. Mitigation actions and resources available to respond effectively when a fire occurs

The DEC has responsibility for managing fire across conservation reserves, as well as fire preparedness and prescribed burning across vast areas of unallocated crown land in Western Australia, and normally struggles to find the resources to undertake this type of proactive planning. The fire initiative has provided clear benefits to Cliffs in terms of managing wildfire risk to its people and assets and to the DEC in addressing its regional fire management obligations.

As a result of the success of the fire management initiative under the joint project, separate funding was made available by the state government to extend the work to the entire 16 million ha of the surrounding Great Western Woodlands. The success of the initial Cliffs-funded work provided the leverage for its extension across a much larger area of the state, benefiting government and other stakeholders.

Flora Management

The flora management program involved research and regional flora surveys to improve the information on flora in the project area. The funding was used to engage and equip a botanist to undertake regional field surveys. The project also funded the position of a DEC conservation officer (flora) based in the regional office working in the project area and across the whole region.

The survey work has proved highly successful in expanding the information regarding the distribution and abundance of flora of conservation significance in the project area. Results obtained include

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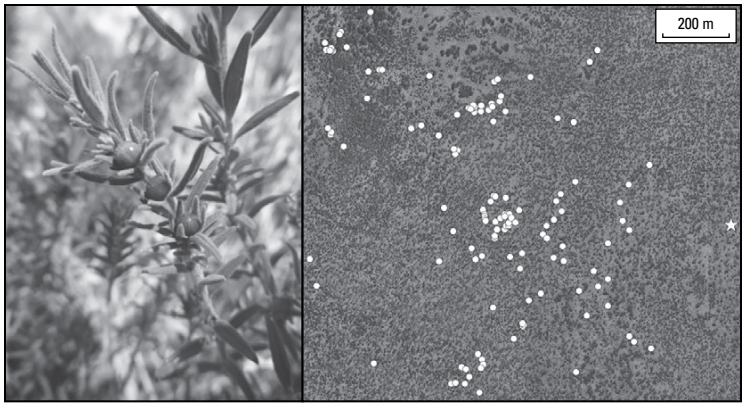


Figure 8.9 *Spartothamnella* sp. Helena and Aurora. Map shows new records (circles) obtained by flora surveys in the Johnston Range area. The star shows the original record of a single individual.

- New locations identified for 50 of a priority target list of 80 species and
- Significantly increased sizes and numbers of populations of more than half of the 25 species in the highest-priority category.

These are species that were previously only recorded in limited numbers and had the potential to constrain future mine development. For example, prior to the project commencing, fewer than 100 individuals of *Spartothamnella* sp. Helena and Aurora Range were recorded from areas in the proximity of current and planned mine pits at Koolyanobbing, Mt. Jackson, and Windarling (Figure 8.9). The survey work increased numbers to more than 600. Similarly, records for *Bossiaea* sp. Jackson Range, a species that presented a significant permitting issue for Cliffs' Mt. Jackson mine development, have increased from around 350 to more than 2,000.

To ensure that the information is retained and publicly accessible, the survey data was entered into the state flora database and herbarium. The project also funded work to allow previously unprocessed records of these species to be entered at the same time.

Fauna Management

The fauna management program took a similar approach, involving targeted research and regional surveys. The work aimed to support the protection of rare species and to improve knowledge of the distribution and abundance of species that are currently classified as rare or potentially having restricted distributions (i.e., "short-range endemic" species).

Two projects on invertebrate fauna were completed. A project undertaken by the Western Australian Museum focused on increasing the knowledge around locally occurring millipede species and their distributions. The work resulted in

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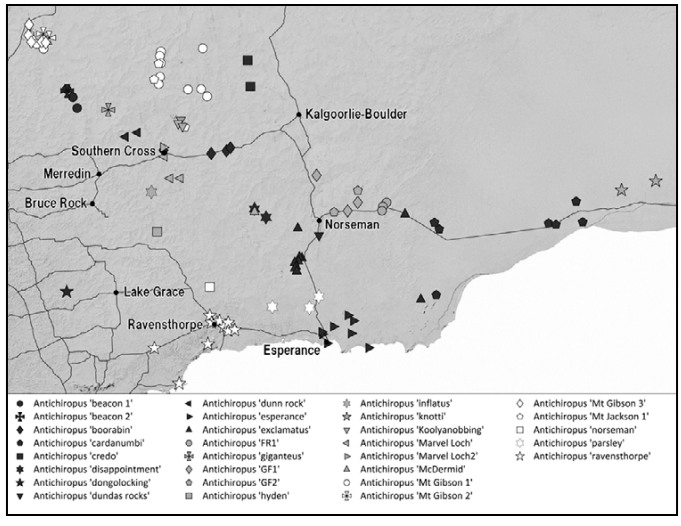


Figure 8.10 Distribution of *Antichiropus* millipedes in or near the Great Western Woodlands of Western Australia as determined by the Western Australian Museum study

the identification and description of 29 new species in the *Antichiropus* genus (Figure 8.10).

A related project was undertaken at the University of Western Australia to examine the degree of genetic similarity of populations of millipedes occurring on BIFs in the project area. The study found that for the millipede species *Atelomastix bamfordi* there was clear genetic differentiation among populations occurring on different BIF ranges in the project area (Figure 8.11).

The fauna management program also funded annual predator baiting and monitoring in the project area. This work is linked to annual surveys of the endangered mound-building bird *Leipoa ocellata* (malleefowl) undertaken by Cliffs. The baited area covers 206,000 ha centered on the Mt. Jackson area and extending into adjacent unallocated crown land and conservation reserves. Predator monitoring occurs within the baited area and in adjacent nonbaited sites. Results to date show a major impact of baiting on the abundance of predators, followed by a gradual recovery in predator numbers between baiting events. Of key interest is the effect of baiting over a number of years, that is, whether there occurs a long-term decline in feral predator numbers and a resultant sustainable recovery of the vulnerable native fauna. Hence, a critical aspect of the program is its long-term nature, and this program is continuing beyond the initial 3-year term of the joint project.

The joint project also funded a population viability analysis of the malleefowl by the University of Melbourne (Bode and Brennan 2011). This work has provided important information about how management efforts can best be applied to protect the long-term viability of malleefowl populations. The study concluded that measures to protect adult birds in particular are the most effective way to preserve

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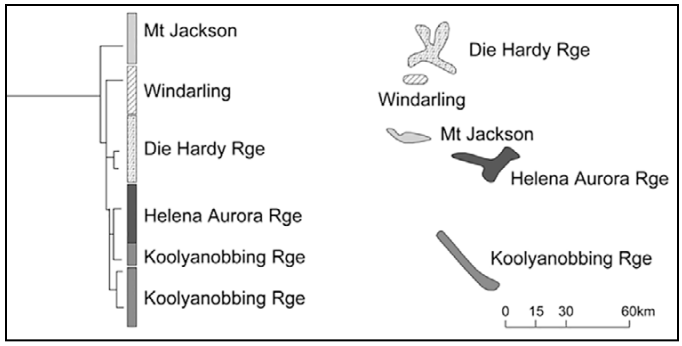


Figure 8.11 Phylogenetic tree for populations of *Atelomastix bamfordi* associated with five spatially separate BIF ranges in the project area. The approximate spatial separation of the ranges is depicted at right.

local populations. The work has reinforced the value of current efforts to protect mature birds, such as the application of speed limits on roads through known malleefowl habitat and regular baiting programs to control feral predators.

CONCLUSIONS

The Cliffs–DEC Northern Yilgarn project represented a significant financial investment by Cliffs, but one that has clearly brought significant benefits, including the following:

- Important new data on the regional distribution and abundance of flora and fauna species of conservation significance. The data are valuable to the company as well as the state in terms of its contribution to improved decision-making around conservation, assessment, and the permitting of future mine developments.
- Career and employment pathways for local Indigenous people in the land management area and development of a new training partnership model.
- Enhanced communication and relationships between Cliffs and the DEC. The DEC is the state environmental regulatory agency and also has responsibility for the management of conservation reserves.
- An effective vehicle for addressing wildfire threats. Where previously there was little understanding of the threats posed by fire, there is now a fire mitigation plan in place underpinned by sound science.

In recognition of the continuing value to the company and the government, at the end of its initial 3-year term the project was extended into a second phase. The project has proven highly successful in meeting its aims and is widely recognized as a successful model for collaboration between industry and government. Importantly, the project is a tangible application of Cliffs' sustainability strategy.

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CHAPTER 9

Spider Conservation and Mining*

Paul L. West, Robert K. Howard, Michael J. Bamford, and John Nielsen

BACKGROUND

The Yilgarn region in Western Australia has notable biodiversity and wilderness value and is receiving increasing attention for its global significance (Watson et al. 2008). The banded iron formation (BIF) ranges in the Yilgarn region are also recognized for their significant biodiversity value (DEC 2007). BIF ranges of the Yilgarn are isolated, ancient ranges set in a predominantly flat landscape that provide unique habitat for flora and fauna due to their different geology, soils, and landform (DEC 2007).

These features are scattered across the region, forming "islands" of biodiversity where the vegetation often contains groupings and species that differ from one range to the next. This situation is thought to arise from the spatial separation of these ranges, resulting in the isolation and divergence of populations over millions of years of geological stability. This view is supported by the large number of rare and geographically restricted flora species and assemblages found on BIF ranges. The ranges also support short-range endemic (SRE) fauna, primarily invertebrate species, with highly restricted spatial distributions. SRE fauna are in part characterized by poor dispersal capabilities, confinement to disjunct habitats, and low fecundity (Harvey 2002; Ponder and Colgan 2002).

In addition to significant biological values, these formations contain significant iron ore deposits and gold mineralization. Despite the geological potential of the area, the iron ore industry in the Yilgarn region is small with only two iron ore operations present.

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Cliffs Asia Pacific Iron Ore Pty Ltd. (Cliffs) operates the Koolyanobbing Iron Ore Project in the central Yilgarn region. The Koolyanobbing Iron Ore Project includes the mining of iron ore deposits in BIFs on the Mt. Jackson Range, Windarling Range, and the Koolyanobbing Range.

In 2007, a series of biological surveys were undertaken to assess the impacts of development projects on the fauna of Mt. Jackson, Windarling, and Koolyanobbing ranges. During these surveys, the tree-stem trapdoor spider *Aganippe castellum* (Main 1986) was identified. At the time, the spider was considered to be rare and was listed under Schedule 1 of Western Australia's Wildlife Conservation Act 1950. Schedule 1 fauna are considered rare or likely to become extinct. The spider was also considered to be an SRE as it was only known from a few small areas in the central Western Australian Wheatbelt (BCE 2008a).

AGANIPPE CASTELLUM

A. castellum (Figure 9.1) belongs to the mygalomorph group, which is commonly referred to as "trapdoor" or "funnel web" spiders (Main 1986). Mygalomorphae spiders are ambush predators that strike their prey close to their burrow entrance. They can live for up to 25 years, with some adults not reaching sexual maturity until they are about 6 years old (Raven 1985). Their burrows, which may extend as much as 50 cm into the ground, provide protection from predators and desiccation in hot, dry environments.

A. castellum forms a burrow with a hinged-lid covering (Figure 9.2) and lives most of its life underground. The burrow extends from the ground as a tube up the base of small shrubs and trees to a height of approximately 7 cm. There is a large fan constructed of twigs at the rim of the tube that hangs down. This fan has lines of silk attached that the spider uses as sensors, alerting the spider when potential prey touches the fan.

Until recently, *A. castellum* was known only from Western Australian populations distributed across the northeastern Wheatbelt from south of Mullewa and Dowerin to east of Tammin and Southern Cross. Most of the populations at the time were restricted to undisturbed areas either on nature reserves, road verges, or private property and were assessed as being in decline (Russell 2006). According to Russell (2006), in 2005, there were only 12 known populations of *A. castellum*, ranging in size from 6 to approximately 190 individuals. Following survey work performed on behalf of Cliffs in 2007, new populations of *A. castellum* were recorded in the Yilgarn region on the Mt. Jackson, Windarling, and the Koolyanobbing ranges (BCE 2007a, 2007b; BES 2009).

FIELD SURVEYS

Intensive surveys were undertaken to elucidate the abundance and distribution of *A. castellum* on Mt. Jackson Range (BCE 2009a; BES 2009) and Koolyanobbing

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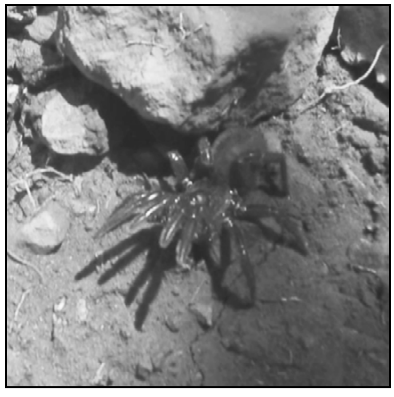


Figure 9.1 *A. castellum* specimen collected at Koolyanobbing Range

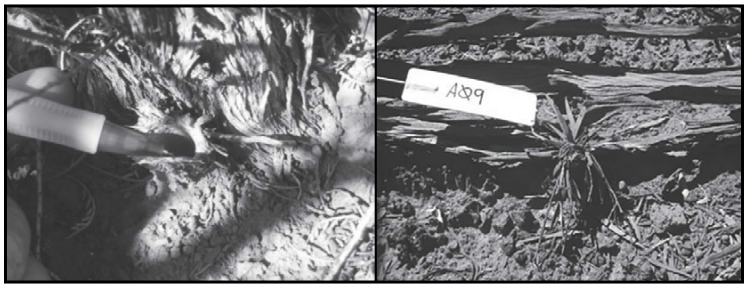


Figure 9.2 Camouflaged burrows with hinged lid of *A. castellum*

Range (BCE 2007a, 2008b, 2009b) so as to assess the impacts new mining developments may have on these populations. Less intensive regional surveys were also undertaken to develop a greater understanding of the distribution of this species across BIF ranges within the Yilgarn region (Cliffs 2009; Figure 9.3).

When undertaking field surveys, the elasticity of the lid's hinge was used to classify the burrow as active or inactive, with active burrows possessing a lid hinge that was recently maintained. Active burrows were of most interest during surveys as they were considered more likely to contain a resident spider.

Mt. Jackson Range

Intensive surveys of *A. castellum* were carried out on Mt. Jackson Range between 2007 and 2009 (BCE 2007b, 2008b, 2009a; BES 2009). The survey methods included searching extensively for *A. castellum* burrows in 10 m × 10 m quadrats spaced at 50-m or 100-m intervals along transects orientated perpendicular to the range. The transects were arranged to cross the landscape, and covered ridge, slope, and plains environments.

The *A. castellum* population on Mt. Jackson Range occurred in an almost continuous distribution along the range. It exhibited a preference for constructing burrows on gravelly loam soils of the hill slopes in *Acacia* and/or *Allocasuarina*

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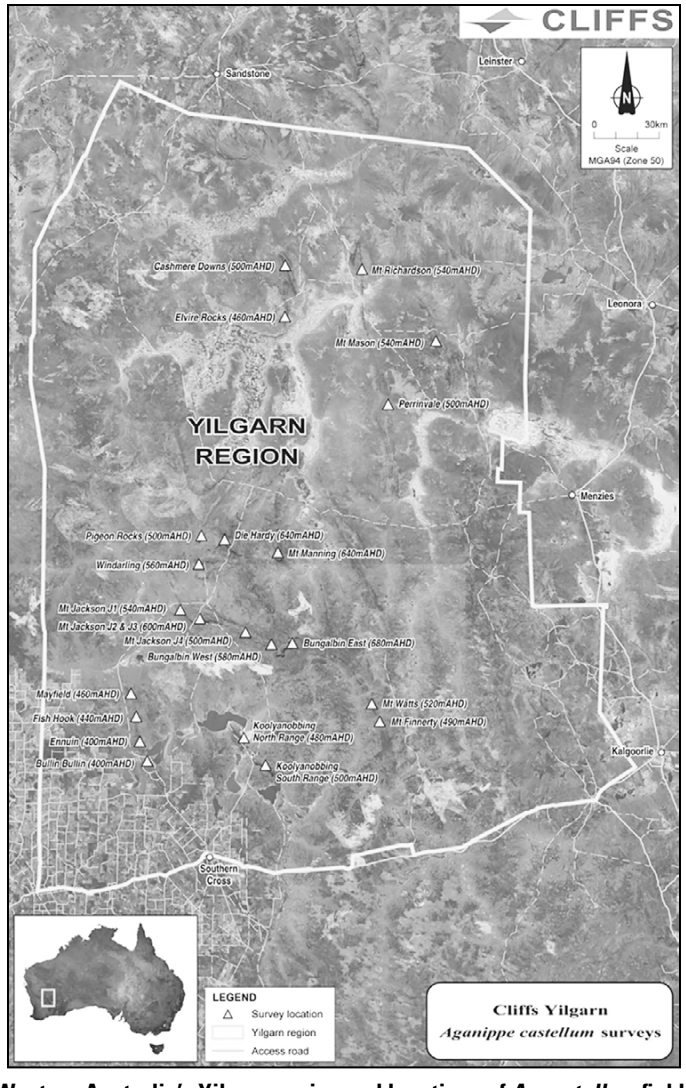


Figure 9.3 Western Australia's Yilgarn region and locations of *A. castellum* field surveys

shrubland. Burrows were mostly against live plants (notably species of epacrid and members of the genus *Philotheca*) between 50 and 150 cm in height. The spiders did not appear to exhibit a preference regarding which side of the host plant the burrow was located. Burrow widths ranged between 5 and 23 mm and showed a bimodal frequency distribution, which was suggestive of at least two size/age classes.

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Koolyanobbing Range

The average density of active burrows was estimated to be 79.4 per hectare. The total area of inferred spider habitat, based on soils, vegetation, and position in the landscape, was estimated to be more than 2,520 ha. The total population size, based on the average density of occupied burrows and the size of inferred spider habitat, was estimated to be more than 200,000 occupied burrows across the range.

The presence of *A. castellum* on the Koolyanobbing Range was identified during a general survey of the range conducted in August 2007 by BCE (2007a). Further surveys were conducted throughout 2008, that is, February and March (BCE 2008a) and December (BCE 2009b). As for Mt. Jackson, the survey methods included searching extensively for *A. castellum* burrows in 10 m × 10 m quadrats spaced at 50-m or 100-m intervals along transects orientated perpendicular to the range. The transects were arranged to cross the landscape and covered ridge, slope, and plains environments. The purpose of these surveys was to improve population estimates of *A. castellum*, delineate their habitat on the range, and determine potential impacts of Cliffs' development projects on the Koolyanobbing Range population.

Burrows were found to be distributed over a wide variety of soil types that comprised various combinations of gravel, loam, clay, and larger cobbles and rocks. The majority of burrows occurred on gravelly loam soils. Burrows were also distributed across a wide variety of vegetation types comprising *Acacia* shrublands and thickets, *Allocasuarina* shrubland, and *Eucalyptus* and mixed shrublands. Across these vegetation types, *A. castellum* burrows were found to be attached to a wide variety of plant taxa, including *Acacia*, *Allocasuarina*, *Atriplex*, *Dodonea*, *Eremophila*, *Grevillea*, *Hibbertia*, *Leucopogon*, *Olearia*, *Philotheca*, *Ptilotus*, *Scaevola* and *Senna*.

The *A. castellum* population was dominated by small and medium-sized spiders (Figure 9.4) indicative of a population that is actively breeding and recruiting. The low numbers of very small spiders (internal diameter <8 mm) were considered to be a sampling artifact because these burrows are small and difficult to find and therefore probably under-sampled (BCE 2008a). Very large burrows (>15 mm), however, should be easy to find, so the low proportion of large burrows was almost certainly real. These large burrows probably represented adult females that may be up to 25–30 years old. The medium-sized burrows (10–15 mm) were thought to be predominantly adult males. Adult males are believed to breed only once, so the high annual mortality of adult males would explain the skewed size/age structure.

Where suitable habitat was present, small and large active burrows were identified within 20 m of the edge of a large pit that has been mined over many decades. Based on the location of these burrows, it appears that noise and vibration do not deter the spider from remaining within or establishing new burrows immediately adjacent to active mine pits.

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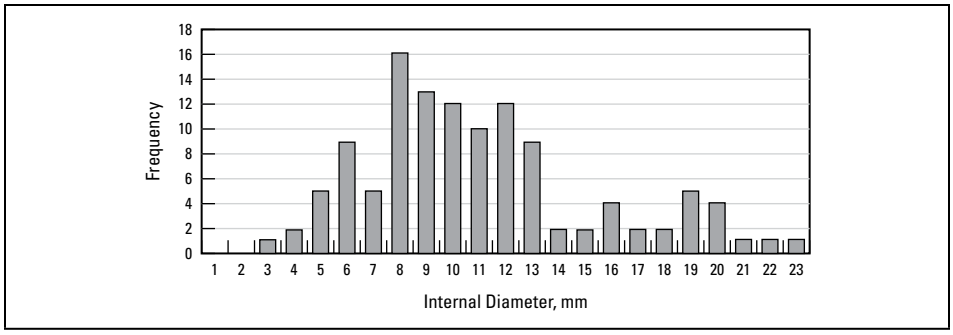


Figure 9.4 Size–frequency distribution of *A. castellum* burrows measured in March 2008 based on lumen diameter (age is directly proportional to lumen diameter)

The area of favorable *A. castellum* habitat on the central and southern Koolyanobbing Range was estimated to be ~602 ha. The average density of active burrows was estimated to be 73.8 per hectare. At an average estimated density of 73.8 active burrows per hectare, and habitat size of 602 ha, the total population across the central and southern Koolyanobbing Range was estimated to be >44,000 active burrows. This population size was considered to be a conservative estimate (BCE 2009a) because burrows are cryptic and therefore difficult to find (i.e., not all burrows present may have been detected). Suitable *A. castellum* habitat was found to be continuous along the central and southern Koolyanobbing Range, supporting the viewpoint that the population would be genetically linked; that is, genetic variations along the ridge, if present, would be gradual rather than there being genetically distinct populations.

Helena and Aurora Range

The Helena and Aurora Range was surveyed in May 2009. The survey included hills occurring between Mt. Jackson Range and the Helena and Aurora Range to determine whether spider populations were distributed somewhat continuously across these areas. The intensive survey was carried out by searching opportunistically along transects and using 10 m × 10 m quadrats.

Burrows were not confined to the higher slopes associated with the Helena and Aurora Range and were found to be distributed across the landscape (BCE 2009c). In contrast to previous studies at Mt. Jackson and Koolyanobbing, spiders were found on the surrounding plains, which is likely to reflect the presence of suitable vegetation and soil in the plains surrounding the Helena and Aurora Range. In the hills west of the Helena and Aurora Range, a total of 70 quadrats were searched and 16 active (and 21 inactive) burrows found. Burrows were in greatest density on the lower slopes and plain (75 and 65 burrows/ha, respectively), but also occurred mid-slope and on the crest. Based on the observations that *A. castellum* burrows

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occur outside of the ranges, it is reasonable to expect this species to occur within similar habitat through to Koolyanobbing, approximately 60 km away.

Of particular interest is that some of the highest densities were observed on or adjacent to old exploration survey tracks. Two burrows also occurred on a revegetated waste-rock landform. These observations suggest that *A. castellum* is readily adaptable to disturbed landscapes. The observed distribution of *A. castellum* burrows at the base of eucalyptus trees, rocks, spoil heaps, and within clumps of grass indicate that, although densities may vary depending on habitat type, *A. castellum* is capable of inhabiting much of the Helena and Aurora Range and surrounding hills.

Die Hardy Range

The Die Hardy Range was surveyed in May 2009 and confirmed the presence of *A. castellum* burrows. The survey was carried out by walking survey transects to record burrows opportunistically. Ten burrows were detected during 15 hours of surveying.

Mt. Manning

Mt. Manning was surveyed in May 2009. The survey involved walking transects equaling approximately 6 km. No *A. castellum* burrows were recorded within the Mt. Manning area, which may indicate that Mt. Manning is beyond the limit of its distribution.

SUMMARY OF FIELD SURVEYS

Results of surveys undertaken in 2009 identified that *A. castellum* is wide ranging in distribution and occupies a variety of habitats. The surveys demonstrated that the spider occurred in large numbers on several ranges. Population estimates based on the survey results have conservatively identified that 250,000 spiders reside across the Koolyanobbing and Mt. Jackson ranges. The regional surveys demonstrated that the spider resides throughout the greater Koolyanobbing region at Windarling, Helena and Aurora Range and adjacent rises, Koolyanobbing North, the Die Hardy Ranges and adjacent rises. The spider burrow density was relatively high wherever preferable habitat was identified, such as in the Koolyanobbing and Mt. Jackson ranges. In addition to establishing burrows within undisturbed areas, given the observations of burrows on old exploration survey tracks, *A. castellum* is also capable of being a colonizer, moving into previously disturbed areas where suitable vegetation occurs.

GENETICS STUDIES

The identification of the trapdoor spider recorded throughout the Yilgarn region as the Schedule 1 listed species *A. castellum* had been based on the burrow structure

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and the general morphology of a limited number of female spiders. The identification of spider species through burrow structure is an accepted and nondestructive means by which trapdoor species can be identified. However, there was uncertainty as to whether the trapdoor spiders recorded at the Mt. Jackson Range, Windarling Range, and Koolyanobbing Range were in fact *A. castellum* (or a subspecies) or, alternatively, a different species with similar characteristics. Accordingly, a study was undertaken to determine whether the populations at the Mt. Jackson, Koolyanobbing, and Helena and Aurora ranges were the same species as the type *A. castellum* population and, if so, to determine the genetic variation across these populations.

A. castellum individuals (identified on the basis of burrow morphology) were collected from Mt. Jackson Range, Koolyanobbing Range, Helena and Aurora Range, Merredin (164 km SW of Mt. Jackson), Kwelken (150 km SW of Mt. Jackson), Heitmans (200 km SW of Mt. Jackson), and Depot (176 km SW of Mt. Jackson). The latter four Wheatbelt sites are all in a 140-km arc of the type locality near Minnivale and the closest, Heitmans, is less than 50 km away from the type locality.

A bootstrapped neighbor-joining tree and distance matrix was analyzed to identify the relationships among the samples (Helix 2009). This neighbor-joining tree clearly grouped all specimens of *A. castellum* in a well-supported clade, or group that shares one common ancestor, with average genetic distances among specimens in the order of 3%–4%. The interpretation of the data identified that specimens from Mt. Jackson, Helena and Aurora, and Koolyanobbing ranges were the same species as those collected from the Wheatbelt sites. The data suggests some pattern of isolation by distance, that is, populations closer together are most closely related; however, it did not appear that there was a major geographic barrier to gene flow. The distribution of *A. castellum*, confirmed to extend from the type locality at Minnivale (central Wheatbelt) through to Mt. Jackson Range in the northeast and Koolyanobbing in the southeast, means that it did not fit into the definition of an SRE species.

SPIDER TRANSLOCATION

In 2008, Cliffs obtained approval to expand its Koolyanobbing operation, which involved impacting *A. castellum* and its habitat. One of the management measures proposed by Cliffs was to relocate the impacted spiders to a nearby area.

Following an intense pre-impact survey of the inferred *A. castellum* habitat, 38 burrows were identified, of which 19 were considered active and therefore excavated (Figures 9.5 and 9.6). Of the 13 individuals recovered, 1 died during excavation and 12 were relocated to a translocation pen in a similar habitat outside the impact area.

The translocation pen consisted of a host plant, an artificial burrow, and a plastic tree guard encircling a radius of 500 mm (Figures 9.7 and 9.8). Artificial

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Figure 9.5 Excavated *A. castellum*



Figure 9.6 Excavated burrow with spider still in base of burrow chamber



Figure 9.7 Constructing an artificial burrow



Figure 9.8 Established translocation pen

burrows were constructed by driving a metal rod of a similar diameter as the original burrow into the ground, to a depth of approximately 20 cm, depending on soil conditions. During the construction of the artificial burrow, while the metal rod was in place, the rod and the ground were then doused with potable water to help stabilize the walls of the burrow and increase the soil humidity in the burrow. The spider was released into the artificial burrow soon after construction.

During December 2008 and January 19, 2009, each translocation pen was regularly monitored for spider activity. Of the 12 individual *A. castellum* translocated, 2 died and 5 showed signs of activity (Figures 9.9 and 9.10), ranging from lining the burrows with web to the construction of trapdoor lids. The remaining five spiders showed no signs of activity during the monitoring period, and the fate of each of these spiders is unknown.

The translocation of *A. castellum* had not previously been attempted. Prior to the 2008 translocation program, the approach to addressing the issue of rare spiders

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Figure 9.9 Signs of residency with web lining within artificial burrow after 3 days



Figure 9.10 Same burrow after 18 days, with burrow lid fully formed

existing within proposal footprints exclusively focused on minimizing impacts or undertaking further species research. With further refinement, the ability to translocate trapdoor spiders could provide proponents with another method of mitigating project-related impacts on these types of sedentary spiders.

CONSERVATION STATUS REVIEW

A. castellum was listed as Specially Protected Fauna (Schedule 1) under Western Australia's Wildlife Conservation Act 1950 and was ranked as "endangered" according to the International Union for Conservation of Nature due to its perceived limited and fragmented distribution across the extensively cleared agricultural region of Western Australia. In light of the increased understanding of the abundance of the species and its distribution across the Yilgarn, it was considered that *A. castellum* was not as rare or as threatened with extinction as previously believed and, therefore, did not warrant Schedule 1 listing under the Wildlife Conservation Act 1950.

Following the substantial amount of field and genetic work undertaken on the spider by Cliffs between 2007 and 2009, in March 2010, Cliffs submitted a nomination form to the Department of Environment and Conservation (DEC) to remove *A. castellum* from the Specially Protected Fauna list of Western Australia's Wildlife Conservation Act 1950. Following a recommendation from the Western Australian Threatened Species Scientific Committee, in August 2010, the Western Australia Minister for the Environment approved the removal of *A. castellum* from Western Australia's Specially Protected Fauna list. This is believed to be the first time a spider species had been removed from the list.

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CONCLUSION

In the Yilgarn region, despite it being recognized as supporting high biodiversity, very little information is available on the distribution of invertebrates. Where projects may impact fauna that are considered to be rare or endangered, effort should be made by proponents to determine whether the species of concern is in fact rare or just poorly understood. Projects that impact species that are no longer rare or endangered are more likely to be approved and have reduced monitoring obligations.

When *A. castellum* was first identified within proposed mining development areas, very little information was known about this cryptic species. Cliffs invested significant resources into conducting field surveys, genetic studies, and relocation programs to assist in better understanding the ecology of this spider. The work demonstrated that this species was wide ranging, occurred within a number of habitats, and was not uncommon throughout the Yilgarn region. The surveys also assisted in ensuring that an appropriate conservation classification was assigned. The allocation of the correct conservation status allows DEC and Cliffs to focus its limited resources into other programs that conserve and protect the biodiversity of the region.

ACKNOWLEDGMENTS

The authors thank Wes Bancroft, Ian Harris, Natalia Huang, Pete and Sarah Smith, Mike Walters, Roy Teale, Michael Greenham, Timothy Duff, Daniel Martin, Elaine Kraft, Michelle North, and Nicole Harry for the many hours in the field spent searching for and monitoring *A. castellum*; Stuart Hawkins from Globe Environments for assisting in developing the conservation review strategy; Terrie Finston from Helix Molecular Solutions for performing the genetic studies; Mark Harvey for providing guidance throughout the project; and the staff at Cliffs Natural Resources' Koolyanobbing Iron Ore Project and the Western Australian Government Department of Environment and Conservation.

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CHAPTER 10

Biodiversity Management and Mining in the San Bernardino Mountains

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INTRODUCTION

In the wake of increased land development for renewable energy, minerals, power distribution, road construction, and urban expansion, resource managers are now focusing on the assessment of biodiversity impacts on a regional scale. This approach is particularly important for species that function as a *metapopulation*, wherein a collection of discrete local populations interact as an integrated whole in a source–sink dynamic (Levins 1969). Traditional approaches to conservation, such as "like-for-like" land swaps based on static compensation ratios, may not necessarily result in the best land-use decisions from a biodiversity perspective. Mitigation lands may, in fact, be of lower habitat quality than those impacted by development. *Biodiversity offsets*, on the other hand, are designed to conserve areas of higher biodiversity value than those being lost (Ten Kate et al. 2004). In 2003, the International Council on Mining and Metals (ICMM) and the International Union for Conservation of Nature (IUCN) engaged in a dialogue to explore the social, environmental, and economic benefits of biodiversity offsets. That working group identified five challenges and areas of uncertainty to adopt as conservation measures (ICMM 2005):

1. Measuring impacts and establishing appropriate baselines that include background biodiversity change;
2. How to devise appropriate offsets that are acceptable and link to business impacts on biodiversity ensuring comparability and the use of a common currency;

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3. Issues of time, scale, and equity (i.e., when to deliver offsets in a project cycle, how far away from the project to devise them, and equitable distribution of the associated costs and benefits);
4. Whom to involve in decisions on offsets, who ultimately decides, and what role government plays;
5. How to ensure offsets are appropriately managed and are financially and ecologically sustainable.

Furthermore, traditional approaches to land-use planning on a project-by-project basis often result in creating isolated and overly fragmented areas of conservation. In contrast, *regional habitat conservation plans* that account for the cumulative impacts of land development over time are gaining popularity as a more holistic approach to biodiversity management. Two multi-stakeholder and cross-jurisdictional initiatives in Southern California have developed workable solutions to some of the issues first identified with implementing these two emerging practices.

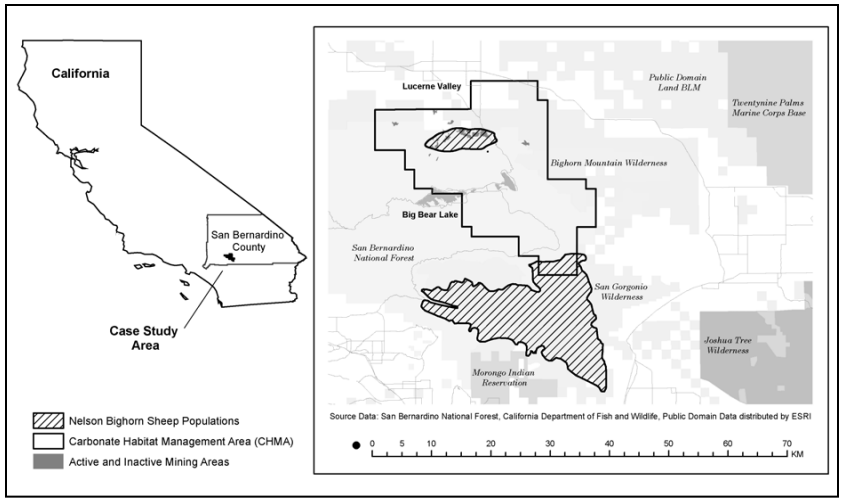
Case Study Area

The north slopes of the San Bernardino Mountains in Southern California, the area of focus for this case study, form a nexus of unique geological, ecological, and cultural significance. The San Bernardino Mountains support a high concentration of botanical rarity and endemism with numerous plant species that occur nowhere else in the world (S. Eliason, personal communication). The complex geological environment created by the orogenesis of this mountain range has allowed for the formation of extremely uncommon limestone deposits that represent the largest producing district of high-brightness, high-purity limestone in North America (Brown 2008). These limestone deposits are located between two communities, the high-desert agricultural community of Lucerne Valley to the north and the four-season mountain resort communities surrounding Big Bear Lake to the south (Figure 10.1).

Geological and Ecological Context

The San Bernardino Mountains are part of the Tranverse Ranges that form a barrier separating the Mojave Desert from the Pacific Coast. The San Bernardino Mountains support approximately 2,000 plant species. These represent nearly one-third of the total number of species in California, occurring on less than 1% of the total area of the state (S. Eliason, personal communication). The north slopes of the San Bernardino Mountains rest in a highly biodiverse ecological transitional zone, from pinyon-juniper woodland to mixed desert and blackbrush scrub. These same slopes also host commercially viable limestone deposits that extend for approximately 24 miles. While carbonate rocks are common on all continents, the geological history of the San Bernardino Mountains has allowed the formation

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Courtesy of Onyx Mining Services.

Figure 10.1 Case study area

of uncommon high-brightness, high-purity limestones (Brown 2008), referred to locally as *white gold*. Brown notes that the formation of these rare deposits is dependent on the combination of several independent geologic processes over a significant period of time, including

- Deposition of originally pure limestone in shallow, high-energy marine environments;
- Post-depositional changes, including metamorphism and magmatic processes that disperse impurities and recrystallize the rock;
- Structural controls including folding, faulting, and orogenic processes to place the rocks in desirable structural settings; and
- Uplift, erosion, and preservation through geologic time.

The orogenesis of the mountain range results in steep topographical relief, an important habitat requirement for mountain sheep. The study area includes stable bedrock slopes, rocky talus slopes, desert washes, and alluvial deposits—each providing suitable micro-habitats for four federally listed plant species that occur almost exclusively on the carbonate soils.

Cultural and Economic Context

Beginning with the first peoples inhabiting the area more than 2,500 years ago, the San Bernardino Mountains and High Desert have witnessed a history of transitional land use and cultural change. The first inhabitants were the *Serrano*, translated from Spanish as "highlander" or "mountaineer." They believed that their

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Creator, Kruktat, formed the Serrano people from the clay soils of Big Bear Valley. Upon his death, his funeral pyre burned so hot that it left behind the barren red talus slopes of Gold Mountain, and from his ashes sprang all the diverse wildflowers of the mountains (Krantz 1990).

In 1860, William Holcomb discovered gold in the San Bernardino Mountains, precipitating the largest gold rush in Southern California (U.S. Forest Service 1999). Just one year later, John Cushenbury discovered silver in the limestone deposits along the north slopes of the San Bernardino Mountains. Gold and precious metal discoveries would continue until the 1950s, when it was realized that the limestone rocks hosting the precious metals had considerable value themselves. Kaiser Steel Company soon developed the area for flux stone to feed the steel plants of Fontana and quarried the adjacent canyons for cement throughout the 1980s, until ownership shifted to Pfizer and Pluess Staufer, two specialty limestone producers. The lands controlled by those three progenitor companies have now transferred to the current operators: Mitsubishi Cement Corporation, Minerals Technologies Inc. (MTI), and Omya Inc. The district remains an important supplier of cement-grade limestone and specialty high-bright limestone that is used in paint, paper, plastics, glass, and other manufacturing products.

THE CARBONATE HABITAT MANAGEMENT STRATEGY

The San Bernardino National Forest has one of the highest concentrations of threatened and endangered (T&E) plants in the world, with a total of 18 T&E plant species protected under the Endangered Species Act of 1973 (ESA). In 1994, five plant species associated with the carbonate geology of the San Bernardino Mountains and Lucerne Valley were listed as threatened or endangered under the federal ESA. Four of these species occur almost exclusively on some of the purest economically viable limestone deposits in North America: Cushenbury buckwheat (*Eriogonum ovalifolium* var. *vineum*), Cushenbury milkvetch (*Astragalus albens*), Cushenbury oxytheca (*Oxytheca parishii* var. *goodmaniana*), and Parish's daisy (*Erigeron parishii*). In 1999, a multi-stakeholder process among government, non-profit organizations, and the private sector resulted in the development of a habitat management plan that balances regional economic needs against critical habitat conservation. This effort, known as the Carbonate Habitat Management Strategy (CHMS), was completed in 2003 and guides the permit approval of future mining expansions. The efficient regulatory scheme serves to streamline compliance with the ESA while building a habitat reserve over time.

Natural History of the Carbonate Endemics

The rich biodiversity in the region, first recognized by the Serranos, was later documented in the 1880s by naturalists during the height of the Holcomb Valley Gold Rush, including the first accounts of the carbonate endemics. Cushenbury

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buckwheat (*E. ovalifolium*) was first collected by the naturalist S.B. Parish in 1894, near the Rose mine south of Big Bear Lake. It is a mound-forming shrub typically found on rocky talus slopes, along cracks in bedrocks and stable bedrock slopes. Cushenbury milkvetch (*A. albens*) was first collected by Parish and Parish in 1885. It occupies areas with an open canopy, less litter accumulation, and shallower slope angles than other carbonate sites that do not support these plants (Gonella and Neel 1995). Parish's daisy (*E. parishii*) is an herbaceous perennial first collected at Cushenbury Springs in 1881 by S.B. Parish. It is commonly found along washes, loose alluvial deposits, and steep rocky slopes. Cushenbury oxytheca (*O. parishii*) is an annual; little has been published on this species as it did not become a subject of study until the cumulative impacts of limestone mining on the other carbonate endemics became a conservation focus. It is found on steep, dry calcareous slopes, mostly in loose scree and talus derived from limestone (Hickman 1993). These steeper slopes present an ecological advantage, because potentially competitive species like trees and shrubs have a difficult time establishing themselves in this environment.

Strategy Overview

Due to the historical and ongoing regional importance of the area's limestone mining and construction industry, it was soon recognized that in the absence of an integrated strategy to preserve the carbonate plants, the cumulative impacts of mining activity over time would come into direct conflict with the ESA (Olson 2003). In 1999, a working group comprised of resource management agencies, private mining interests, and representatives of the conservation community began a constructive dialogue to resolve this conflict (Table 10.1). In a series of consultations and collaborative dialogues over the next 5 years, a regional strategy was

Table 10.1 Carbonate Habitat Management Strategy working group

Resource management agencies	Bureau of Land Management California Desert District County of San Bernardino U.S. Fish and Wildlife Service San Bernardino National Forest
Mining and private land interests	Mitsubishi Cement Corporation Minerals Technologies Inc. OMYA Inc. Sentinel Mining Butterfield family Cushenbury Mine Trust Gresham, Savage, Nolan & Tilden, LLP McKay & McKay
Conservation community	California Native Plant Society White & Leatherman BioServices

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developed to "facilitate economic limestone mining activity while conserving the Carbonate Plants under a sensible and efficient regulatory regime" (Olson 2003).

As summarized in Table 10.2, the management framework of the CHMS balances the economic, conservation, and regulatory objectives of the participating stakeholders. This management plan is not mandatory; it is a voluntary program in which each stakeholder may elect to participate and meet its respective objectives. Mining interests obtain more regulatory certainty by making voluntary contributions to the habitat reserve. Resource management agencies granting the project approvals meet their obligations under Section 7 of the ESA, and in so doing resolve any existing or future litigation against them. By issuing a favorable programmatic biological opinion for the overall strategy, the United States Fish and Wildlife Service (USFWS) increases the certainty that a permanent habitat reserve will be established to meet the survival and recovery needs of the carbonate plants.

The Carbonate Habitat Management Area (CHMA) includes 160,000 acres of public and private land, divided into five administrative units, as illustrated in Figure 10.2. As summarized in Table 10.3, lands within the CHMA are assigned to one of three primary land-use categories: mining lands, conservation uses, and uncommitted lands. The CHMS systematically allows for certain lands to be added to the mining category, so long as sufficient lands are being contributed to the habitat reserve for permanent conservation (Olson 2003). Based on exhaustive field mapping and a matrix of land-use designations and multipliers, a Conservation Value is assigned to all lands within the management area. The initial habitat reserve sets aside a total of 19,264 acres of permanently preserved habitat, representing 30% of the total Conservation Value contained in the CHMA. Although fragmented, this initial habitat reserve provides a "solid base of conservation" upon which to build the habitat reserve with additional contributions over time (Olson 2003).

An overview of the CHMS identifying the respective roles, objectives, and basic transactions of the participants is illustrated in Figure 10.3. Various mechanisms to establish this initial habitat reserve are identified under the framework. Federal contributions to the habitat reserve can take the form of federal designations, federal purchase, or land exchanges. Mining interests participating in the CHMS are afforded a streamlined path to ESA compliance, as summarized in Table 10.4. Private parties (landowners or claim holders) receive Conservation Credits that may be used directly for compliance with the ESA or may be held for future use or sale to another private party at a price the current market will bear (Olson 2003). Upon submission of the required Conservation Credits, signatories to the CHMS memorandum of understanding (MOU) will receive a concurrence letter from the U.S. Forest Service documenting that the project has satisfied the requirements of the ESA. All credits are tracked in the Credit Registry, a database managed by the U.S. Forest Service that is inclusive of all records and legal documents related to the transactions authorized under the CHMS.

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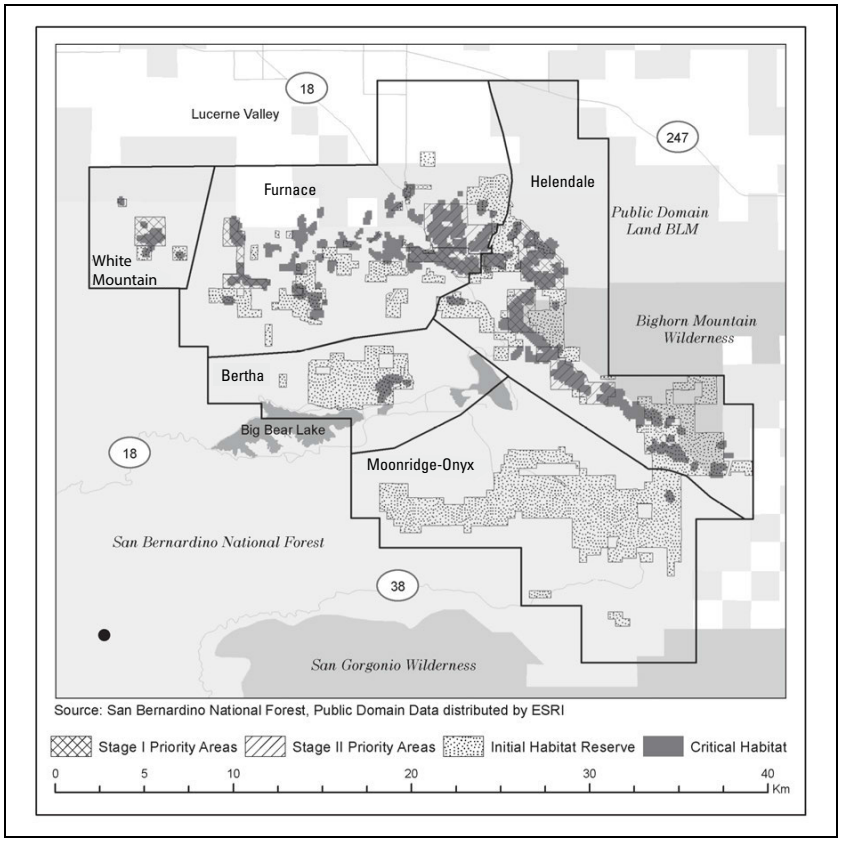
Table 10.2 Carbonate Habitat Management Strategy goals and objectives

Goal: Facilitate economic limestone mining activity while conserving the carbonate plants under a sensible and efficient regulatory regime.

Economic Objectives	Conservation Objectives	Regulatory Objectives
1. To increase the regulatory certainty that the most valuable mineral deposits within the Carbonate Habitat Management Area (CHMA) may be mined in the future. 2. To protect the availability of limestone resources that are vital to the construction industry in the southwestern region of the United States. 3. To protect the viability of the mining-based economy of the northeastern San Bernardino Mountains and Lucerne Valley region. 4. To provide a definitive, streamlined process for future mining activities within the CHMA to comply with Endangered Species Act of 1973 (ESA) regulation of the carbonate plants. 5. To provide a framework for streamlining National Environmental Policy Act requirements for future mining activities. 6. To reduce the costs and time associated with county processing of mining-related land-use applications by providing a comprehensive approach to addressing impacts to the carbonate plants under the California Environmental Quality Act (CEQA). 7. To help avoid the need for future ESA listing of species that occur within the CHMA and to provide a process for addressing such listings if they are proposed to occur.	1. To maintain and manage the geomorphic and ecological processes of the landscape in large, well-placed blocks of habitat where the carbonate plants are found within the CHMA such that the carbonate plants are likely to persist indefinitely. 2. To avoid "jeopardy" to the continued existence of the carbonate plants (as defined in Section 7 of the ESA and its regulations). 3. To avoid "destruction or adverse modification" of critical habitat for the carbonate plants. 4. To contribute to the recovery and ultimate de-listing of the carbonate plants under the ESA. 5. To help avoid the need for future ESA listings of species that occur within the CHMA. 6. If other species that occur within the CHMA are listed under the ESA in the future, to avoid jeopardy to those species (as defined in Section 7 of the ESA and its regulations). 7. To provide a mechanism for tracking both the loss and conservation of habitat for the carbonate plants over time.	1. To streamline the application of the ESA to mining activities within the CHMA. 2. To provide a biological basis for addressing the carbonate plants in future federal land plans. 3. To streamline the County's CEQA review of the biological impacts of mining projects on private land within the CHMA. 4. To streamline the county's implementation of the California Surface Mining and Reclamation Act of 1975, as amended (SMARA) within the CHMA. 5. To provide a means for the Bureau of Land Management (BLM) to comply with certain stipulations with respect to the Carbonate Habitat Management Strategy in *Center for Biological Diversity vs. BLM*, Case No. C-00-0927 WHA (JCS) in the United States District Court, Northern District of California, San Francisco Division. 6. To provide a means for the U.S. Forest Service to comply with certain stipulations in *Southwest Center for Biological Diversity vs. Sprague*, Case No. C 98-2434 SC in the United States District Court, Northern District of California.

Source: Adapted from Olson 2003.

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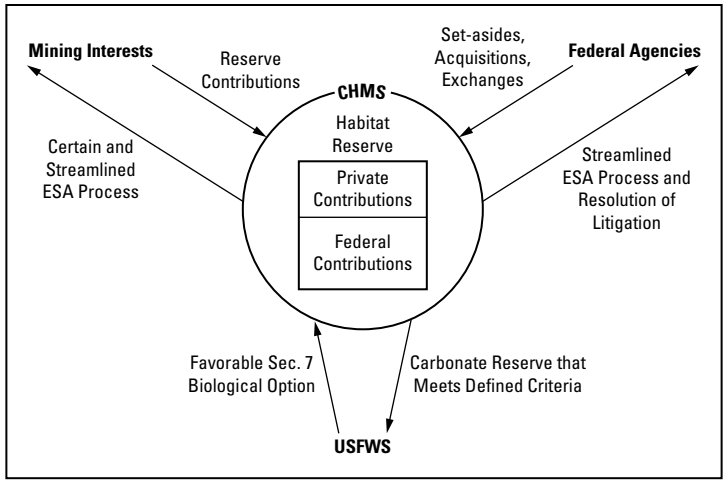
Figure 10.2 Critical plant habitat and administrative units of the Carbonate Habitat Management Area

Table 10.3 Land-use designations of the Carbonate Habitat Management Strategy

Mining Uses	
M1:	Approved under a mining plan
M2:	ESA compliant, not yet subject to a mining plan
F:	Auxiliary mining use (minor amount of land)
Conservation Uses	
E:	Established reserve (habitat reserve)
Uncommitted Lands	
D:	Default (federal)
P:	Private
X:	Transfer (federal lands earmarked for exchange)

Source: Olson 2003.

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Source: Olson 2003.

Figure 10.3 Overview of the Carbonate Habitat Management Strategy

Table 10.4 Streamlined ESA compliance process provided by the Carbonate Habitat Management Strategy

1. Calculate the number of Conservation Credits required to obtain ESA compliance for the project (3 × the Conservation Value of the land to be mined).
2. Obtain the required Conservation Credits by making Reserve Contributions or by purchasing Conservation Credits from another party.
3. Submit the required Conservation Credits and sign the CHMS memorandum of understanding.
4. The U.S. Forest Service then processes the paperwork and issues a concurrence letter to the applicant that serves as evidence the project has satisfied the requirements of the ESA.

Source: Adapted from Olson 2003.

Habitat Mitigation Based on Conservation Value

Traditional habitat mitigation ratios are based on calculations of raw acreage that may not necessarily result in the best results from a conservation perspective. In such cases, larger tracts of land accepted as mitigation for a project may be of lesser overall habitat quality for the target species of concern. Furthermore, mitigation lands are often geographically displaced from the point of disturbance. In contrast, the CHMS framework establishes Conservation Units that measure the Conservation Value of lands within the management area in terms of its ecological value to the survival and recovery of the carbonate plants. Based on exhaustive field mapping of the entire management area, each acre is assigned to one of four land parcel designations, as summarized here by Olson (2003):

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- *Occupied Habitat* represents land that is occupied by one or more of the carbonate plants. This land designation excludes Revegetated Habitat.
- *Suitable Habitat* represents land possessing habitat qualities necessary to support occurrences for one or more of the carbonate plants but is not currently occupied by any of the four listed species. These areas are considered important because they support many plant and animal species (including pollinators) that are associated with the carbonate plants.
- *Revegetated Habitat* represents mining land that has been revegetated, meeting all the requirements for obtaining Conservation Credit. The amount of Conservation Credit obtained for revegetated mine land varies depending on the revegetation success criteria that is met.
- *Other Beneficial Habitat* includes undisturbed natural land that provides some geomorphological, hydrological, or other habitat configuration of benefit to carbonate plants.

A multiplier is applied to each respective category wherein parcels with more biodiversity (i.e., with occurrences of more than one carbonate plant species per acre) are assigned a higher Conservation Value than unoccupied habitat or parcels occupied by only one sensitive species (Table 10.5). Likewise, disturbed lands that have been revegetated with the T&E species are assigned a Conservation Value that is a function of the success criteria established by the framework (Table 10.6). These land categories are tracked in a GIS database referred to as the Habitat Inventory which may be updated by the U.S. Forest Service as needed based on (a) more accurate survey information, (b) evidence of naturally occurring changes in environmental conditions or dispersal patterns, (c) successful revegetation of disturbed habitat, and (d) other contributions to the habitat reserve by participants in the CHMS (Olson 2003).

A Compensation Requirement Worksheet is completed by the project proponent to determine the conservation value of the lands proposed for disturbance (Table 10.7). Mitigation lands considered for contribution to the habitat reserve are then assessed using the Reserve Contribution Valuation Worksheet shown in Table 10.8. If there are multiple discontinuous land parcels, the respective worksheets are completed independently for each parcel to properly assess the *edge effects* of each conservation area. In general, parcels that share fewer edges where human activities could disrupt reserve function are of greater value to the species that it supports (Olson 2003). Therefore, as each worksheet and the following formulae illustrate, the CHMS evaluates the spatial configurations of land parcels by making Net Edge Adjustments based on the lineal mileage the parcels share with the permanently preserved areas. The final Adjusted Conservation Value (ACV) for each land parcel is therefore calculated as follows:

$$ACV_{\text{Reserve Contribution}} = CV - (\text{Net Edge Adjustment})$$

$$ACV_{\text{Mining Proposal}} = CV + (\text{Net Edge Adjustment})$$

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Table 10.5 Conservation value multipliers of the Carbonate Habitat Management Strategy

1.75 ×	Acres containing Occupied Habitat for *all four* carbonate plants
1.50 ×	Acres containing Occupied Habitat for *any three* of the carbonate plants
1.25 ×	Acres containing Occupied Habitat for *any two* of the carbonate plants
1.00 ×	Acres containing Occupied Habitat for *any one* of the carbonate plants
0.50 ×	Acres containing Suitable Habitat for any one or more of the carbonate plants
0.25–1.00 ×	Acres containing Revegetated Habitat (depending on the success criteria met)
0.25 ×	Acres containing Other Beneficial Habitat
0.00 ×	All other acres (containing no habitat benefitting the carbonate plants)

Source: Olson 2003.

Table 10.6 Conservation value multipliers for Revegetated Habitat

A conservation multiplier of between 0.25 and 1.00 per acre will apply to Revegetated Habitat as follows:

- 0.25 per acre of Revegetated Habitat without carbonate plants
- 0.50 per acre of Revegetated Habitat with at least one carbonate plant species
- An additional 0.20 per acre of Revegetated Habitat that meets *enhanced* success criteria
- An additional 0.10 per acre for each additional carbonate plant species occurring (for an addition to the multiplier of up to 0.30 per acre)

Source: Olson 2003.

where CV, expressed in terms of Conservation Units, is the baseline Conservation Value calculated using the respective multipliers specified in Tables 10.5 and 10.6. The CHMS then creates Conservation Credits that serve as a *common currency* given to private parties in exchange for Reserve Contributions to the habitat reserve. A Conservation Credit represents one unit of Conservation Value (Olson 2003).

Mine Revegetation with the Carbonate Endemics

The magnitude of the conservation value multipliers applied to revegetated habitat is a function of the occurrences of carbonate plants as well as other success criteria. Baseline reference data was generated for each "vegetation zone" based on sampling data generated across more than 600 sampling plots between 1990 and 1998. The target vegetation and success criteria for each revegetation site are based on the reference data for the appropriate vegetation zone. Allowances to update these criteria based on future sampling and new information are included in the CHMS. The use of soil or "growth medium" salvaged from a new disturbance site to reclaim older sites is encouraged to minimize extended soil stockpiling and thereby take advantage of the active seed banks in recently transplanted soils. All revegetation sites must meet general success criteria to receive Conservation Credit under the CHMS. However, higher Conservation Value multipliers will be applied to those

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Table 10.7 Compensation Requirement Worksheet for obtaining ESA compliance

1	Enter the Conservation Value of the parcel.	_____
2a	Enter the lineal mileage of any portion of the edge of the parcel that meets Uncommitted Category lands.	_____
2b	Enter the lineal mileage of any portion of the edge of the parcel that meets the existing habitat reserve.	_____
2c	Enter the lineal mileage of any portion of the edge of the parcel that meets existing Mining Category lands.	_____
2d	Enter line 2a × 12.	_____
2e	Enter line 2b × 24.	_____
2f	Enter line 2c × 12.	_____
2g	Enter line 2d + line 2e – line 2f (can be a negative number); this result is the Net Edge Adjustment.	_____
3	Enter line 1 + line 2g (if negative, enter 0); this result is the Adjusted Conservation Value.	_____
4	Enter line 3 × 3.00 (the Compensation Ratio); this result is the Compensation Requirement in terms of Conservation Credits.	_____

Source: Olson 2003.

parcels that meet enhanced success criteria. These guidelines are summarized in Table 10.9.

The mine operations actively engage the community in habitat restoration by sponsoring the construction of greenhouses on area school campuses that are managed by community collaboratives. The mine operations then purchase the plants from the collaboratives for use in mine reclamation efforts. The Lucerne Valley chapter of the Future Farmers of America and the Desert Crossroads Garden Club collect seed and propagate plants that are tended on the Lucerne Valley High School campus (Figure 10.4). In conjunction with applied learning courses, students visit the mine sites to participate in seeding, outplanting, and site-monitoring activities. As each reclamation site achieves the success criteria set forth in the CHMS, the contributions may be submitted to the habitat reserve. Revegetation sites with occurrences of at least

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Table 10.8 Reserve Contribution Valuation Worksheet

1	Enter the Conservation Value of the parcel.	
2a	Enter the lineal mileage of any portion of the edge of the parcel that meets Uncommitted Category lands.	
2b	Enter the lineal mileage of any portion of the edge of the parcel that meets the existing Mining Category lands.	
2c	Enter the lineal mileage of any portion of the edge of the parcel that meets the existing habitat reserve *and that was previously Category D or P land*.	
2d	Enter the lineal mileage of any portion of the edge of the parcel that meets the existing habitat reserve *and that was previously Category M land*.	
2e	Enter line 2a × 12.	
2f	Enter line 2b × 24.	
2g	Enter line 2c × 12.	
2h	Enter line 2d × 24.	
2i	Enter line 2e + line 2f – line 2g – line 2h (can be a negative number; this result is the Net Edge Adjustment).	
3	Enter line 1 – line 2i (if negative enter 0); this result is the Adjusted Conservation Value.	
4	If the parcel is being contributed as a Permanent Contribution, enter 1.00; if as a Relocatable Contribution, enter 0.50 (the permanence factor).	
5	Enter line 3 × line 4; this result is the Conservation Credits that would be given for contributing the parcel.	

Source: Olson 2003.

one of the four carbonate species earn twice as much Conservation Credit as sites without carbonate plants. Additional value is credited for each additional carbonate plant species introduced to the site. Each of the mine operations have successfully transplanted, seeded, or outplanted three of the four carbonate plant species regulated

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Table 10.9 Revegetation success criteria to achieve Conservation Credit under the CHMS

	General Success Criteria	Enhanced Success Criteria
Cover	Achieve a mean native vegetation cover that is at least 50% of the mean native cover value specified in the baseline data of the appropriate vegetation zone.	Achieve a mean native vegetation cover of at least 75% of the mean native cover value specified in the baseline data of the appropriate vegetation zone.
Native herbaceous component		Achieve a relative abundance of three native herbaceous species with relative abundance equivalent to or greater than that specified in the baseline data.
Density	Achieve a mean density of each of three climax/dominant species that is at least 50% of the baseline data for the appropriate vegetation zone.	Same standard as general guidelines.
Richness	Achieve a mean species richness that is at least 50% of the value specified in the baseline data.	Achieve a mean species richness that is at least 75% of the value specified in the baseline data.
Non-native species cover	Non-native species cover will be no more than an absolute cover of 15%, and annual monitoring data will show a downward trend, documented by a declining regression co-efficient (negative *b value*) over the monitoring period.	Same standard as general guidelines.
Non-native species relative abundance		Do not exceed the *average relative abundance* of non-native species specified in the baseline data.
Aggressive/invasive weeds	Nine highly invasive exotic species have been identified under the CHMS, and these must not occur on the site to achieve Conservation Credits.	Same standard as general guidelines.
Ecosystem function	Demonstrate *one* quantitative measure of ecosystem function (e.g., soil respiration, mycorrhizal hyphal mass in soil, glomilin assays, pollinator visitation, and wildlife use).	Demonstrate *two* quantitative measures of ecosystem function (e.g., soil respiration, mycorrhizal hyphal mass in soil, glomilin assays, pollinator visitation, and wildlife use).

Source: Adapted from Olson 2003.

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(A) (B) (C)

Courtesy of JJ Restoration Service.

Figure 10.4 Examples of community engagement in mine reclamation activities: (a) students from the Lucerne Valley chapter of the Future Farmers of America and members of the Desert Crossroads Garden Club prepare plant bands for use in mine reclamation; (b) plants are propagated from locally collected seed and tended by community members at the Lucerne Valley High School greenhouse; and (c) students from Lucerne Valley High School plant native nursery stock at the MTI operation as part of an applied learning course.



(A) (B) (C)

Courtesy of JJ Restoration Service.

Figure 10.5 Mine revegetation sites that meet the success criteria specified under the CHMS are eligible for contribution to the habitat reserve: (a) Parish's daisy (*E. parishii*) introduced to a mine revegetation site at the Marble Canyon quarry operated by MTI; (b) Cushenbury milkvetch (*A. albens*) introduced on a revegetated mine bench at the Mitsubishi cement plant; (c) Cushenbury buckwheat (*E. ovalifolium* var. *vineum*) on a waste-rock pile at the White Knob quarry operated by Omya.

by the CHMS as part of its ongoing reclamation activities (Figure 10.5). These sites are being monitored in accordance with the guidelines of the CHMS for potential future contribution to the habitat reserve.

Amendments and Adaptability

The CHMS recognizes the need to strike a workable balance between *adaptability* to new information and circumstances and *stability* in terms of maintaining enough regulatory certainty to meet the respective objectives of the participants. Administrative changes may be made at the discretion of the resource management agencies if they remain consistent with the provisions of the CHMS. Examples of administrative changes would include modifications to the Habitat Inventory as previously discussed, procedural changes in the Credit Registry, and the establishment of mechanisms to make the CHMS data available to the public. Amendments

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shall require both concurrence of the USFWS and the approval of all other MOU parties that could be adversely impacted by the proposed change. The CHMS also addresses the eventuality that additional species occupying the CHMA may be proposed for listing under the ESA in the future. In such cases, the MOU parties may elect, by unanimous consent of the affected parties, to conference with the resource management agencies and the USFWS to identify what measures would be necessary to obtain a biological opinion that "any take of the [proposed] species pursuant to the CHMS shall not jeopardize the continued existence of such species." The MOU parties may then make amendments to the CHMS as required to achieve the conference opinion that would be deemed a new biological opinion in accordance with the ESA and its regulations. In its deliberations to issue a revised CHMS biological opinion, the USFWS shall take into account and give credit for any habitat of the newly listed species existing within the habitat reserve, as well as any other permanent reserve or easements that are included in other jurisdictional conservation planning efforts (Olson 2003).

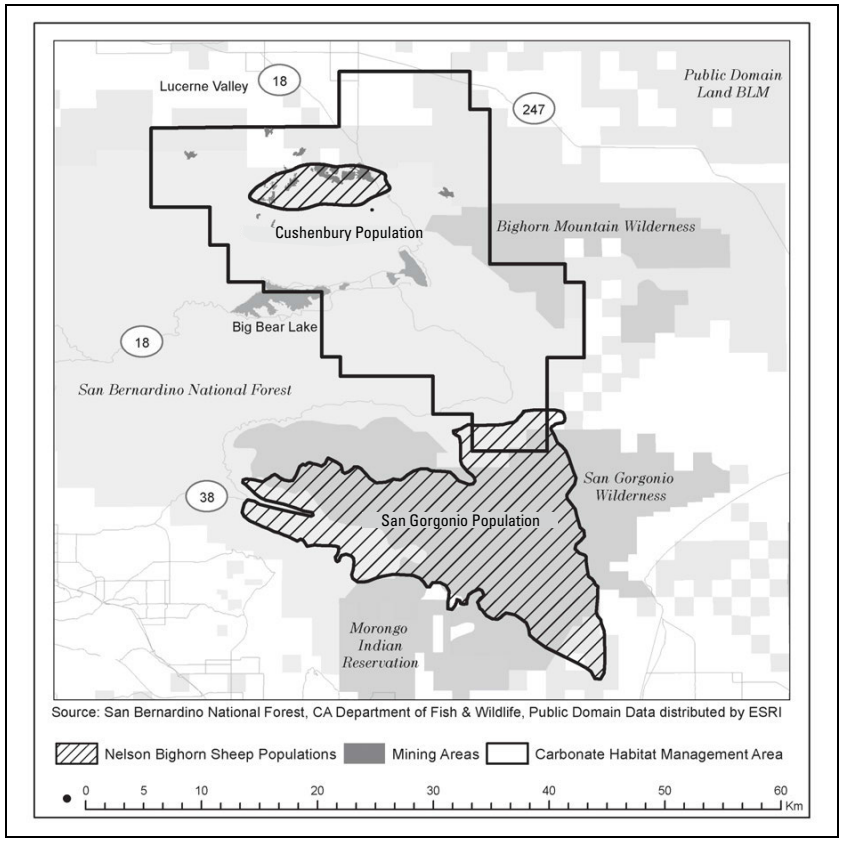
ADAPTIVE MANAGEMENT OF BIGHORN SHEEP

Since the 1990s, mine operations, resource management authorities, and conservations groups have been developing a relationship that has extended into regional conservation efforts for desert bighorn sheep (*Ovis canadensis nelsoni*). A small population known as the "Cushenbury herd" occupies the north slopes of the San Bernardino Mountains. Approximately 12% of the known range of this population overlaps areas of past and present limestone mining activity (Anderson and Villepique 2013). Three limestone mining operations that co-exist on the north slopes of the San Bernardino Mountains have been working closely with management agencies and local communities to monitor this herd through a combination of voluntary wildlife observation programs, habitat restoration projects, and research studies conducted by the California Department of Fish and Wildlife (CDFW) and the San Bernardino National Forest.

Natural History of Desert Bighorn Sheep

North American wild sheep are ecological specialists that typically occupy habitat in proximity to rugged "escape terrain," suitable forage, and adequate water. Escape terrain that provides high visibility is one of the most critical patch attributes for ewes, and the ewes are generally found within 100–200 m of such territory (Leslie and Douglas 1979; Ebert and Douglass 1993). These habitat requirements limit wild sheep to habitat islands that become increasingly fragmented because of anthropogenic changes to land use in the past century. Five recognized subspecies of wild sheep are found in North America. The subspecies desert bighorn (*O. c. nelsoni*), also referred to as Nelson bighorn, is found in seven deserts in habitat characterized by rugged and rocky terrain broken by canyons and washes (Hansen 1980), and constitute a classic example of a metapopulation (Bleich et al. 1996). Two discrete

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Courtesy of Onyx Mining Services.

Figure 10.6 Nelson bighorn sheep populations of the San Bernardino Mountains

subpopulations of Nelson bighorn sheep occupy the San Bernardino Mountains: the San Gorgonio population and the Cushenbury population (Figure 10.6). The identified home range of the Cushenbury population includes the pinyon-juniper woodlands north of Big Bear Lake and the mixed desert scrublands of Lucerne Valley with drastic topographic relief ranging from 4,500 to 8,000 feet. This ecological transition zone creates browse-and-forage habitat more diverse than any of the desert ranges occupied by bighorn sheep (Hansen 1980).

Conservation and Management Issues

For more than 30,000 years, wild mountain sheep and Aboriginal peoples coexisted in North America, both occupying the Southwest by 12,500 before present (Harris 1977). As evidenced by rock art appearing in the Western United States over the past 10,000 years, bighorn sheep played a significant role in Native American cultures, as a source of meat, clothing, and tools and as a ceremonial focus (Grant 1980). This cultural significance continues as contemporary tribes, such as the San

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Manuel Band of Mission Indians, maintain the oral traditions passed down from their Serrano ancestors. In the early nineteenth century, an estimated 1.5 to 2 million bighorn sheep occupied the Western United States, Canada, and Mexico (Seton 1929; Buechner 1960). However, in less than a century as civilization expanded west, many populations disappeared, leaving only 1% of pre-European numbers. Many anthropogenic factors have been attributed to this decline, including over-hunting before the introduction of managed state hunting programs, disease from domestic livestock, competition with feral burros, habitat fragmentation from land development and roads, and low genetic diversity (CDFW 2013). In 1883, bighorn sheep became a "protected species" in California, and other states followed the same example. As conservation efforts and state wildlife management programs have evolved, populations have rebounded in the Southwest. It was estimated that bighorn sheep in California have been restored to approximately two-thirds of the native populations (Epps et al. 2003).

Cushenbury Bighorn Collaborative

In the 1920s, random verbal accounts of bighorn sheep in the canyons above Lucerne Valley were reported to the U.S. Forest Service by deer hunters. It was not until 1975, when a Pfizer geologist took a photograph of sheep in the Furnace Canyon quarry, that the management agencies had reliable evidence of sheep in the area. Small-scale subsistence miners and hunters were more prevalent through the late 1960s and 1970s, and anecdotal reports suggest that bighorn sheep were unlawfully harvested. However, it is suspected that once the commercial mining operations began to control larger tracts of land in the 1980s, the frequency of disturbance by subsistence miners and the general public decreased. In the 1990s, funded by a combination of mine mitigation monies, public funds, and grants from sportsmen conservation organizations, the CDFW and the San Bernardino National Forest initiated numerous aerial surveys and sheep captures to better quantify the size and composition of the Cushenbury Herd. The relationships established by these early surveys have evolved organically into a collaborative partnership that has since extended into regional conservation efforts for desert bighorn.

In 2006, the CDFW, San Bernardino National Forest, the Society for the Conservation of Bighorn Sheep (SCBS), Victor Valley College (Victorville, Calif.), and the three limestone operations came together to form an informal working group called the Cushenbury Bighorn Collaborative to coordinate the scientific research, voluntary conservation efforts, and community outreach for this small population. A year later, a formal research study plan was initiated with an overarching goal to assess the effect of mining activities on bighorn sheep and develop an adaptive management plan that enhances habitat quality, mitigates negative impacts on bighorn sheep, and ultimately maintains a sustainable population (CDFW 2007). Four management objectives were identified in the plan:

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Table 10.10 Management goals and research objectives of the Cushenbury bighorn sheep study

Management Goals: Assess the effect of mining activities on bighorn sheep and develop an adaptive management plan that enhances habitat quality, mitigates negative impacts on bighorn sheep, and ultimately maintains a sustainable population.
Research Objectives
1. Determine basic demographic characteristics of the Cushenbury population.
2. Assess habitat selection relative to mining and reclamation activity.
3. Evaluate movements relative to mining activity.
4. Determine the location of lambing areas.
5. Determine survival rate and causes of mortality.
6. Evaluate forage quality at revegetated and undisturbed sites.
7. Document use of water sources.

Source: CDFW 2007.

1. Work with mines to establish procedures that minimize risk to bighorn sheep;
2. Incorporate high-quality forage species selected by bighorn sheep into revegetation activities as part of a mitigation program;
3. Continue surveillance and remove feral dogs, domestic sheep, and goats; and
4. Implement projects involving local community college and high school students.

As discussed further in this case study, the management goals and research objectives summarized in Table 10.10 are being met collaboratively by the resource management agencies, the mining operations, and the conservation community.

Ongoing research is funded by the mining operations. Data is collected by automated cameras installed at all wildlife water sources in the participating limestone quarries and then integrated into a regional geographic information system (GIS) database collaboratively maintained by the SCBS and the CDFW (Figure 10.7). In the most recent captures, animals were fitted with very-high-frequency-transmitter collars equipped with a "head-up/head-down" activity antenna (shown in Figure 10.7b) that recorded activity every 5 minutes by a data logger. These data, along with the Global Positioning System location data collected every 4 hours, will be combined in a Microsoft Access database to develop a correlate of foraging activity after Oehler et al. (2005). The finer-scale data generated by this study will be cross-referenced with temporal and spatial data provided by the mine operations to evaluate sheep movements relative to mine activity. This research will culminate in a resource selection model to evaluate habitat quality in areas proposed for future limestone mining expansion. The current population, estimated at less than 10 ewes, will warrant augmentation or genetic rescue at a recurring interval of 5–10 years (J. Villepique, personal communication). To address the cumulative impacts that

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(A) Courtesy of Mitsubishi Cement Corporation. (B) Courtesy of Omya Inc.

Figure 10.7 Captures from automated cameras: (a) unmarked Class IV ram observed at a wildlife drinker at the Mitsubishi Cushenbury plant, and (b) two marked rams observed at the Sentinel quarry operated by Omya. The ram on the right is wearing a collar that includes an antenna to monitor when the animal is in a head-up versus head-down position. This data serves as an indicator of foraging activity.

limestone operations will have on the overall carrying capacity for bighorn sheep over time, the affected parties are discussing the establishment of a habitat mitigation fund. To maintain a genetically viable population, the proposed nonwasting endowment would support additional captures and translocations as needed. Each project proponent for future expansions would be assigned a proportional allocation of responsibility based on a formula including the level of use by bighorn sheep in areas proposed for mine expansion, along with a measure of cumulative impact, based on existing mine disturbance within the bighorn sheep range.

Wildlife Monitoring Programs at the Mine Sites

In 2004, the mine operations began a voluntary wildlife monitoring program to document observations of bighorn sheep for inclusion into a GIS database developed by students at Victor Valley College (Figure 10.8). During the subsequent captures, animals were marked with individually identifiable color markers on each collar, as well as color-corresponding ear tags to assist in the collection of resight data (Figure 10.9; CDFW 2007). Where possible, operators are asked to indicate if they observed any of these unique markers. Employees are issued digital cameras to capture photos if opportunity and safety permits. Each sighting card (Figure 10.10) includes a companion map of the respective mining operations for employees to designate where sheep were observed. Blasting crews are also equipped with binoculars to inspect surrounding benches and undisturbed areas upslope before proceeding with standard blasting protocols. Students from an introductory GIS management class at Victor Valley College compiled the wildlife observation data collected by the quarry employees and established a GIS database. Locations and any corresponding photographs from the sighting cards are also added to the database. A companion predator observation form was developed by the students and integrated into the wildlife monitoring program. Remote motion-sensor

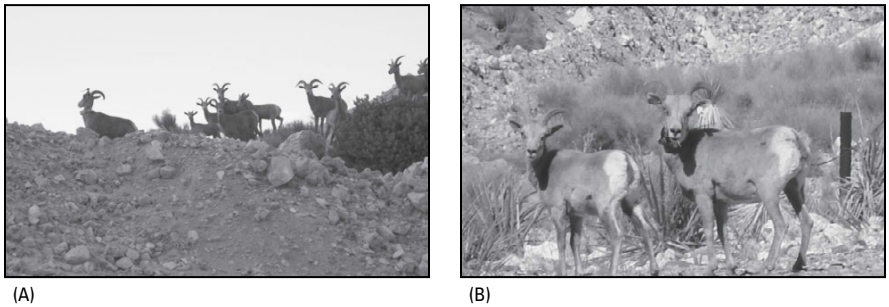
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(A) (B) (C)

Courtesy of Minerals Technologies Inc.

Figure 10.8 Data collected by employees of the three limestone operations are integrated into a GIS database: (a) mine employees complete bighorn sheep observation cards at the end of the shift; (b) Victor Valley College students developed an observation form to monitor predator activity; and (c) any photos collected, such as this group of rams above the main haul road of the Lucerne Valley operations of MTI, are geo-referenced and linked to GIS databases collaboratively maintained by the CDFW and the SCBS.



(A) (B)

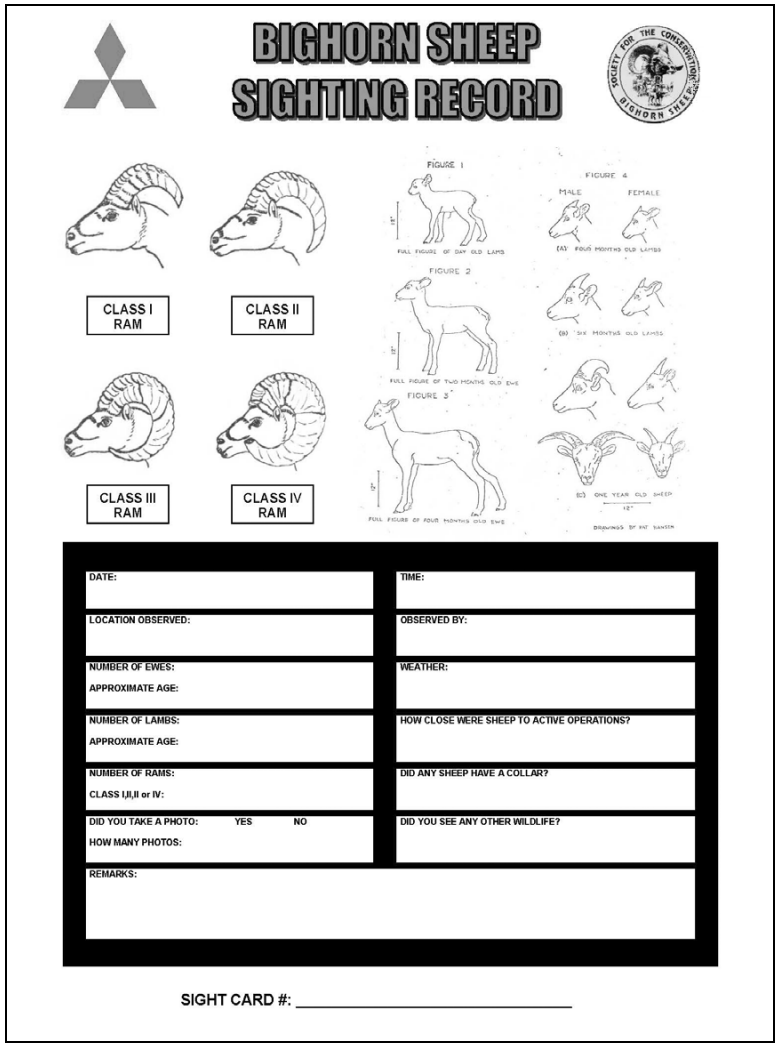
Figure 10.9 As part of the research plan, each marked animal was given a unique color identifier to assist in estimating size and composition of the population: (a) collared ewe (highlighted to the left) and unmarked family group in the Marble Canyon quarry operated by MTI, and (b) ewes observed at a mine revegetation site below the quarry operated by Mitsubishi Cement.

wildlife cameras have also been installed at various water sources within and surrounding the quarry operations. The date and time of each photograph is generated, and all data is integrated into a regional wildlife water source database maintained collaboratively by the SCBS and the CDFW.

The employees of the three mining operations are in a unique position to provide more frequent monitoring of the population than is typically afforded research teams with funding adequate to conduct only weekly, monthly, or seasonal field investigations. The immediate proximity of the mines to the wildlife activity has proved beneficial in a number of circumstances.

1. During the study period when the activity collars were transmitting data, mine management was provided with telemetry equipment to monitor for mortality signals during daily tours of the operations. This allowed for more timely investigations of sheep mortalities. In 2007, a mountain lion (*Puma*

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Courtesy of Mitsubishi Cement Corporation.

Figure 10.10 Sample bighorn sheep monitoring report

concolor), with one of the largest track imprints documented in California, ranged into a youth camp located 11 miles from the limestone operations. It was determined that the same animal caused three of nine sheep mortalities documented during the study period. In addition to natural predators that include bobcats, coyotes, and hawks, feral dogs also present a risk to sheep and have been included in the wildlife monitoring protocols at the mine operations (Figure 10.11).

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Figure 10.11 Wildlife monitoring programs include documenting evidence of predator activity with the automated cameras: (a) mountain lion located in a canyon near the Lucerne Valley plant operated by MTI; (b) three feral dogs cornering a ram (highlighted in the foreground) along the pit crest of MTI's Furnace Canyon quarry; and (c) black bear at Omya's Sentinel quarry wildlife drinker overlooking Lucerne Valley.

2. Domestic sheep and goats can transmit a number of respiratory diseases, including *Mannheimia haemolytica*, that are fatal to wild sheep (Lawrence et al. 2010). When the wild sheep come into contact with those domestic species or feed upon the same vegetation, disease outbreaks and severe die-offs are likely. When a Lucerne Valley landowner began grazing domestic sheep and goats near the mine operations, the domestic flock trespassed onto private property before straying on to public lands where grazing allotments no longer exist. The mine operations notified the CDFW immediately when goats and domestic sheep were observed on their property. The SCBS engaged homeowners in the area to monitor and report future trespasses so immediate action could be taken by local animal control authorities.
3. With lower reproduction rates and higher mortality rates for juveniles than in other big game animals (Toweill and Geist 1999), wild sheep are ecologically sensitive. For any given population, recruitment rates (i.e., survival of lambs to sexual maturity) may be as low as 10% or as high at 80% (CDFW 2013). Determining the recruitment rates and lambing behavior of the ewes, especially for this small population, is a key management objective. Mine employees have been able to notify, and often document with supporting photos, when and where lambs are observed in the spring (Figure 10.12).

Wildlife Water Development and Regional Conservation Partnerships

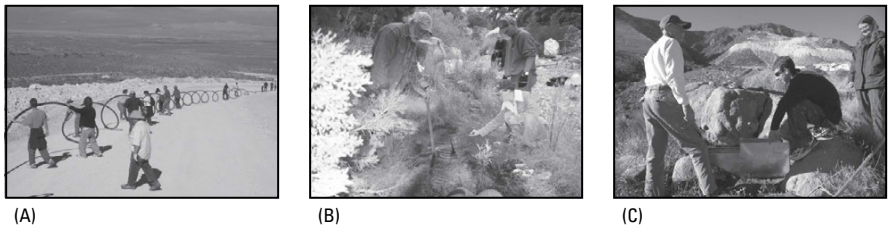
Since 1964, the SCBS has been dedicated to the full restoration of California's desert bighorn to its historic range and the establishment of self-sustaining populations throughout those ranges (SCBS 2013). This nonprofit organization raises funds to monitor natural springs, install wildlife water systems, and support research projects and translocation programs to repopulate historic ranges with new viable desert bighorn populations. Its collaboration with the Lucerne Valley mining operations began in 2000 when SCBS joined other sportsmen conservation groups to fund a capture of the Cushenbury population. Five years later, when a wildlife water system

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(A) (B) (C)

Figure 10.12 Wildlife monitoring programs at the mines provide critical and timely information to aid in quantifying recruitment rates and lambing behavior: (a) family unit with lamb observed below the Marble Canyon quarry operated by MTI; (b) new lamb observed at the Amboy quarry operated by Omya; and (c) lamb observed on a road berm in the C-21 quarry operated by MTI.



(A) (B) (C)

Courtesy of Society for the Conservation of Bighorn Sheep.

Figure 10.13 MTI engages the community in providing more reliable water for wildlife at its Lucerne Valley plant: (a) volunteers from the SCBS and Victor Valley College joined mine employees to unravel 4,000 feet of coiled piping to connect a mine water storage tank to a canyon spring; (b) volunteer crews repair the check dam that collects natural surface water used for dust suppression and mine reclamation purposes; and (c) Brandon Decker of Boy Scout Troop 247 earned his Eagle Scout Award supervising the installation of the new wildlife drinker box.

on the mine property required repair, the partnership evolved further. The system located within the MTI operation was fed by a large water storage tank used for dust suppression and mine reclamation needs. Water availability to the storage tank was unreliable because the old pipeline and fittings feeding the tank required constant maintenance. The SCBS recommended some new durable piping and volunteered to assist the mine operation with the installation of a new water delivery system. Thirty volunteers from the SCBS, Lucerne Valley Boy Scout Troop 247, and Victor Valley College joined mine employees to install the new water system. In six hours, 4,000 feet of coiled pipe was unrolled and carried up a steep canyon to a small check dam collecting surface water from a spring source further up the canyon. Brandon Decker of Lucerne Valley Boy Scout Troop 247 earned his Eagle Scout Award coordinating the installation of the new wildlife drinker box (Figure 10.13).

The relationships between the Lucerne Valley mine operations and the conservation community forged by the Cushenbury study have extended into voluntary conservation efforts for other desert bighorn populations. Water developments have been used by conservation groups and resource managers since the 1940s to improve wildlife habitat in arid environments. These systems have been modeled

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(A) (B) (C)

Courtesy of Society for the Conservation of Bighorn Sheep.

Figure 10.14 Manual replacement of water: (a) caged transport tank donated by MTI to support water-haul projects for other desert bighorn sheep populations; (b) MTI mine employees joined SCBS volunteers on a water-haul project in the Cady Mountains; and (c) bighorn sheep waiting for volunteers near a traditional wildlife water system in the Mojave National Preserve.

after natural water holes called *tinajas*, which describe natural surface depressions in bedrock fed by waterfalls, spring flow, seepage, or rainfall. SCBS has developed more than 70 water systems that collect natural rain water to emulate, as closely as possible, these *tinajas* found throughout the Southwest. However, in the mid-summer months, if rainfall has been scarce or if piping and fittings have failed, some of these systems require supplementation by manual means, transported by air or road. In 2006, MTI donated a 300-gallon caged transport tank to assist in hauling water to these traditional desert water systems (Figure 10.14).

To address the high-maintenance issues and visual impacts of traditional wildlife water systems, SCBS designed the RainCatcher II system consisting of tandem underground water storage tanks and a completely passive, environmentally friendly rainwater catchment. The mining operations have served as proving grounds for this new wildlife water system. Jointly funded by Omya and the California chapter of the Wild Sheep Foundation, the RainCatcher II system was installed in the South Bristol Mountains. Mitsubishi Cement installed a similar system in its Lucerne Valley operation (Figure 10.15). These new self-sustaining systems include a lighter, higher-capacity underground storage tank and durable Hypalon geomembrane to collect rainwater, eliminating the high-maintenance distribution plumbing of traditional wildlife water systems. The use of artificial rock covers blends with surrounding landscapes and minimizes evaporative loss of water. The new system is gaining popularity in regional bighorn sheep conservation efforts as the Nevada Department of Wildlife, Nevada Bighorns Unlimited, and Fraternity of the Desert Bighorn have collectively purchased 55 of the SCBS tanks. Two systems have been installed on military grounds, and both the Texas Bighorn Society and the Arizona Desert Bighorn Sheep Society have expressed interest in the design. Positive effects of water developments on wildlife have been documented for more than 75 years; however, anthropogenic water developments remain controversial given that the overall ecological effects are difficult to quantify. As wildlife management science continues to evolve, replacement water remains an active topic of research requiring longer-term studies with more robust experimental design (Simpson et al. 2011).

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(A) (B) (C)

Courtesy of Society for the Conservation of Bighorn Sheep.

Figure 10.15 Mine operations and a military base served as proving grounds for new underground water tanks designed by the SCBS: (a) installation of underground water tank near the Amboy quarry operated by Omya; (b) mine operators complete installation of SCBS wildlife water system at the Cushenbury quarry operated by Mitsubishi Cement; and (c) artificial rock covers installed at the 29 Palms Marine Corps base blend with surrounding landscapes and minimize evaporative loss of water.

SUMMARY

The use of regional habitat management plans and biodiversity offsets are gaining popularity as an effective and more holistic solution to biodiversity conservation. Two multi-stakeholder initiatives in the San Bernardino Mountains resulted in some creative and workable solutions to some of the issues first identified with implementing these practices. To manage the habitat of four carbonate endemic plants, a transparent methodology to develop a biological baseline was established, and the use of a common currency based on conservation value was integrated into the Carbonate Habitat Management Strategy. To maintain a viable population of bighorn sheep, an adaptive management framework is being implemented to monitor success of active management practices while generating new knowledge about the impacts of mining on habitat selection, foraging activity, and lambing behavior. Both initiatives resulted from collaborative dialogues among resource management agencies, the mining industry, and the conservation community.

ACKNOWLEDGMENTS

The authors gratefully acknowledge the following agencies, organizations, and companies for their contributions to the work highlighted in this case study, as well as the many individuals acting on their behalf:

- California Department of Fish and Wildlife: Jeff Villepique, Vernon Bleich, Steve Torres, Jim Davis, Andy Pauli, and Tim Glenner
- Mitsubishi Cement Corporation: Michael Jasberg, David Rib, Austin Marshall, Doug Shumway, and Millie Rader
- Omya Inc.: Howard Brown, Peter Sutherland, Jimmy Rogers, and Doug Riddel
- Minerals Technologies Inc.: Doug Mayger, Dan Howard, Jim Daley, Larry Ashby, Scott Wallace, Steve Baker, John Parks, Darren Lindsey, and Jeff Schaffer

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- San Bernardino National Forest: Scott Eliason, Robin Eliason, Dev Kopp, Gene Zimmerman, Chris Chandler, and Kathy Meyers
- San Bernadino National Forest Association: Todd G. Olson
- Victor Valley College: Neville Slade, Lili Santilli, Kirsten Johnson, Paul Cook, Johnathon Cook, Robert Bennett, José Yañez, Pat Knecht, and Kim Knecht
- Mojave Water Agency: Curtis James and Brian Hammer
- California Native Plant Society: Ileene Anderson
- Society for the Conservation of Bighorn Sheep: Terry Anderson, Robert Burke, Christian Guntert, Steven Hart, John Hybarger, Mark LeCompte, Norm Lopez, Steve Marschke, Neil Ringlee, George Sutton, Gary Thomas, Bob Bissell, Mike Ralles, Bill Tuck, and all their active volunteers
- California chapter of the Wild Sheep Foundation: Mike Borel, George Kerr, and Kyle Meintzer

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PART IV

CLIMATE CHANGE, ENERGY, AND GREENHOUSE GAS MANAGEMENT

Michelle E. Jarvie-Eggart

Climate change has emerged as one of the most pressing environmental issues of the twenty-first century. The United Nations' efforts to address climate change have led some governments around the world to implement policies to curb greenhouse gas (GHG) emissions. Mining companies are accountable to financial institutions, which see climate change in an investment context. For example, the U.S. Securities and Exchange Commission requires all publicly traded companies to disclose the physical impacts climate change may have on their operations, as well as the financial impacts of climate change regulations.

Not only are regulators requiring information on climate change, the programs and organizations focused on managing and reporting social and environmental risks within the mining industry are including efforts to address climate change through energy and GHG management. The International Council on Mining and Metals (ICMM) requires members to commit to working toward a low-carbon economy by developing GHG reduction strategies, efficiently using natural resources, supporting the research of low-GHG emission technologies, measuring progress, and reporting results. The Global Reporting Initiative's sustainability reporting framework, which ICMM members commit to using, includes reporting on GHG emissions. The Mining Association of Canada also has an energy and GHG emissions protocol requiring energy management systems and goals.

Although considering GHG emissions from a mine or mill may be a relatively new trend, mines and mills routinely track and manage energy consumption as a business expense. In fact, energy management is often used as a proxy for GHG management because mines are more likely to have systems to account for energy

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use on a daily, weekly, or monthly basis as a part of tracking key business performance indicators. The driver for energy management may be financial rather than related to sustainability, but it is not a new concept for mining operations.

The issue of climate change has two sides for mining companies: GHG emissions from mines may contribute to climate change, and climate change may affect mining operations, particularly by causing issues regarding water availability and weather patterns. Part IV begins with a chapter on climate change for mine planners. A summary of climate history and current trends is presented in Chapter 11, including increasing storm events, more severe droughts, changing sea levels, and other physical changes to our environment. The author describes the impact that these changes may have at the operational level of a facility and encourages those involved in long-term planning of active mining operations to consider potential impacts of climate change.

Chapter 12 describes an overall sustainability approach at Molycorp's Mountain Pass facility for rare earth metals. This case study details Project Phoenix, a rebuilding plan that includes paste tailings disposal, water and reagent recycling using a salt conversion facility, and onsite power using cogeneration. Although this project includes several improvements, it is included in this section because a major component of the project is the onsite natural gas–fired combined heat and power plant. This cogeneration project will minimize GHG emissions, provide high-quality power and steam, increase system efficiency, and cut production costs. GHG emissions will be controlled at other combustion operations across the new facility by using cleaner-burning natural gas, reducing the amount of high-emission diesel, propane, and bunker fuel used onsite. This case study demonstrates creative solutions for limiting GHG emission and saving energy costs, and also illustrates how multiple environmental and social impacts can be addressed through a single project.

Chapter 13 looks at the question of mines and energy from a different perspective, exploring how inactive underground mines can be used as energy sources for local industries and communities. They present a case study that investigates the utilization of underground mines as pre-drilled reservoirs for geothermal heat-exchange systems to provide heat for a greenhouse in a Canadian community. Using this novel application of geothermal energy recovery, underground mines may be able to contribute a sustainable energy source to the local community well after closure of the facility.

Chapter 14 discusses the optimal synthesis of energy supply systems for mines. Through mathematical programming, optimal mine site energy supply (OMSES) can be used to examine multiple energy alternatives to determine the best designs for mine energy supply. The authors present the various uses of energy at mine sites, energy benchmarking, and typical consumption at underground versus surface mines, load profiles, energy storage systems, renewable energy technologies, and

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various operational considerations when it comes to mine energy systems. Examples are provided for a basic run of OMSES for an open pit mine, a connection distance analysis for remote mines, OMSES resilience maps, and demand consolidation. Using OMSES, mine energy managers can determine the most cost-effective energy systems for individual mines based on their unique scenarios.

Together, the chapters in this section provide an overview of the importance of climate change in mine planning, the overall benefits that can be gained by implementing energy-saving projects at facilities, the innovative extension of the useful life of an underground mine to provide energy, and facility-specific energy optimization. These chapters highlight just some of the progressive ways that mines can address the risk of climate change to their operations and manage energy use and GHG emissions from planning to operation through final closure.

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CHAPTER 11

Climate Change for Mine Planning

R. David Williams

INTRODUCTION

Why Does a Changing Climate Matter?

Climate change matters because civilization's path over the last several centuries has been aided by the relative stability of the climate. This has allowed agricultural and industrial development that has benefited society, leading to the increase of life spans and economic opportunities for millions of people. There is increasing evidence that the climate's stability is at risk as the climate changes in response to anthropogenic increases in atmospheric carbon dioxide (CO_2), a powerful greenhouse gas (GHG). Increasing CO_2 concentrations in the atmosphere are projected to raise atmospheric temperatures and lead to a variety of challenges, including increased frequency and severity of storm events and droughts, as societies attempt to deal with a new and different climate.

Why Does a Changing Climate Matter to Mining?

Climate change matters to mining because it will affect weather patterns, which increase uncertainties related to all aspects of water management at mine sites and related infrastructure. Storms are likely to become more intense at the same time; therefore, overall precipitation may become more problematic. This will challenge conventional reclamation practices. Increasingly intense storms will affect all aspects of mine infrastructure and related transport of product. Increasing sea levels and associated storm surges have the potential to extensively disrupt shipping of products. This chapter covers some of the relevant background information and identifies in more detail some of the challenges the mining industry will face with a changing climate.

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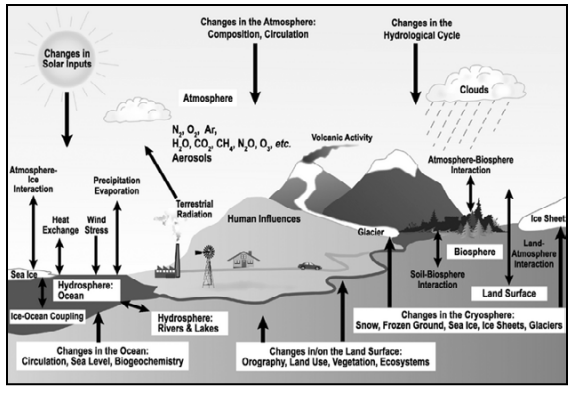
A Brief History of Climate Science

Climate science traces its origins back to the discovery of the earth's "greenhouse effect." This initial attempt to understand the earth's climate dates back nearly 200 years to the work of the French mathematician and physicist Jean Baptiste Joseph Fourier in 1824 and 1827. Fourier had made some fundamental calculations of what the temperature of a body in space should be given its distance from the sun. He found the temperature of the earth, approximately 14°C (57°F), to be substantially warmer than his calculations, which estimated a temperature of approximately –18°C (0°F). Fourier proposed that the incoming "luminous heat" was able to pass through the earth's atmosphere but that "non-luminous heat" was unable to pass back through the atmosphere. The science and the scientific instruments of the 1820s were not sufficiently advanced to detect this non-luminous heat as the infrared radiation we now know it to be. In 1872, John Tyndall, an English physicist and mountaineer, conducted experiments and described the capacity of various gasses to absorb radiant heat. He identified water vapor and CO_2 as the principal "greenhouse" gasses.

In the late nineteenth century, Swedish chemist Svante Arrhenius, working with Swedish geologist Arvid Hogbom, worked to develop more details on the history and role of CO_2 in the earth's climate. Hogbom had been doing work on the natural geologic cycling of CO_2. Together they asked what role might CO_2 emissions from coal-burning factories play in changing the climate. Arrhenius made calculations for what a doubling of CO_2 levels in the atmosphere would do to temperatures. His calculations, which can be regarded as little more than "back of the envelope" calculations by today's detailed modeling standards, came up with 5–6°C (9–10.8°F) warming. This has since become known as the "climate sensitivity," and Arrhenius's calculations have proved surprisingly accurate. The current estimate of climate sensitivity is estimated by the Intergovernmental Panel on Climate Change (IPCC) to be 2.0–4.5°C (3.6–8.1°F) with a best estimate of about 3°C (5.4°F) (IPCC 2013). This was not viewed as a problem at the time for several reasons: Industrial CO_2 emissions in the late nineteenth century were a fraction of later emissions, the oceans were thought to be capable of absorbing most of the emissions, and Arrhenius, being from Sweden, did not necessarily think a slightly warmer climate was a bad idea.

In the early twentieth century, scientific disagreements about the role of CO_2 and two world wars led to a hiatus during which there was little scientific progress on the role CO_2 might play in changing the climate. After the Second World War, a new generation of scientists made huge strides in understanding and presenting detailed information about the role of CO_2 in changing the earth's climate. This was followed in 1967 by the first comprehensive computer model of the earth's climate, developed by Japanese and American climatologists Syukoro Manabe and Richard Weatherald. This model, though primitive compared with more current

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Source: From *Climate Change 2007: The Physical Science Basis. Working Group I Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* (FAQ 1.2, Figure 1). New York: Cambridge University Press.

Figure 11.1 Systematic view of the components of the earth's global weather and climate system, which involves mutual interactions among components of the atmosphere, hydrosphere, lithosphere, and biosphere

climate models, reinforced predictions of a warming climate with increased atmospheric CO_2 and even today predicted some of the current observations in a changing climate.

This increased understanding of the role CO_2 plays in the earth's climate lead to the formation of the IPCC in 1988. The IPCC reports, through the fifth assessment report released in September of 2013 (IPCC 2013), have continued to refine the science and inform policy makers.

CLIMATE FUNDAMENTALS

Climate vs. Weather

Weather is what you feel when you go outside, whether it is raining, windy, sunny, cold, or hot. It is the sum total of the temperature, humidity, cloudiness, wind, and precipitation at a given location and time. Weather is a short-term phenomenon, wherein it can be cold and rainy today, and hot and sunny tomorrow. We typically think of weather in terms of daily or weekly weather forecasts. Figure 11.1 is a graphic summary of the differences between weather and climate.

Climate is essentially the sum total, or statistical overview, of the weather over a longer period of time, typically 30 years, for a given location. Climate can vary over short periods of time in response to specific known causes like El Niño or La Niña, or in response to unpredicted geologic events like volcanic eruptions. The earth's climate has also changed repeatedly over geologic time in response to a wide variety of solar, orbital, and geologic forcings (see Table 11.1). A common

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Table 11.1 A quick summary of the differences between weather and climate

	Weather	Climate
Definition	Describes the atmospheric conditions at a specific place at a specific point in time.	Describes the average conditions expected at a specific place at a given time.
Time frame	Short term: Minutes, hours, days, or weeks	Long term: Months, years, decades, or longer
Determined by	Real-time measurements of atmospheric pressure, temperature, wind speed and direction, humidity, precipitation, cloud cover, and other variables	Aggregating weather statistics over periods of 30 years ("climate normals")
Study	Meteorology	Climatology

Source: Adapted from NASA 2010 and Diffen LLC.

way of expressing the difference is: "You pick your vacation destination based on the climate but pack your suitcase based on the weather."

Climate System

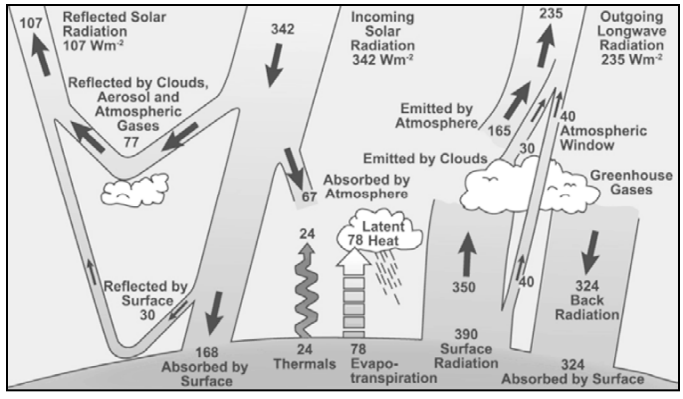
The earth's climate system is portrayed in a general sense in Figure 11.1. It is the sum total of all the energy that is in the system, added to the system, and removed from the system through radiation into space, expressed in watts per square meter. Figure 11.2 shows a more detailed look at some of the inputs and outputs.

The various components of the climate system include phenomena that humans have no control over: incoming solar radiation, volcanic and tectonic activity, natural changes in variability like El Nino and La Nina, snow/ice cover, cloud development, and localized factors like wildfires. The system also includes components over which people do have some control: land and water uses, particulate air pollution, and the composition of the atmosphere. Changes in the composition of the atmosphere through the addition of GHGs to the atmosphere can change the amount of energy radiated back into space, warming temperatures in the lower atmosphere.

Climate and Society

The earth's climate has changed continuously over the 4.5 billion years of geologic time. These changes have normally occurred over tens of thousands of years or more in response to geologic events, solar changes, or orbital changes. After the last ice age ended approximately 10,000 years ago, the earth's climate has been dominated by the slow changes in response to orbital variations known as Milankovitch cycles. This has led to a relatively stable climate, which has enabled humans to develop agricultural societies as they advanced from simple hunter–gatherer cultures and

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Source: Kiehl and Trenberth 1997. © American Meteorological Society. Used with permission.

Figure 11.2 Detailed inputs and outputs for the earth's climate system

then more complex societies and cities, leading up to the industrial age and the complex interdependent world we live in today. Our complex world still depends on reliable weather and precipitation to support the cultivation of agricultural products, the harvest of fisheries, and the manufacture of consumer goods, including the mining of raw materials. The infrastructure that supports this complex society has been designed to reflect the current climate as well. Modern ports used for shipping in support of this international commerce are based on the existing sea and lake shipping routes. To the extent the climate is changing, it can threaten our ability to plant and harvest agricultural crops, harvest fisheries, and to the infrastructure that supports our complex industrial society.

CLIMATE HISTORY

Climate in Geologic History

The earth has been fortunate to have had a relatively stable climate throughout most of its 4.5-billion-year history. Throughout virtually all of its history, the earth has had liquid water present somewhere on the globe, indicating limits to the range of variability the earth has experienced. Geologists know this from evidence that show sedimentary rocks dating back 3.9 billion years (Beatty et al. 1999; Trent et al. 2010), only 600,000 years after the earth was formed. Mineralogical evidence suggests liquid water well before this date (Valley et al. 2002).

Ice Age Climate

Approximately 2.6 million years ago, the start of the Pleistocene epoch began. The Pleistocene epoch is marked by widespread continental glacial advances and retreats, known as glacial and interglacial periods. These interglacial and glacial periods were

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believed to be controlled by the Milankovitch cycles mentioned previously, with CO_2 concentrations acting as a powerful feedback. Recent work (Brigham-Gette et al. 2013) suggests that some of the interglacials were "super-interglacials" that saw the complete disappearance of the Greenland and West Antarctic ice sheets with temperatures as much as 8°C (14.4°F) warmer than current temperatures.

The "ice age" is generally considered to have ended after the last glacial maximum (LGM) approximately 26,000–19,000 years ago. The ice age climate is generally thought to have been cold, dry, and dusty. Many of the earth's deserts expanded dramatically during this period. Sea levels were as much as 130 m (427 ft) below the current level. For much of the ice age, humans inhabited southern Europe and other ice-free areas.

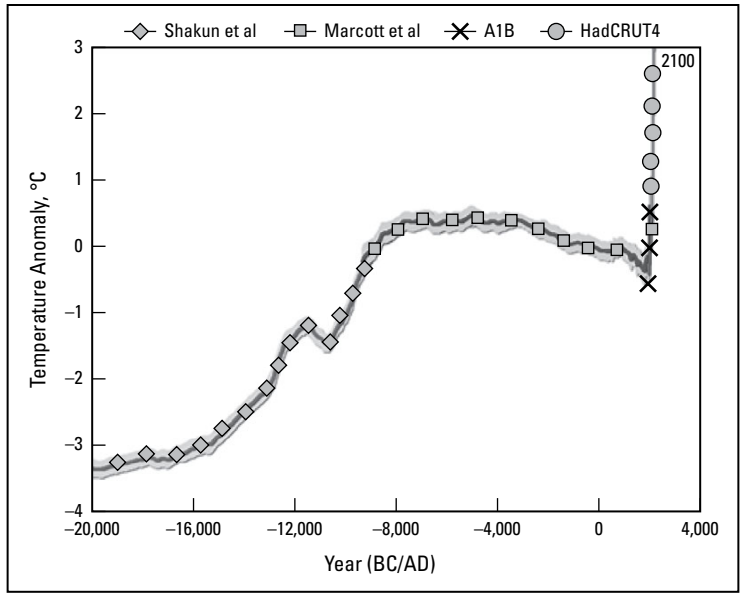
The Recent Climate

After the LGM, the climate has for the most part warmed gradually until very recently. The Younger Dryas (12,800–11,550 BP) and the Medieval Warm Period (MWP) (950–1250 AD) were notable variations to the general trend. The Younger Dryas was a reversion to cooler climatic conditions that may have been related to the collapse of the North American ice sheet and dramatic changes in global ocean currents. The MWP was primarily a northern hemisphere event and is not well represented elsewhere. The MWP was followed by another cooler period known as the Little Ice Age (LIA). The LIA saw the return of slightly cooler temperatures and minor glacial advances. As with the MWP, there is conflicting evidence regarding the global extent of the LIA (IPCC 2007). Since the LIA, the climate has been fairly stable until recently. The recent climate has been characterized by increasing temperatures and extreme weather events, as shown in Figure 11.3. HadCRUT is the dataset of monthly instrumental temperature records compiled by the Hadley Centre of the United Kingdom Met Office and the Climatic Research Unit (CRU) of the University of East Anglia.

Extreme weather events are a bit of a subjective classification but have generally been considered to be events that occur less than 5% of the time. People tend to think of extreme weather events as major storms like tornadoes and hurricanes. In fact, any weather event that causes extensive damage can be considered an extreme weather event regardless of whether it was a tornado or a named tropical cyclone. Figure 11.4 shows damage to electrical lines in Northwest Connecticut following a series of powerful thunderstorms in June 2011 where power was out for several days.

Because there is no one metric that captures the extent of extreme weather events, disruptions to the electrical grid have been used as a proxy for extreme weather events. As shown in Figure 11.5, the number of annual weather-related electrical grid disturbances have increased a hundredfold since 1992. Another metric, increases in the percentage of precipitation falling as heavy precipitation (Figure 11.6), has also been used as an indicator of extreme weather. In particular,

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Source: Hagelaars, n.d.

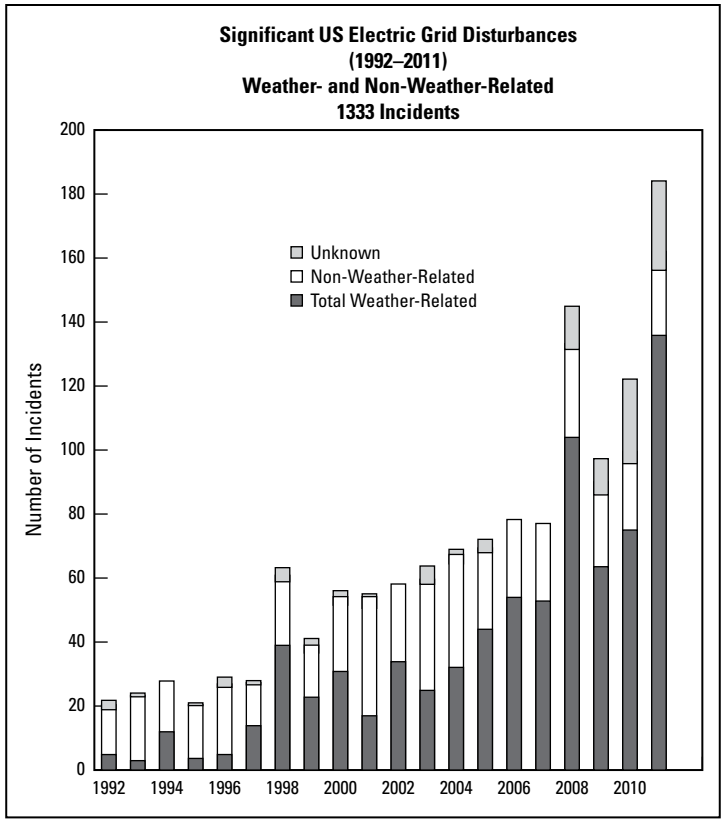
Figure 11.3 Temperature reconstruction of Marcott et al. and Shakun et al. (as cited in Hagelaars n.d.) combined with the instrumental period data from HadCRUT4 and the model average of IPCC emission projections for the A1B scenario up to the year 2100



Figure 11.4 Damage to power lines in Northwest Connecticut in June 2011

the northeastern United States has experienced a 67% increase in the amount of very heavy precipitation from 1958 to 2012, more than any other region in the United States.

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Source: Mills 2012.

Figure 11.5 Significant disruptions to the U.S. electrical grid

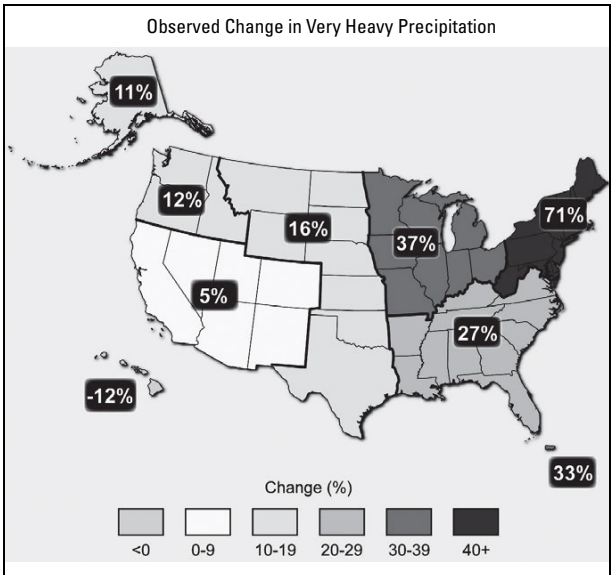
Collectively, these examples clearly display a trend toward increasing extreme weather events. In response to these trends, long-range mine planning should include additional measures for the management of precipitation, spring runoff, and winter storm events.

CLIMATE PROJECTIONS

Temperatures and Precipitation

Temperature and precipitation projections for various GHG concentrations or representative concentration pathways (RCPs) are based on climate projections developed in the 2013 IPCC report. These 2013 scenarios were developed based on possible changes to anthropogenic greenhouse emissions ranging from constant CO_2 emissions to dramatic increases and two alternative scenarios between the extremes.

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Percent changes in the amount of precipitation falling in very heavy events (the heaviest 1%) from 1958 to 2012 for each region. There is a clear national trend toward a greater amount of precipitation being concentrated in very heavy events, particularly in the Northeast and Midwest. (Figure source: updated from Karl et al. 2009c).

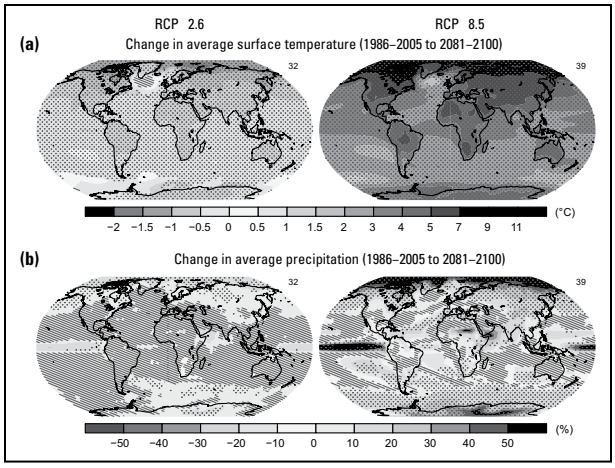
Source: Melillo et al. 2014.

Figure 11.6 Increases in the amount of precipitation falling in very heavy precipitation events, 1958–2012

General projections regarding climate change have focused on the increased average temperature and changes in mean annual precipitation for different regions. In general, these projected changes are reflected in Figure 11.7 (IPCC 2013). These temperature projections are based on different GHG concentrations (or RCPs).

Regional estimates are available from several sources (IPCC 2007; NRCAN 2008; Karl et al. 2009; Katzfey et al. 2010; Ciscar et al. 2009, 2011; Ashton 2010; Melillo et al. 2014), but in general, they can be summarized as projecting that past climatic norms will routinely be eclipsed with warmer temperatures, more intense precipitation events, more severe episodes of drought, and more pressure on water resources as well as physical and biological resources over the next century. Figure 11.8 displays projected changes in precipitation and shows a global representation of the expected regional changes in "heavy rain events." For mine long-term planning, this means the management and routing of precipitation runoff may be a significant operational concern. In arid regions, where process waters may already be scarce and difficult to procure, water is likely to become an even more constrained resource. Some emission-based scenarios from the 2013 IPCC report have been used to project changes in the various levels of precipitation for the United States, as presented in Figure 11.9.

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Source: From "Summary for Policymakers." In *Climate Change 2013: The Physical Science Basis. Working Group I Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Figure SPM.8). New York: Cambridge University Press.

Figure 11.7 Projected changes in temperature and precipitation for different model GHG concentration assumptions

Sea Level

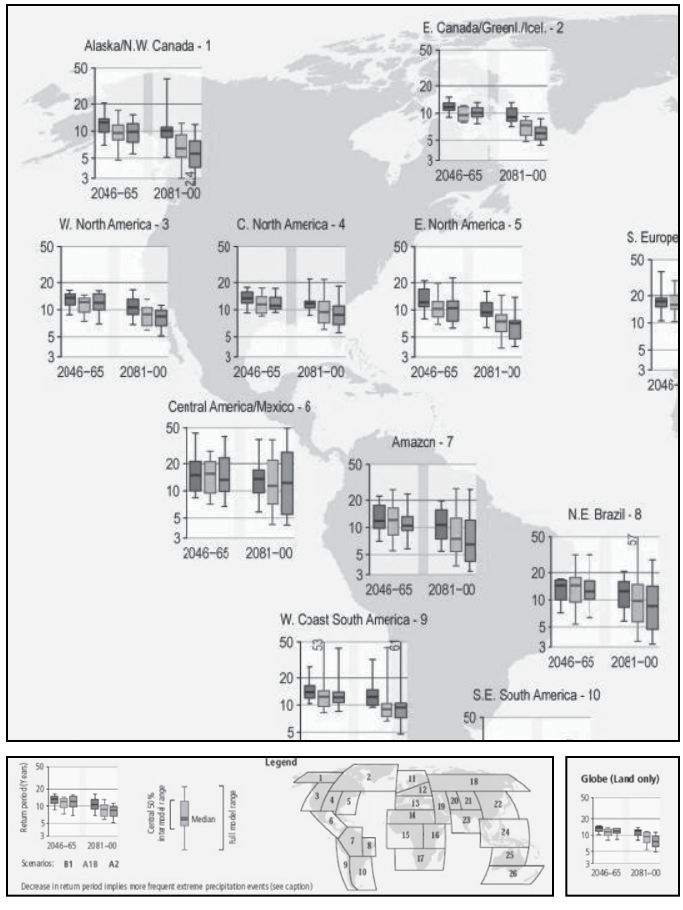
As the climate warms, water stored in glaciers and ice sheets on the continents is released to raise sea levels worldwide. The ocean itself expands slightly as well in response to warmer temperatures. Estimates of the rise in sea level range from a low of approximately 0.4 m (1.3 ft) to an upper level estimate of 2.0 m (6.6 ft). (IPCC 2007; Rahmstorf et al. 2012; Parris et al. 2012).

Extreme Weather Events

As is obvious from the projections regarding changes in precipitation patterns, severe weather events are also projected to increase in the future (IPCC 2012). An indication of the likelihood of these projections can be seen in Figures 11.10 and 11.11 detailing recent trends.

The projections regarding the increasing likelihood of severe weather events may be one of the most important projections for the mining sector. The impact of severe weather events was particularly prominent in the United States in 2011. That year ranks as having the most billion-dollar weather disasters (14), eclipsing 2008, the previous record year (9). Closely associated with the "declared disasters" is the information related to insured losses from catastrophes. This information, displayed in Figure 11.11, breaks down the information by different class of insurance and whether or not the losses were weather related.

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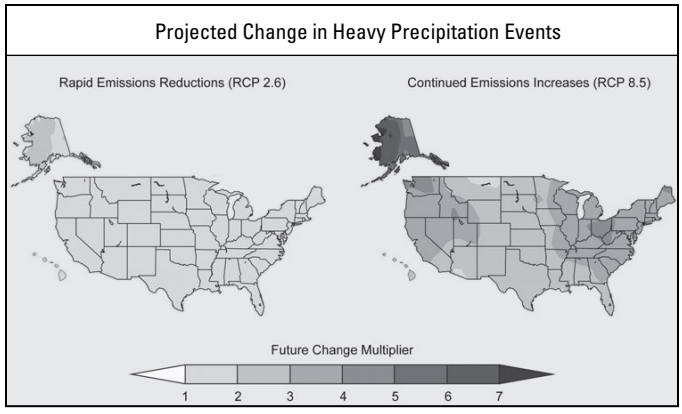
NOTE: This figure has been truncated to include only North and South America for simplicity.

Source: Adapted from IPCC 2012. *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change*. A Report of Working Groups I and II of the Intergovernmental Panel on Climate Change. New York: Cambridge University Press.

Figure 11.8 Projections of increased heavy rain events

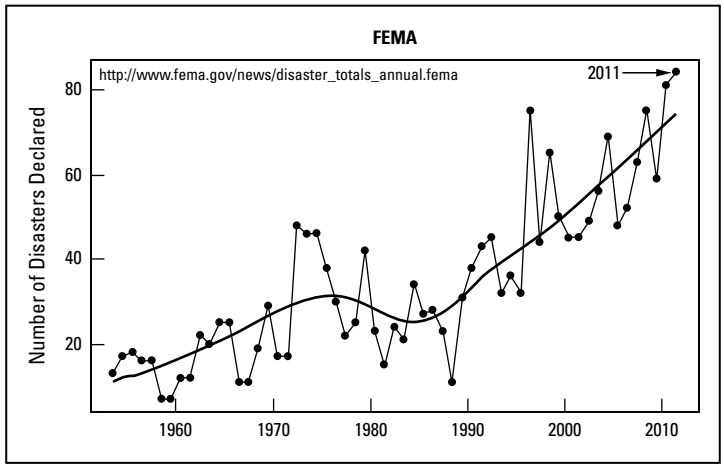
Specific regional projections for the United States are covered in the 2009 Global Climate Change Impacts in the United States, (Karl et al. 2009). Tornadoes and tropical storms (cyclones and hurricanes) are an ongoing research topic related to climate change. The consensus on tropical storms is that we may see fewer cyclones and hurricanes, but the potential for more intense storms is quite high (Elsner et al. 2008; Emanuel 2005), particularly when considered in the context of rising sea level. Mining and port facilities near seashores may experience increased vulnerabilities related to tropical storms.

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Source: Melillo et al. 2014.

Figure 11.9 Projected changes in the pattern of precipitation based on variouis RCPs

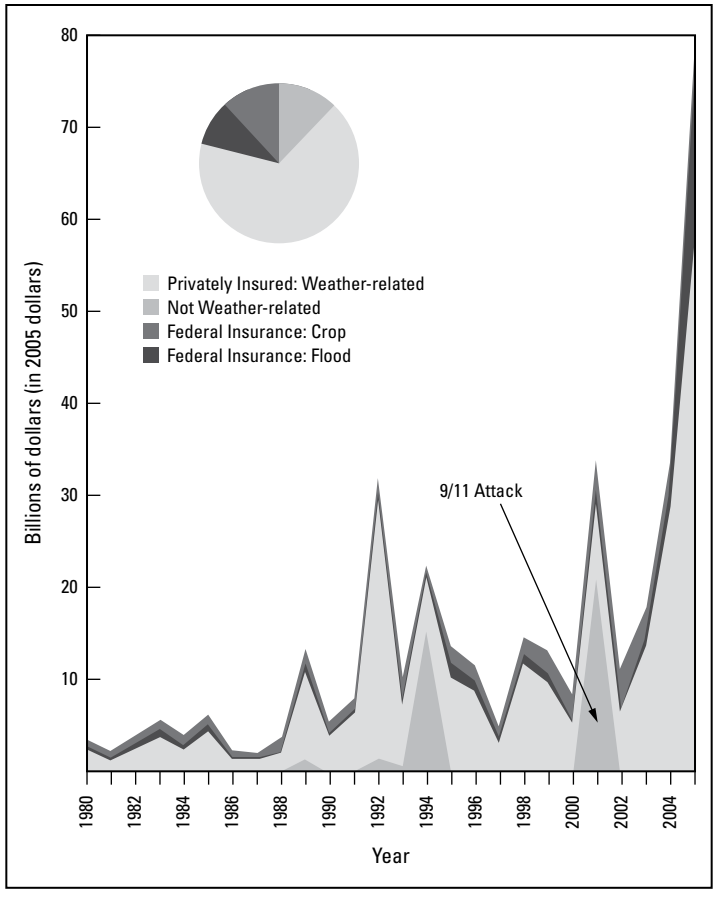


Source: FEMA 2011.

Figure 11.10 Number of declared disasters in the United States

Although increasing temperatures and atmospheric moisture would suggest fuel for more intense thunderstorms and tornadoes, in fact, there are competing forces that may act to limit the formation of tornadoes while more severe thunderstorms form (Masters 2013). Even as tornadoes remain an uncertainty, projections are for a substantial increase in severe thunderstorm days in much of the Southeast and Central United States (NASA 2013). At mine sites, more severe thunderstorms could result in greater damage to infrastructure and an increase in the number of days in which blasting must be avoided or restricted because of electrical activity that poses safety hazards during blast preparation work.

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NOTE: Weather-related insurance losses in the United States are increasing. Typical weather-related losses today are similar to those that resulted from the 9/11 attack. About half of all economic losses are insured, so actual losses are roughly twice those shown on the graph. Data on smaller-scale losses (many of which are weather related) are significant but are not included in this graph because they are not comprehensively reported by the U.S. insurance industry.

Source: Karl et al. 2009.

Figure 11.11 Insured losses due to weather-related catastrophes

Another aspect of extreme weather events will be an increase in wildfire concerns, particularly in western North America and Australia. Projections are for an increase in the number of days with extreme fire danger conditions (Abatzogloul et al. 2009; Pitman et al. 2007). Mines in areas where wildfires are a potential concern may be forced to restrict activities during periods of high fire danger.

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Personnel and Safety Issues

A changing and warming climate will also impact the mining industry's work force. Increasing temperatures will likely increase the distribution and occurrence of tropical diseases such as malaria, cholera, and yellow fever. Increasing temperatures will also impact worker productivity by increasing the likelihood of heat-related injuries or illnesses. The increasing likelihood of severe weather events will also pose physical safety issues for workers (BSR 2013).

THE MINING INDUSTRY AND CLIMATE CHANGE

Potential Impacts

Climate change is relevant for mine design, operations, and closure because climate change will impact average temperatures and the amount, nature, and timing of precipitation at mine sites. All aspects of water management are critical issues at mine sites, and the projected changes in the nature and timing of precipitation events have the potential to impact all facets of mining activity throughout the mine life.

The risk drivers for potential impacts to mines throughout the life-of-mine are

1. Warmer temperatures (IPCC 2007; NRTEE 2009; Stratos 2009, 2011);
2. More precipitation (IPCC 2007; Karl, et al. 2009; NRTEE 2009; Stratos 2009, 2011);
3. More frequent drought conditions (IPCC 2007; Karl et al. 2009; NRTEE 2009);
4. More extreme weather events (IPCC 2007, 2012; Karl et al. 2009; NRTEE 2009), including more severe thunderstorms (NASA 2013);
5. For northern climates, loss of permafrost (NRTEE 2009; Stratos 2009, 2011);
6. For shipping and coastal operations, higher sea levels (IPCC 2007; Karl et al. 2009) or lower Great Lakes levels (United States), which may affect shipping and support facilities (USGCRP 2009); and
7. Increasing health and safety concerns for mine staff (BSR 2013).

The importance of these potential impacts will vary depending not only on the physical location and setting of a mine site and its associated support facilities but also on where the facilities are in the mine life cycle.

Operational Considerations

Although increased temperatures and precipitation could potentially provide a more favorable setting for the oxidation of sulfide minerals and acid rock drainage, it is not likely that increased temperatures and precipitation alone represent the critical issue with respect to climate change. These factors could potentially

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Figure 11.12 Exploration activity near an active mine site

complicate water treatment, stormwater management, and reclamation options. The likely larger issues are extreme weather events and less-reliable precipitation, which could affect the success of reclamation efforts and pose a safety risk, especially for workers in hot climates.

Most mines have an operational life in the 20-to-30-year range and thus are well below the likely time frame of the expected maximum climate change impacts. Mines can be expected to be able to effectively plan and manage climate change impacts during the operational life of the mine because they have money available, they have labor and equipment available, and they have an incentive to prevent disruptions to mining and milling operations. Over the course of a 20–30 year life of a mine, the likelihood of a fatal defect in dealing with climate change may be low since the mine facilities are likely designed with a longer return interval than the anticipated life of the mine. Other mine life periods, discussed in the following sections, may have greater risks culminating in the mine closure time period, which for a large site is essentially perpetuity. Mine life-cycle events are evaluated in the following subsections for relative risk.

Exploration

In the exploration period, the likelihood for adverse impacts related to climate change is low because surface disturbance is generally limited and the time window is relatively brief. Activity at the drill pad shown in Figure 11.12 lasted only a matter of weeks and the site was then reclaimed. Total disturbance for an exploration

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Courtesy of Barrick Gold Corporation © 2010.

Figure 11.13 Mine during development phase. Note the extent of disturbance.

project can range from as little as 1 ha (2.5 acres) to as much as 50 ha (124 acres) on a large exploration project.

The use of standard best management practices (BMPs) can help limit any potential erosion issues resulting from heavy rains, but the main factors limiting the likelihood of climate change impacts are simply the limited acreage disturbed and the short time duration (weeks to months) of the activity. BMPs generally focus on limiting the timing and extent of disturbance, effective management of run-on water, effective management of water on the disturbed site, and prompt reclamation and revegetation upon completion of activities. Detailed information on BMPs is commonly available from surface management agencies or from various Websites.

Development

During development, there is an increasing likelihood of minor impacts as surface disturbance increases and water management infrastructure may not be fully implemented. The time window is on the order of 1 to 3 years, but the increased disturbance and incomplete infrastructure raises the risk level (see Figures 11.13 and 11.14).

Features at risk during extreme weather events include all areas under construction: mill and office facilities, transportation infrastructure, and tailing impoundments (if included). Total disturbance for the development phase of a large project can be as much as 600 ha (1,483 acres) or more. Facilities and equipment at risk are less mobile and could be exposed depending on the nature of severe weather. The extent

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Courtesy of Barrick Gold Corporation © 2010.

Figure 11.14 Development work on water control infrastructure. This work would be extremely vulnerable to an extreme event at this stage.

of disturbance and possible incomplete water management infrastructure makes this relatively short time frame a particularly low risk–high consequence period. However, workers may be at risk during extreme weather events, because adequate shelters may not be available during storms on developing sites. As with exploration, detailed planning and use of robust BMPs throughout the disturbed areas can help limit the risk.

Operations

During operations, there is limited likelihood of major impacts due to fully implemented water management infrastructure and ready availability of staff and equipment. The relatively higher risk due to the longer time window (years to decades) is at least partially offset by the mine's ability to more effectively manage precipitation events and a strong incentive to respond quickly to avoid lost production. Equipment may have less flexibility for mobility than during exploration and development. Figure 11.15 is a mine site in Montana with site-wide water management infrastructure in place.

Metal tailings and coal refuse may be at increased risk for "black water" (coal refuse water) and other releases due to storm events overflowing retention basins and ponds (if not properly planned for). Flooding events may pose greater risks to overall dam and dike stability, and may cause operational issues with the need for additional pumping of pits and underground mines. More severe thunderstorms

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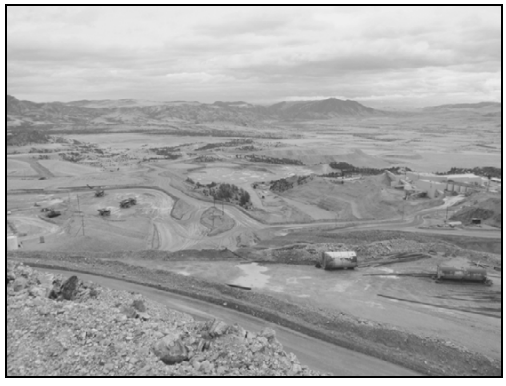


Figure 11.15 Operational mine site in Montana with all water management infrastructures in place

could result in a greater number of days in which blasts must be avoided at open pit mines due to safety considerations.

In the western United States and Australia, which are already relatively arid, water-limited climates, increased droughts and water shortages are likely to occur. Mines in these areas may increasingly come into conflict with other local users of water, such as agriculture, municipalities, and other industries. Droughts in these areas may also cause an increased likelihood of fires, posing an operational and safety risk to active facilities.

Shipping to and from active mines may be affected by climate change. According to the U.S. Global Change Research Program (USGCRP), "Sea-level rise and storm surge will increase the risk of major coastal impacts, including both temporary and permanent flooding of airports, roads, rail lines, and tunnels" (USGCRP 2009).

For mines in northern North America, the ice road season has and will continue to shorten (NOAA 2013), and melting permafrost may damage infrastructure. Although arctic warming is anticipated to lengthen the ocean transport season by decreasing sea ice cover, more coastal erosion is expected to be caused by increased wave activities, which could affect port facilities (USGCRP 2009). Additional challenges may be posed by shorter, warmer, and wetter winters. Shorter winter seasons with more freeze–thaw and rain or snow events can seriously challenge reclaimed and native slopes. There are limits to how effectively a mine will be able to design for and manage these potential challenges in a changing climate.

Current climate models do not yet have the refinement to project changes in precipitation and storm events at the scales needed to effectively design and manage at a specific mine site. As storm recurrence intervals change, water management infrastructure and processing impoundments may become dramatically undersized with an increasing potential through the mine life of emergency overflows or releases, or failure. These events can dramatically change the level of financial, environmental, and safety/personnel risks associated with the project.

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If a project is dependent on at-risk infrastructure—vulnerable coastal shipping facilities, ice roads, power lines to remote sites, permafrost areas, use of freezing techniques, interior shipping routes—these uncertainties may need to be accounted for in the project's financial plan. In some cases, it may be necessary to plan and budget for alternative power sources, access, or shipping routes.

Few examples of mine site/project-specific detailed mitigation/adaptation strategies are available. Mine sites in northern Canada have, on the whole, been more keenly interested in mitigation/adaptation strategies, in part because climate models are much clearer on the range of impacts in the northern latitudes than in other geographic areas (Pearce et al. 2009). In spite of this, Pearce et al. noted that one interviewee reported "incredible stubbornness" to the adoption of adaptation strategies.

Closure

During closure, virtually all constructed and reclaimed features are at risk. The threat is highest before the reclamation is fully established and facilities may be in salvage. Longer-term risk is again counterbalanced by the longer time window, perpetuity, for extreme weather events to occur. Foreseen or unforeseen changes in temperatures and precipitation patterns may dramatically impact revegetation and cover performance, which may impact water management and related costs. Reclamation vegetation may also be impacted by increased pressure from weeds, diseases, and insect pests, which are anticipated to benefit from warming (Figures 11.16 and 11.17). Vegetation success may be a particular concern in arid climates as "Deserts and drylands are likely to become hotter and drier, feeding a self-reinforcing cycle of invasive plants, fire, and erosion" (USGCRP 2009). As reclamation is completed and the site is potentially returned to other ownership following release of the financial assurance instrument, there is an increased likelihood of minor/major impacts. Longer time frames increase the likelihood of severe events. Equipment at the site is generally mobile.

Related Long-Term Issues

A changing climate poses a myriad of complex issues related to mine development. Not the least of these is the extent to which the anticipated challenges related to a changing climate and the related risks should be disclosed to potential investors. In fact, in the United States, the Securities and Exchange Commission has issued guidance on corporate obligations to disclose climate impacts to investors (SEC 2010).

Increasing competition for water in a changing climate will stress all water users and put increasing pressure on mines to effectively manage and treat water (IPCC 2007). This may be of particular concern at mines that have long-term

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Figure 11.16 Recently completed reclamation work. This work is vulnerable until vegetation is fully established, a time period that can range from 1 to 3 years.



Figure 11.17 Established reclamation work. This slope is less susceptible to damage from an extreme event because of the mature vegetation and diversion structures.

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postclosure water treatment obligations, especially those where impacted waters may require treatment.

Mitigation Measures

Mitigation measures for a changing climate can represent a bit of a moving target since the anticipated impacts are based on complex models that generally are not refined enough to give us site-specific metrics. For some aspects of climate change, there is no mitigation possible and adaption will be required.

For mining operations in northern latitudes, the loss of permafrost will impact the travel season by shortening the time that access by road is possible. The only realistic alternative for many sites will be to access sites by air during times when thawing permafrost precludes access. This can have a substantial economic impact on a project. Likewise, any mining techniques that rely on either the existence of permafrost or freezing ground as part of a project will become increasingly difficult.

Coastal sea level rise can be mitigated through anticipating and constructing coastal facilities engineered to be adaptable to higher sea levels. If storm surge is a possible issue, this will have to be accounted for as well.

More extreme weather events also present a challenge. In the United States, mines have typically relied on National Oceanic and Atmospheric Administration (NOAA) storm atlas volumes to determine storm frequency and precipitation intensity. In many portions of the country, these volumes are dangerously outdated (Figure 11.18) and can lead to dramatically undersized water control infrastructure.

Several alternative sources can be accessed to develop more current and realistic storm numbers. Use of the U.S. Geological Survey's (USGS's) National Streamflow Statistics Program (http://water.usgs.gov/osw/programs/nss/summary.html), StreamStats Program for ungauged streams (http://water.usgs.gov/osw/streamstats/), and flood frequency analysis software program (http://water.usgs.gov/software/PeakFQ/) are alternatives. Other helpful sites include the U.S. Bureau of Reclamation's list of AgriMet stations (www.usbr.gov/gp/agrimet/agrimet_station_list.html) and the Western Regional Climate Center (www.wrcc.dri.edu/summary/Climsmnidwmt.html).

Collectively, these sites can bring storm and flow predictions into the twenty-first century. This is an area of active research because it is critical not just for mines but for all aspects of infrastructure. The IPCC fifth assessment report has additional details on precipitation extremes, but complex spatial variability makes site-specific projections a continuing challenge (IPCC 2013). Additional engineering controls may be designed for stormwater by directing it around a site, and/or having equalization basins to catch tailings basin and refuse pond overflow from storm events. In the absence of more detailed guidance, the use of geomorphology-based landforms in reclamation can be a logical first step as they can be more robust than engineered features in many cases.

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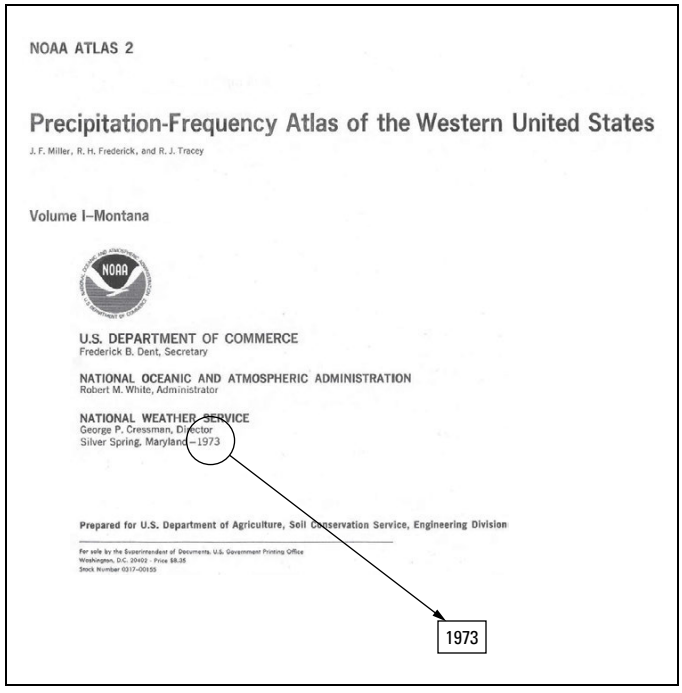


Figure 11.18 NOAA storm atlas cover for Montana showing date

More frequent drought conditions present yet another challenge for reclamation. Mitigation could include planting native drought-tolerant species that anticipate future projected changes in precipitation timing and intensity. The use of geomorphology-based landforms can also help to minimize soil loss, which will be a critical factor in a changing climate where drought is more frequent. Fire preparedness and response plans will be especially important in dry and arid climates. Increased efforts to minimize water use and recycle water within process streams at processing facilities will become increasingly important as competition increases for constrained water resources.

A developing consideration may be the threat to existing and proposed reclamation vegetation as invasive species compete with selected revegetation species. Selected revegetation species may become stressed as the climate changes, making them increasingly susceptible to being outcompeted by invasive species (Kerns and Guo 2012). Mitigation would likely include increased invasive species control measures and vegetation maintenance or even replacement in the event planted species simply cannot survive a changing climate.

Worker and personnel issues in a warmer climate will require mitigation that increases vigilance and incorporates programs to ensure that workers are adequately protected from heat stroke and exhaustion due to higher temperatures. Increased

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risk of exposure to tropical diseases and severe weather events will require appropriate responses within mine safety and crisis plans. In some cases, operations may require either more extensive use of or more powerful air conditioning of facilities that will also increase costs.

Regulatory pressures placed on facilities due to climate change are increasingly requiring emissions reporting, and, depending on the state or province, emissions caps may already be in place. Careful accounting for GHG emissions will become increasingly important as mines of the future will more than likely be required to manage their emissions or provide offsets. Offset projects may provide opportunities for some facilities, such as gassy coal mines, to develop and sell carbon credits to others.

SUMMARY AND CONCLUSIONS

It will be critical for mining companies to plan for extreme weather events as a contingency throughout the mine life and design their closure plans to survive them. The level of detail and commitment required will vary throughout the mine life depending on the nature of the disturbance, the facilities at risk, the availability of staff and equipment at hand, and the relevant time window for potential extreme events. The highest level of risk is likely to be during the extended time period following closure of the mine principally because the time window is essentially infinite. There may be limited staff and equipment available to deal with a multifaceted extreme weather event, and funds are likely to be limited postclosure. The uncertainty of what a 25-year storm or recurrence interval means in a time of changing climate suggests that mine planners should be extremely conservative in developing erosion control and water treatment infrastructure to account for the uncertainties. The uncertainties associated with changing temperatures and precipitation patterns are also relevant for cover design for waste facilities and should encourage operators to evaluate geomorphic-based alternatives to more conventional engineered waste-rock stockpile reclamation.

Worker health and safety issues may well lead to decreased productivity as programs are developed that protect workers from projected changes and risks. Regulatory agencies will be faced with the complexity of developing adequate financial guarantee mechanisms that can realistically account for the myriad uncertainties a changing climate presents.

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CHAPTER 12

Molycorp's Project Phoenix—Water and Reagent Recycling with Clean Power*

Scott Honan and Douglas D. Daugherty

INTRODUCTION

The mission of Molycorp's Mountain Pass rare-earth resource and processing facility in southeastern California is to become one of the largest rare-earth production centers in the world while also reducing wastewater discharge. The Mountain Pass facility achieves this reduction by recycling waste streams into reagents using on-site, natural gas–fired cogeneration of electricity and steam. This unified approach achieves many environmental benefits over a conventional approach: it conserves water, protects surrounding water resources, reduces the intensity of greenhouse gas (GHG) emissions, protects habitat, and reduces raw material use.

The original facilities at Mountain Pass were built during the 1950s and 1960s. Starting in 2004, processes were redesigned, allowing the recycling and reuse of wastewater and raw materials. This major rebuilding, expansion, and modernization endeavor is called Project Phoenix.

This approach greatly improves operational efficiencies and achieves environmental benefits, although it comes with a high capital cost. Although emissions intensity will be reduced in the new facility (less emissions are released per unit of production) than in historic operations, the new facility is projected to produce a higher amount of overall air emissions. However, the cogeneration facility is projected to provide more reliable power at a lower cost per kilowatt hour while providing the needed electricity to recycle key process reagents. This unified approach also eliminates the need for 100 acres of wastewater evaporation ponds, which reduces maintenance requirements and protects existing habitat.

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BACKGROUND

Rare Earths

Rare-earth elements (REEs or rare earths) is a set of 17 elements in the periodic table, specifically the 15 lanthanides (lanthanum, cerium, praseodymium, neodymium, promethium, samarium, europium, gadolinium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, and lutetium) plus scandium and yttrium (IUPAC 2005). Scandium and yttrium are considered REEs because they tend to occur in the same ore deposits as the lanthanides and exhibit similar chemical properties. REEs are relatively plentiful in the earth's crust. However, REEs are not often found in quantities and concentrations that are economic to mine and have therefore been named "rare."

Rare earths are used in many products including emerging clean energy technologies such as wind turbines, compact fluorescent bulbs, and hybrid vehicles. The next generation of wind turbines uses direct-drive turbines employing highly efficient rare-earth permanent magnet generators. REEs are used in energy-efficient compact fluorescent lamps. Rare-earth materials create enabling technologies that are found throughout hybrid electric vehicles (HEVs), plug-in HEVs (PHEVs), all-electric vehicles (EVs), as well as in standard gasoline- or diesel-powered vehicles. Virtually all HEVs, PHEVs, and EVs on the road today also rely on rare earths (primarily lanthanum) in the battery pack that stores energy normally wasted during coasting and braking, saving it until needed by the electric motor. In addition, rare earths are used in battery technologies, smartphones, computers, and many military and homeland security systems.

Because many products require rare earths, the United States is making efforts to understand and address its dependence on other countries for rare earths (Grasso 2012). The rare-earth market is currently dominated by China. China produces approximately 95% of the world output (USGS 2013). In addition, China exercises restrictive rare-earth policies. According to Grasso, in March 2012, "President Obama announced that the United States had joined with Japan and the European Union to bring a World Trade Organization joint dispute resolution case against China because of China's restrictive policies on rare earths and other minerals."

The United States has also begun to evaluate the importance of a domestic supply of rare earths because of the importance of rare earths in many products and the foreign dominance of the market. The Congressional Research Service has raised concerns about domestic production capabilities staying within the United States (Grasso 2012). The most viable domestic supply of rare earths is from Molycorp's Mountain Pass rare-earth deposit, which has been the only significant domestic source of rare earths since the 1950s. Molycorp is enhancing its capabilities to manufacture high-purity rare-earth products at Mountain Pass.

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Molycorp's Mountain Pass Facility

Molycorp is a rare-earths and rare metals company that intends to combine a rare-earth mineral deposit at Mountain Pass, California, with advanced high-purity rare-earth and rare metal processing capabilities. With 26 locations across 11 countries and more than 2,600 employees, Molycorp is vertically integrated across the global rare-earth materials supply chain (Molycorp 2013d). The Mountain Pass facility is located in Southern California, about an hour southwest of Las Vegas, Nevada.

The facilities at Mountain Pass were originally built in the 1960s when Molycorp was primarily producing the heavy rare-earth europium for color television sets. In the 1970s and 1980s, the facilities were expanded as demand for rare earths increased and Molycorp extended its product lines. Today, these legacy facilities at Mountain Pass are still producing rare-earth products, but they are being replaced and upgraded under Project Phoenix.

The Mountain Pass deposit contains on average 8% rare earths, mostly within the mineral bastnasite (Molycorp 2013e). The Mountain Pass facility mines and processes these rare earths into high-purity products. Across its integrated supply chain, Molycorp produces custom-engineered materials from 13 rare earths, plus yttrium, with purity levels in some cases of up to 6N (99.9999%).

Beginning in 2004, Molycorp scientists and engineers began to redesign the production processes used at Mountain Pass. They ultimately created new process technologies that change how Molycorp produces rare earths. Some of these new process technologies enable the recycling and reuse of wastewater and reduce the use of raw materials. Molycorp is in the process of completing construction and commissioning of the facilities necessary to take all of the new process technologies, and the efficiencies they create, to commercial scale.

Molycorp's Vision for Sustainability

Since the 1950s, Molycorp has made steady reductions in the environmental impacts at its Mountain Pass facility through innovative engineering solutions. In 2011, Molycorp engineers took seemingly disparate ideas related to water, energy, and reagent usage and combined them into a single unified business and sustainability mine upgrade and expansion. This chapter discusses the history of the Mountain Pass facility and the options evaluated for the upgrade and expansion. Specifically, this chapter focuses on the integration of three technologies—paste tailings disposal, water and reagent recycling, and on-site power—the implementation of which will further Molycorp's corporate business and sustainability goals. This chapter concludes with details on the business and sustainable benefits that should be realized at the Mountain Pass facility.

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Molycorp's four corporate goals (Molycorp 2013a) lay the basis for its sustainability program:

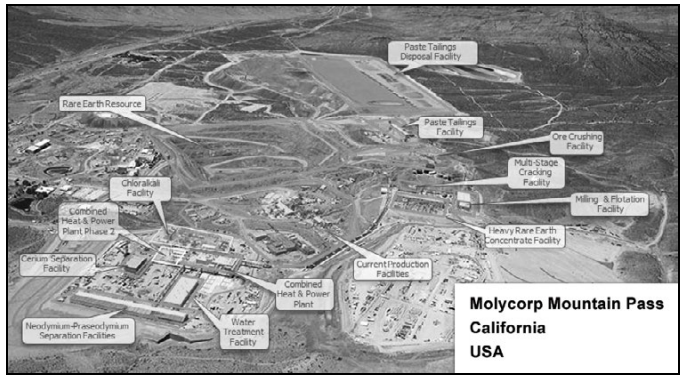
1. Develop game-changing rare-earth technology and products vital to clean energy, high technology, and national security applications for this and future generations.
2. Be commercially sustainable, globally competitive, and environmentally superior.
3. Act as a responsible steward of our rare-earth resources.
4. Use our technology to improve the daily lives of people everywhere.

Molycorp's corporate sustainability goals have guided the company to rethink the way its Mountain Pass facility approaches REE production. Molycorp's Mountain Pass facility is undergoing a $1.5 billion expansion and upgrade, which is planned to be one of the most sustainable and largest rare-earth resource and processing facilities in the world. It will reduce wastewater discharge by recycling waste streams into reagents and water using power from one of the most energy-efficient and clean power sources—on-site, natural gas-fired, combined heat and power. This unified approach minimizes the environmental impacts of the facility through water conservation, protecting surrounding water resources, reducing GHG emissions intensity, protecting habitat, and reducing raw material use. Thus, there is an opportunity here for the Mountain Pass facility to realize Molycorp's corporate business and sustainability goals and to make Mountain Pass a significant rare-earth resource and processing facility.

After receiving the necessary regulatory approvals in 2010, Molycorp began construction at Mountain Pass in January 2011. After construction and commissioning are complete, rare-earth extraction and processing at Mountain Pass is projected to include the following major operations:

- Mining
- Physical separation of rare-earth ore through crushing, milling, and flotation
- Dissolving of the rare earths
- Separating different rare earths and producing separated rare-earth products
- Drying and packaging
- Disposal of tailings using paste technology for low-impact tailings disposal and water recovery
- Recovering reagents and water with a salt conversion facility
  - Recycling waste streams to make reagent (hydrochloric acid [HCl], sodium hydroxide [NaOH], and sodium hypochlorite)
  - Minimizing wastewater
  - Minimizing freshwater usage
- Producing electricity and steam from an on-site, natural gas-fired cogeneration facility

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Source: Molycorp 2013b.

Figure 12.1 Main facilities at the Mountain Pass site

Figure 12.1 shows the different operational units at Mountain Pass, including the current production facilities that were primarily built in the 1960s.

Table 12.1 provides a summary of some of the sustainability improvements that will be realized through the Project Phoenix facility upgrade. Details of the three main process changes that will be implemented to achieve these goals (paste tailings disposal, water and reagent recycling using a salt conversion facility, and on-site power using cogeneration) will be discussed later in the chapter.

Table 12.1 Mountain Pass facility operations with Project Phoenix

Technology	Traditional Method	Molycorp's Innovations
Tailings disposal and water/solid separations	The business-as-usual process at Mountain Pass required storing mine tailings and process water behind a tailings dam.	Molycorp's new facility will form a paste by removing most of the water from tailings. The water will be recycled and the paste will be deposited in successive layers that achieve structural integrity in a short time period. This will eliminate the need for a tailings dam and reduce the footprint of the tailings storage facility, minimizing potential habitat impacts of tailings storage.
Water recycling	Legacy processes produced up to 850 gpm of waste salt water at Mountain Pass, which had to be piped miles away to permitted evaporation ponds for disposal. Mountain Pass also used to require extensive use of evaporation ponds to deal with wastewater produced by legacy systems.	The new plant at Mountain Pass will be a near-zero wastewater disposal facility, virtually eliminating potential environmental impacts associated with wastewater discharges, and recycling virtually all process water. Molycorp's new facility will recycle process wastewater, eliminating the need for more than 100 acres of evaporation ponds.

Table continued next page

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Table 12.1 Mountain Pass facility operations with Project Phoenix (continued)

Technology	Traditional Method	Molycorp's Innovations
Freshwater use	Traditional rare-earth operations require large amounts of freshwater pumped from local underground sources, which then produced large amounts of wastewater as a by-product.	Molycorp's new facility will recycle process water used in the operation, dramatically reducing the need for freshwater.
Chemical reagent recycling	Traditional processes at Mountain Pass required between 15 and 25 tanker trucks per day of chemical reagents that were transported by truck to the facility from locations such as Las Vegas and beyond.	Molycorp's new facility will recycle salt water produced in the operation and use it as a feedstock to regenerate chemical reagents in a continuous closed-recycling loop, minimizing the need for reagent truck deliveries.
Clean power generation	Mountain Pass's traditional process required large amounts of costly grid power from the local utility. Poor power quality and service interruptions increased production costs. Many pieces of on-site equipment used high-emission diesel, propane, and "bunker fuel."	The on-site natural gas–fired combined heat and power plant at the new facility will provide high-quality power and steam, increasing system efficiency and greatly cutting production costs. Other combustion operations across the new facility will use cleaner-burning natural gas, reducing the amount of high-emission diesel, propane, and bunker fuel used on-site.
Greenhouse gas and air emission reductions	The traditional processes at Mountain Pass produced significant emissions per unit of production.	Molycorp's new processes will increase overall system efficiency and reduce air emissions—including carbon dioxide—as compared to the business-as-usual technology approach. By incorporating on-site power generation and reagent regeneration into the design, diesel truck traffic to and from the facility will be dramatically reduced.
Ore milling and processing	The legacy mill and processing facility at Mountain Pass could achieve a recovery rate of only about 50%–55% of rare earths from the ore to solution.	Molycorp's new facility incorporates a variety of operational improvements to dramatically increase rare-earth recovery rates, which will extend the life of the resource.

Source: Adapted from Molycorp 2013c.

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MOLYCORP'S SUSTAINABILITY APPROACH: PAST AND PRESENT

Since the 1950s, the Mountain Pass facility has implemented a number of iterative designs to address production and sustainability opportunities such as solids disposal, water disposal, reagent use, water supply, and energy supply. These have been driven mainly by water disposal, which first requires the effective separation of solids and water wastes. Molycorp took advantage of a water–solid separation process that allowed recycling of the wastewater (as opposed to historical disposal solutions). In conjunction with the water recycling, Molycorp has developed a methodology to recycle wastes in the water stream back into reagents using a clean source of energy. Overall, Molycorp has approached these various environmental and economic issues one by one in the past, but now has combined many seemingly separate engineering solutions into an integrated sustainability approach in the development of Project Phoenix.

Water–Solid Separation and Solids Disposal

As with many mining operations, disposal of unwanted solids can present environmental and logistical challenges. Unwanted solids typically come from overburden (rock on top of the ore as well as rock that is within the mining envelope, which does not contain economic rare-earth concentrations) or tailings (the non-rare-earth-bearing minerals that are present in the ore that are separated out during milling and wet flotation). At Mountain Pass, the dry overburden was stockpiled and subsequently used for construction fill.

Tailings are small particles suspended in water that result from the milling and flotation processes. Because the particles are small, they can settle slowly and have the potential to be transported by the wind when dry. From the 1960s through 2002, Molycorp employed conventional tailings impoundment methods for managing the tailings produced from the milling process. Because the rare-earth ore at Mountain Pass averages approximately 8% rare earth by weight, the tailings represented, by far, the largest waste stream generated at the operation. Two tailings impoundments historically used were called P1 and P16. These impoundments used conventional tailings management technology and were established by constructing engineered earthen dams across natural valley landforms at the Mountain Pass site. Neither impoundment was equipped with a liner, because this was not required by government regulation at the time. Relatively dilute slurries of tailings solids and water were pumped to these impoundments, where the solids would settle out and a supernatant pond of water would form. The supernatant water, or "reclaim" water, was recycled to the milling operation. However, a significant portion of the water present with the tailings was lost in this process due to evaporation from the large surface area of the impoundment as well as infiltration into the groundwater system. The portion of the supernatant water that infiltrated into the groundwater

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system also created localized groundwater quality problems, because the supernatant water had elevated salt concentrations.

Permits to operate the tailings impoundments expired in 2002, and by that time, Molycorp had developed two alternatives to provide for extensive additional tailings storage capacity at the Mountain Pass facility. These options were known as the "East Tailings" and the "Northwest Tailings."

The East Tailings facility was planned to be a conventional tailings impoundment similar to P1 and P16. An earthen dam would be constructed across a valley on the east side of Molycorp's property. The dam and resulting impoundment would occupy 222 acres of relatively undisturbed desert habitat. In keeping with current standards, the impoundment would be equipped with a lining system that contains two plastic membranes, clay, composite material, and soil that exceeds California's lining requirements as a means to protect groundwater resources. This plan was presented to the regulatory community and was met with some skepticism. Environmental issues identified with the East Tailings facility included the following:

- The previous unlined facilities had leaked and impacted groundwater. Although a lining system was proposed for the East Tailings, applying a geosynthetic lining system to such a large area raised the potential for possible groundwater impacts.
- The selected site for the East Tailings had been studied extensively and was known to have three sites within its footprint of archaeological and cultural resource significance that would require mitigation.
- Deposition of the tailings material around the perimeter of the facility would generate a pond of supernatant water that could be recycled, but was also projected to create substantial areas of dry tailings "beach." The dry tailings could be susceptible to wind transport and deposition because the facility is located at the top of a naturally windy mountain pass.
- The reclamation and vegetation of the tailings ponds could only commence once milling operations had ceased (i.e., at the end of the facility's operational life) and after the remaining supernatant water had evaporated.
- The size and height of the tailings impoundment would make it very visible to people in the area, which was undesirable from an aesthetic standpoint.
- There was concern about the risk of placing a large earthen dam uphill of a major interstate highway, I-15.

The Northwest Tailings was conceptually much different than the East Tailings and took advantage of recent advancements in tailings disposal technology and philosophy (Schmidt et al. 2013). The basis of the Northwest Tailings was paste tailings disposal technology. Paste tailings are conventional tailings with the majority of

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the water removed, leaving a thick, viscous, homogeneous material that contains 15%–25% water. This material is pumpable using commercially available positive displacement pumps. The water removal can be accomplished by conventional filtering technologies, which allows for the immediate recycle of the reclaim water to the milling process. When pumped or placed into the paste tailings impoundment, the low water content of the tailings and the generally dry and hot conditions at the facility result in almost no supernatant water. It quickly became apparent that the Northwest Tailings had some inherent environmental advantages over the East Tailings:

- Removal of the majority of the water prior to deposition in the paste tailings impoundment and the subsequent rapid drying of the tailings mass allows for not only a more efficient water recycling process, but it also minimizes the potential for reclaim water to impact the groundwater system.
- The tailings material can be deposited in sheets or thin lifts that rapidly dry and gain strength in the desert environment. The paste material gains sufficient strength such that a pile can be built of the tailings. The ability to stack the material in this fashion means that the footprint of the facility can be substantially reduced. The Northwest Tailings facility was designed to be 90 acres in size (less than half the size of the East Tailings alternative) and is able to contain the same quantity of tailings as the East Tailings facility.
- As the tailings material is deposited in successive lifts, the tailings can be covered and vegetated. Concurrent reclamation not only improves the aesthetics of the facility, but the soil cover and vegetation minimize the potential for the tailings to become windblown and impact adjacent undisturbed habitat.
- The Northwest Tailings facility is situated behind an existing overburden stockpile and is effectively hidden from view by most of the public, thus improving aesthetics. In addition, impacts to known archaeological and cultural resource sites have been avoided.
- Because there is no pond of supernatant water with the paste tailings, there is no need for a large earthen dam. A perimeter berm to contain the initial lifts of tailings and to prevent stormwater run-on is all that is required.

As an alternative to the East Tailings, the Northwest Tailings was viewed favorably by the regulatory community and later by the public as Molycorp plans were subjected to the public review process in California. Although the Northwest Tailings facility has numerous advantages, additional capital is needed to design and construct the filtration and pumping plant that is necessary to convert conventional tailings into paste. This is potentially offset by the smaller footprint of the eventual tailings impoundment and the elimination of the cost for a large earthen dam.

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Advanced Approaches to Wastewater

Management thinking in the 1980s and 1990s, as water demands for the operation grew, was based on a "once-through" philosophy. At a basic level, rare-earth recovery operations dissolve the rare earths present in the ore, separate those rare earths from each other, and then neutralize the resulting acidic solution. This type of chemistry produced water and salt ($HCl + NaOH = H_2O + NaCl$ [sodium chloride]) in the form of a brine. The brine is typically concentrated enough that it is too costly to treat simply to recover the water, and a way would still be needed to deal with the resulting salt after recovery of the water.

The general historic flows of wastewater at Mountain Pass included wet tailings (waste) from the mill. The tailings were approximately 30% water by weight and were pumped to a wet tailings pond but had water losses from infiltration and evaporation, as previously discussed. There was also wastewater output from the beneficiation facilities, along with pit water and remediation water that were sent to a treatment system. The treatment system neutralized excess acid with soda ash and/or caustic (NaOH), and removed precipitates that were generated by the neutralization process. The clear overflow was fed by gravity to the evaporation ponds. For these wastewater streams, Mountain Pass has undergone three phases of wastewater disposal strategies: water evaporated off-site, water evaporated on-site, and water recycling.

In the early history of Mountain Pass, brine was discharged to an evaporation/infiltration basin located in a dry lake bed east of the operation. At the time, this treatment seemed economically and environmentally sound. The cost to construct the evaporation/infiltration basin and associated pipeline was also reasonable, and the groundwater underlying the dry lake bed was demonstrated to contain naturally high levels of salt.

Following this operational philosophy, water was pumped from the groundwater basins and through the rare-earth recovery operations at Mountain Pass, resulting in a brine that was in turn pumped to the evaporation/infiltration basins for disposal. This led to relatively high levels of water consumption. In addition, there were a number of spills and leaks from the 14-mile-long discharge pipeline that connected the operation to the evaporation/infiltration basin. Despite these drawbacks, this strategy was effective in sustaining the operation through the late 1990s.

The shortcomings in the once-through strategy led to the investigation of other methods for managing water. In the late 1990s and early 2000s, the strategy shifted from off-site to on-site brine water disposal. The pipeline to the evaporation/infiltration basins was decommissioned, and a series of on-site evaporation ponds was constructed. The on-site evaporation ponds were constructed with a state-of-the art lining system in 2000 (two ponds) and 2006 (two additional ponds). This strategy allowed for the on-site management of the wastewater produced. The

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capital cost was very high, at approximately $1 million per acre of pond. As with the earlier strategy, the philosophy with respect to water was once-through with the evaporation ponds representing the terminal point in the system. The limitations of this strategy soon became apparent, because the generation of brine was limited to the amount of water that could be evaporated, with allowances made for storm events and seasonal variations in evaporation rate. In addition, the terminal evaporation pond would eventually produce solid salts that would need to be removed and disposed of.

In the mid-2000s, an improvement to the strategy with respect to water was developed. Rather than dispose of the brine produced in the rare-earth recovery operations, the brine would be purified and converted into the primary reagents used in the operation—HCl, NaOH, and sodium hypochlorite (bleach). This design required the construction of the conversion facility, a power plant to supply electricity, and a water-treatment system to purify the brine before feeding it to the conversion facility process. Although the capital cost was projected to be high, this strategy allowed for a potentially high recycle rate for water when compared to historic practices, with freshwater from the groundwater sources only needed to make up for the water lost to evaporation, entrained in products produced at the facility, or lost as steam.

Reduced Reagent Usage Through Recycling

On-site production of HCl, NaOH, and bleach from brine water provides considerable stability with respect to the supply of key reagents to the operation. Prior to this innovation, Mountain Pass was reliant on external supplies of chlor-alkali products (HCl, NaOH, and bleach). Prices and availability of these reagents can change dramatically. In 2008, the combination of severe weather and the economic downturn resulted in a serious deficit of supply for chlor-alkali products. Weather events impacted production at a number of large chlor-alkali producers near the Gulf of Mexico, and the economic downturn reduced the amount of by-product HCl produced by the plastics industry. Prices increased markedly for key reagents in a few months, and supplies were limited enough that Mountain Pass could only operate at a reduced capacity for several months in 2008. By producing key reagents from the brines at Mountain Pass, the operation's sensitivity to fluctuations in the chlor-alkali market is reduced and a more sustainable environmental approach is achieved.

Less Freshwater Sourcing as a Result of Advanced Reagent Recycling and Wastewater Treatment

The initial supply of water for the facility came from a series of groundwater pumping wells located in the Ivanpah Valley, approximately 9 miles east of Mountain Pass. The production wells ranged in depth from 500 to 1,000 ft, and the valley

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itself is approximately 2000 ft lower than the Mountain Pass operation. The elevation difference required three boosting stages to get the water to a head tank at Mountain Pass, which resulted in a relatively high pumping cost to deliver the water to the operation.

Development in the Mountain Pass area has been growing in recent years, and the water supply available from the groundwater aquifers is limited. In the long run, groundwater supply is likely to be constrained by the amount of water that periodically recharges the groundwater aquifers. The availability of water in the Ivanpah Basin has been studied periodically over the years, with the most recent work completed to support the environmental analysis of a proposed solar power plant in the Ivanpah Valley (Timothy J. Durbin Inc. 2007). Although this report concludes that sufficient recharge is available to sustain the current and planned water uses in the Ivanpah Valley, the analysis relies on assumptions regarding groundwater recharge to the basin, which are difficult to measure directly. Clearly, Mountain Pass is operating in a dry climate, and there is a corresponding need to conserve groundwater resources.

As the operation expanded, the initial response to the water supply issue was to install a second groundwater supply system in a separate groundwater aquifer known as Shadow Valley, located approximately 9 miles west of Mountain Pass. The Shadow Valley system became operational in the early 1980s. This provided the operation with some insurance against problems or disruptions with the water supply from the Ivanpah Valley.

Molycorp expects to reduce its freshwater consumption to approximately 390 gpm by implementing the paste tailings process and through recycling. For perspective, the amount of freshwater consumed by the facility in 1996 was approximately 850 gpm or an estimated 1,388 acre-ft from the two well fields. The 5-year annual average for freshwater consumption between 1993 and 1997 was 795 gpm or 1,281 acre-ft (Braun et al. 2010).

Lowering Air Emissions Intensity Through Clean Power Supply

When operations commenced in 1952, there was little infrastructure in the Mountain Pass area to support an industrial operation. The only option for power was the local electric grid, and the unit operations that required heat and steam were based on imported fuels, mainly no. 6 and no. 2 diesel fuels. Although this combination of grid power and imported fuels was adequate to serve the operation and even allow it to grow, this grouping of power sources was both unreliable and relatively inefficient when compared with current technologies. Grid power reliability has always been an issue for the operation, because key aspects of milling and rare-earth separation rely on continuous operation to operate efficiently. Grid reliability issues result from the location of Mountain Pass at the far eastern end of a main distribution line originating in the Los Angeles (LA) Basin, such that

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any problems with the system between Mountain Pass and LA results in the loss of power at Mountain Pass. During July of 2008, operations were shut down for 88 hours because of the loss of grid power.

Steam is also very important in rare-earth separations. Bastnasite, the rare-earth-bearing mineral at Mountain Pass, is separated from the other minerals in the ore using froth flotation. The particular froth flotation process used at Mountain Pass operates best at an elevated temperature, with the heat provided by steam from the cogeneration facility or other sources. Leaching and solvent extraction operations at Mountain Pass are also optimized at elevated operating temperatures. The initial designs for steam production at Mountain Pass were based on traditional steam boilers, which are relatively inefficient when compared to modern equipment.

In 1992, the Kern River Gas Transmission Company commissioned a natural gas pipeline within 9 miles of the Mountain Pass operation, which represented an alternative source of energy for electrical power and steam. Agreements were formalized in the 2008–2010 time frame, which allowed for the construction of a natural gas lateral pipeline to Mountain Pass concurrently with the construction of Project Phoenix. The natural gas is combusted in a cogeneration power plant, which uses turbines and heat-recovery steam generators to supply the electricity and steam that the facility requires. Natural gas cogeneration is a relatively clean and efficient energy source.

CONCEPTUAL DESCRIPTION OF MOLYCORP'S CURRENT INTEGRATED SOLUTION

Mountain Pass will be implementing a solution to recycle waste streams back into inputs. This solution achieves Molycorp's corporate sustainability goals by conserving water, protecting surrounding water resources, reducing waste, and reducing GHG emissions.

Molycorp's solution focuses on converting waste salt water into clean water and chemical reagents. This reduces wastewater, conserves freshwater, and reduces the need to truck in reagents produced elsewhere. The recycling occurs in the new plant that is being constructed at Mountain Pass, where electricity is used to convert the salt water into the aforementioned inputs. The electricity will come from an on-site natural gas–fired cogenerating power plant as an alternative to purchasing electricity from the local grid. Mountain Pass will also recover the heat from the cogenerating power plant to use in the facility instead of creating the heat from separate boilers, thereby reducing the intensity of GHG and other air emissions.

Figure 12.2 compares the traditional once-through approach with the new "cradle-to-cradle" approach previously described. The new approach is an integrated solution that uses waste materials and waste heat (i.e., energy) as inputs to the system.

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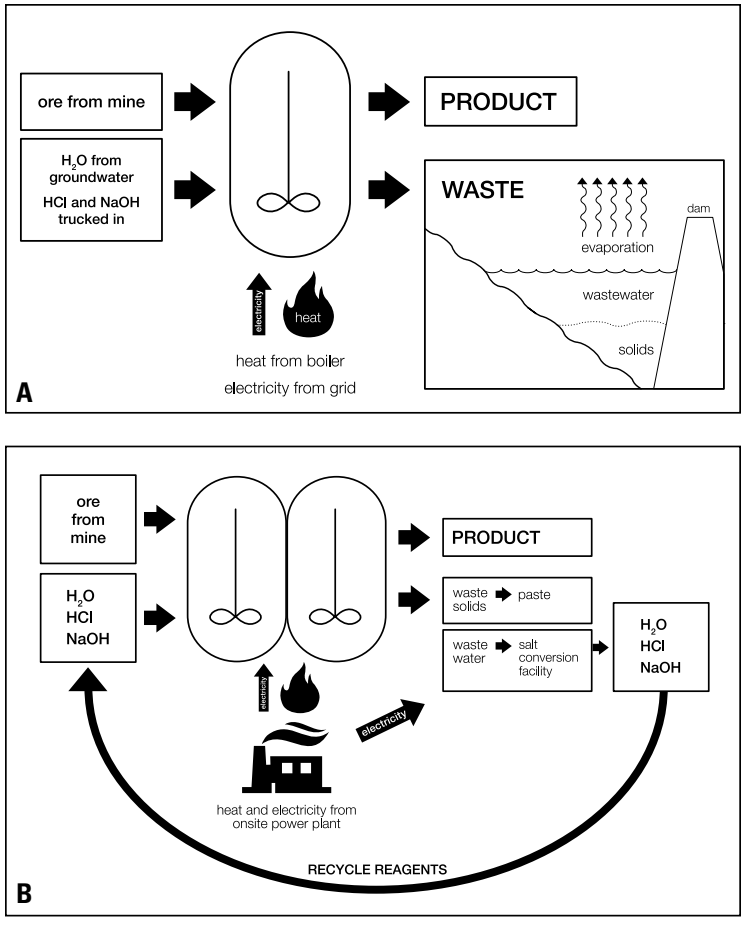


Figure 12.2 Schematic illustration of the (a) once-through approach compared to the (b) new cradle-to-cradle recycling approach at the Mountain Pass facility

Molycorp made the conscious decision to locate these activities at the Mountain Pass facility as opposed to purchasing these commodities from a third party. Although this new approach is projected to improve operational efficiencies, it comes with a capital cost and an increase in overall facility-specific air emissions (but does lower the emissions intensity) when compared to historic operations. The three main design components—paste tailings disposal at the paste plant, water and reagent recycling using a salt conversion facility, and on-site power using cogeneration—feed into a multitude of sustainability achievements within Project Phoenix, as outlined in Table 12.2.

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Table 12.2 Mountain Pass facility operations with Project Phoenix

Sustainability Achievement (social and environmental impacts reduced)	Project Phoenix Design Component		
	Paste Plant	Salt Conversion Facility	Cogeneration
Protected habitat	X	X	
Reduced wastewater disposal	X	X	
Fewer releases to water	X	X	
Fewer chemical inputs		X	
Decreased traffic/transportation		X	
Reduced freshwater use	X	X	
Less GHG intensive			X
Less air emission intensive			X
Reduced need for electricity infrastructure			X

Project Phoenix Design Details

Molycorp's corporate goals and values framed the discussion for being an environmental steward. Molycorp engineers carefully considered their goal of making Mountain Pass into one of the largest rare-earth production centers in the world. They also contemplated the potential environmental impacts from the mine and developed prospective sustainable solutions that are in the process of being tested and implemented on a plant scale. The following sections describe additional details regarding the three major innovations that allow the Mountain Pass facility to realize Molycorp's corporate sustainable goals:

1. The paste plant will allow the effective separation of the water and tailings.
2. The new salt recycling plant will take the salt water from various parts of the facility and turn it into clean water and reagents using electricity.
3. The cogeneration facility will provide the electricity.

Paste Plant

The paste plant will allow the effective separation of tailings into reusable water and paste tailings. The plant will therefore facilitate water recycling, minimize potential releases to groundwater, diminish the need to use groundwater, reduce the necessity to change desert habitat into evaporation ponds, and enable the other sustainable engineering solutions such as salt recycling. Even though the paste plant makes a paste from the mill tailings that can be stacked and will then dry into a solid, the benefits from the project depend on the ability to make a material suitable for paste disposal.

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Paste is a proven technology being used worldwide. Studies completed to date demonstrate that tailings at the Mountain Pass mine, received from the milling and flotation processes, are well suited for paste production. The Mountain Pass paste disposal solution is described as follows:

1. The milling process will generate tailings.
2. Paste production equipment will dewater the tailings and water mixture into a paste stream and a water stream.
3. The paste production equipment will recombine the liquid and solid streams to make a paste.
4. The system will dispose the paste into a paste tailings disposal area (Schmidt et al. 2013).

The paste plant will receive material from the milling and flotation processes. Milling is a physical process that reduces the size of the material to be processed. Flotation then separates the rare-earth minerals in the ore from the tailings. The tailings slurry solids concentration is approximately 30% by weight.

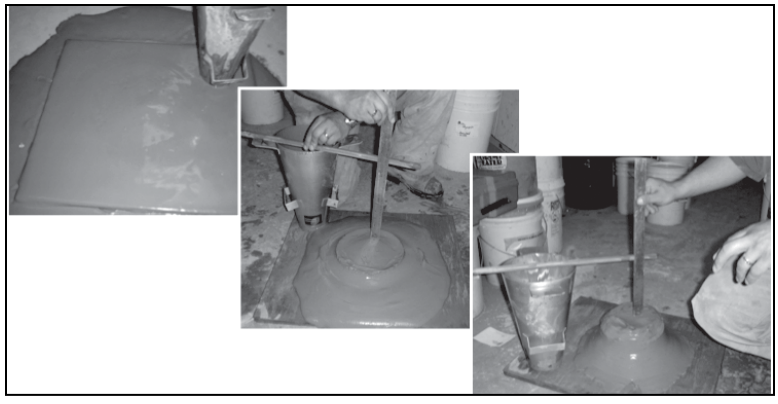
Tailings will be pumped as a dilute slurry from the mill to the paste plant for filtration. Filtration will be performed by pressure filters, with each filter dewatering the thickened tailings to a "cake" consistency in a batch cycle.

A thickener will receive the tailings slurry from the milling and flotation processes. Here, solids will be settled and the resulting water will be recycled to the mill for reuse. A thickened slurry will be sent to the paste plant from the thickener. This system for recycling water will decrease water use and thereby reduce the need for freshwater.

The filter cake will be combined with slurry from a thickener to produce a paste at the proper "slump." Paste slump is an important parameter when producing paste. Figure 12.3 show slumps for different tailings/water mixtures. The bottom right photo shows a high slump and is considered a paste. Careful control of the slump is needed to ensure that the paste material produced has the correct properties for stacking in the paste tailings impoundment.

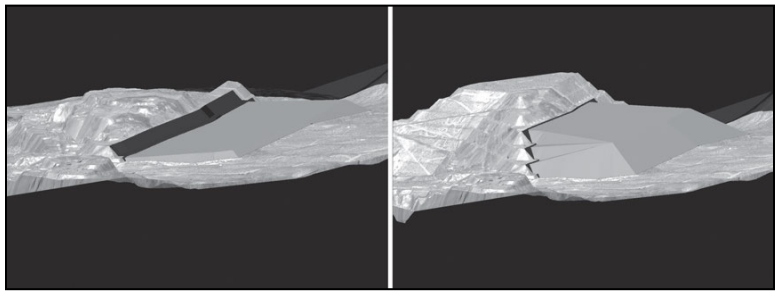
The paste is transferred to the paste impoundment and layered into stacks where it dries into a solid. Studies on the Mountain Pass tailings completed in the lab have demonstrated the correct geotechnical and geochemical properties for manufacturing paste. In addition, climatic conditions at the mine site are particularly favorable for managing a paste tailings material—a high evaporation rate (96 in./yr) and very low precipitation rate (6.2 in./yr). Figure 12.4 shows the plan for Mountain Pass's Northwest Tailings disposal facility and illustrates how important it is that the paste can be effectively stacked. Being able to stack the paste reduces the footprint needed for disposal, thereby reducing the prospective impact to the land. Because paste dries into a solid, paste stacking also reduces the ability for the tailings to be transported by wind or water.

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Source: Sharrer et al. 2002.

Figure 12.3 Various tailings water mixtures and slump ratings



Source: Sharrer et al. 2002.

Figure 12.4 Northwest Tailings disposal facility's 10- and 30-year paste disposal plan

Salt Recycling Plant

The purpose of salt recycling is to recycle the salt water generated in the plant and manufacture HCl, NaOH (caustic), and sodium hypochlorite (bleach). The HCl, caustic, and bleach could then be recycled back into other processes on-site or potentially sold to off-site customers. The recycling of these materials reduces the need to ship in raw reagents from off-site and reduces the need to source freshwater.

The salt recycling operation uses electricity in conjunction with membrane technology to first produce chlorine, hydrogen, and caustic. The chlorine, hydrogen, and some of the caustic can then be used to produce HCl and bleach. The hydrogen produced will be used entirely to convert chlorine into HCl. The remaining chlorine will be reacted with caustic to produce bleach.

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Cogeneration Facility

The cogeneration facility (using combined heat and power, or CHP) will provide electricity to the Mountain Pass facility. The salt recycling operation will use a substantial amount of the electricity generated to recycle waste streams into reusable water and reagents.

The CHP facility has four Solar Turbines Titan combustion gas turbine generators and heat recovery steam generators (HRSGs) with supplemental firing of the duct burners. The exhaust heat from the turbines in combination with the additional heat from the duct burners is captured in the HRSGs to produce steam that will be used for processes. This cogeneration enables the recovery of heat and thereby reduces fuel usage (and associated air and GHG) emissions. The HRSGs include feedwater economizers designed to maximize the heat extraction from the turbine exhaust, thereby producing the maximum amount of usable heat while using the minimum amount of fuel.

Mountain Pass is located at an elevation of approximately 4,500 ft in a dry desert environment with daily high-temperature swings throughout the year. Considering site conditions and average annual temperature, the combustion turbines will have an average gross power generation capacity of about 12 MW each. The turbines are installed with combustion air inlet cooling to increase the power generation capacity during the warmer times of the year.

The natural gas–fired turbines are equipped with Solar Turbine's low oxides of nitrogen (NO_x) SoLoNOx low-emissions combustion technology. The exhaust gas will be treated to reduce air emissions using selective catalytic reduction and oxidation catalyst technologies to meet the "best available control technology" (BACT) regulatory requirement of the Mojave Desert Air Quality Management District. The cogeneration system will reduce the air and GHG emissions over a business-as-usual approach. Much of the steam generated is from the waste heat from the turbines that would have otherwise gone to waste. In addition, the entire system uses natural gas, which creates much less emissions than diesel (the original fuel source for boilers before the cogeneration facility was commissioned).

The existing Southern California Edison electrical supply line will remain in use. The plant's electrical system is designed such that the new CHP system will operate separately and will not be connected to the utility in parallel generation mode.

REALIZED BENEFITS

These three solutions (paste disposal, salt conversion, and cogeneration), when integrated together, will enable the Mountain Pass mine to realize Molycorp's corporate business and sustainability goals. The integrated solution will help to preserve desert habitat, reduce wastewater disposal, require fewer purchased chemicals to be used

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and transported to the site, decrease traffic/transportation needs, reduce freshwater use, make the process less GHG and air emission intensive, and reduce the need for electricity infrastructure. These environmental, social, and economic benefits are discussed in more detail in the following sections.

Habitat

Choosing to use paste disposal and the salt conversion facility instead of evaporation ponds will avoid the environmental impact to 100 acres of relatively undisturbed desert habitat. It will also eliminate the social impact of disturbing three sites with archaeological and cultural resource significance.

This desert habitat has the potential to host the threatened desert tortoise. In addition to avoiding this habitat impact, a Desert Tortoise Head Start Facility was built (Molycorp 2013f). The 7-acre facility was completed in 2011 and is operated by the National Park Service. The land, power, and water are supplied by Molycorp, and the facility was constructed by Chevron. The facility consists of a LEED (Leadership in Energy and Environmental Design) Silver research station and several pens ranging from 10,000 to 22,500 ft^2. Research conducted at the facility will provide critical information regarding tortoise hatchling and juvenile ecology, behavior, physiology, and survivorship.

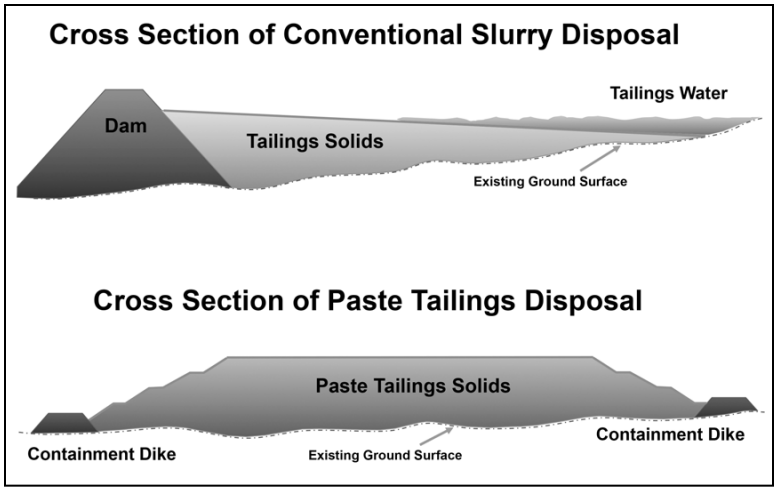
The facility is specially designed to protect young tortoises by using a "head-starting" technique that includes gathering a sample population of gravid desert tortoises just prior to egg-laying. The sample population is placed into a caged enclosure, and the females are allowed to deposit their eggs in a natural setting. After their eggs are deposited, the females are returned to their original capture sites. The eggs are allowed to hatch in situ, and hatchlings are allowed to grow at natural rates to a size considered to be safe from most predators (5 to 7 years).

The released tortoise will then be tracked following release using a revolutionary telemetry technology. Headstarting will increase the size of desert tortoise populations in the vicinity of the facility. The first phase will involve 60 hatchling tortoises, and the initial research is expected to last for at least 7 years. Efforts at the facility will result in the development of new technology and will provide new data important for range-wide efforts to recover the desert tortoise.

Wastewater Disposal

The combination of the paste technology and salt recycling will eliminate substantial volumes of process water disposal (Molycorp 2011). Without these technologies, the water would need to be disposed of either off-site or on-site. The paste-disposal approach eliminates the need for an earthen dam that would have held the water and the tailings, as illustrated in Figure 12.5. By reducing the need for a dam, impacts to native lands and habitats are reduced. In addition, long-term operational

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Source: Sharrer et al. 2002.

Figure 12.5 Schematic of traditional tailings disposal (dam) and paste tailings disposal. For the same land area, the paste solution can hold more tailings.

maintenance required of such a dam and potential safety considerations are also eliminated.

Releases to Water

By recycling the water, Mountain Pass reduces its environmental risks by minimizing the possibility of unintentional discharges from pipes because there will no longer be miles of piping that go off-site. Additionally, Mountain Pass minimizes the possibility of unintentional discharges from the evaporation ponds into the surrounding water table by removing the water from the tailings mass prior to impounding the tailings. When tailings are disposed of as a paste, they are relatively immobile and dry quickly, minimizing the potential for groundwater interactions.

Chemical Inputs

Creating the chemical inputs on-site reduces Mountain Pass's need to purchase these chemicals from a third-party vendor. This is analogous to "local sourcing" of one's groceries or growing one's own vegetables in the backyard instead of purchasing items that are produced far away. In addition, because Mountain Pass is using natural gas cogeneration technology and diligently reusing the heat from the power plant, it is likely that the creation of these chemicals is less energy intensive than if these chemicals were produced elsewhere at less modern and less energy efficient facilities, thus reducing the overall environmental impact of the chemical use.

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From a cost-and-business continuity standpoint, creating the chemicals on-site protects Mountain Pass from cost fluctuations and market scarcities. Prices and availability of these reagents can change dramatically, as previously discussed. By producing key reagents from the brines at Mountain Pass, the operation's sensitivity to fluctuations in the chlor-alkali market is minimized, reducing economic risks to the operation.

Traffic and Transportation

On-site production directly reduces the number of truck trips needed to deliver these reagents to the site. By reducing traffic on the roads, safer driving conditions exist for local traffic, minimizing a local social impact of the facility. Environmental impacts are also reduced, because air pollution and GHG emissions are also decreased with less traffic. Molycorp estimates that the salt conversion facility will eliminate the need to buy numerous truckloads of acids and bases each day, thereby reducing GHG emissions by approximately 700 tpy (assuming the acid would come from nearby Las Vegas, Nevada).

Freshwater Use

The integrated water solution project (paste disposal and salt recycling technologies) will reduce the need to source freshwater. As part of the comprehensive plan for continued operations, Molycorp placed emphasis on on-site management as well as treatment of process water and maximizing reuse. The increase in water reuse and the reduction in water usage required for mineral recovery operations will reduce freshwater consumption on-site.

Molycorp expects to reduce its freshwater consumption to 390 gpm. For perspective, the amount of freshwater consumed by the facility in 1996 was approximately 850 gpm or 1,388 acre-ft from the two well fields. The 5-year annual average between 1993 and 1997 was 795 gpm or 1,281 acre-ft (Braun et al. 2010). This reduction in freshwater use is in accordance with Molycorp's corporate goals concerning sustainability because the operation is located in the high desert mountainous region where water conservation is critical. By reducing freshwater uses, the facility is minimizing its impact on the local environment and water resources. The remainder of the site's water needs could be supplied by water that flows into the mine pit from the surrounding aquifer as well as from intensive internal recycling.

Greenhouse Gas Emissions

The cogeneration facility enables the use of the salt conversion facility, which in turn enables the sustainability achievements previously described. This natural gas–powered CHP plant is intended to cut Mountain Pass's energy costs by more

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than 80% and improve energy reliability (Molycorp 2011). In addition, the plant is expected to have fewer environmental impacts by reducing the GHG emissions by 19% over what would have been produced using conventional technology (Molycorp 2011).*

The use of natural gas delivered by pipeline also minimizes the amount of fuel deliveries to the site by truck. In addition, the natural gas pipeline and power plant facilitate the operation of the salt recycling plant (which will use a substantial amount of the generated electricity), which also minimizes reagent deliveries to the site by truck. The net impact of the natural gas pipeline and cogeneration plant is a localization of GHG emissions, given that the emissions associated with reagent production occur at the plant as opposed to another entity's production facility. Consequently, the inherent efficiency of on-site generation combined with the elimination of truck trips between reagent and fuel suppliers and the Mountain Pass facility will result in a lower GHG emissions intensity than with historical operations.

Air Quality

Although the Mountain Pass operations are expanding and increasing the overall on-site air emissions, the facility is displacing emissions from elsewhere. For example, the construction of an on-site cogeneration facility replaces some of the need to purchase electricity from the grid. Because the cogeneration facility is using a relatively clean fuel (natural gas) and reusing the waste heat, it is emitting only a fraction of the pollution that would occur on- and off-site if it had been purchasing the electricity from the grid and using conventional boilers to produce the heat. Thus, the cogeneration facility lowers the intensity of airborne emissions and reduces the environmental impacts of the facility.

The equipment is subject to strict air-quality rules, and the cogeneration facility turbines are equipped with low NOx, low emissions combustion technology, as well as an emissions reduction catalyst. The chemical processing facilities use state-of-the-art pollution control equipment to capture and recycle much of the potential pollution, such as hydrochloric acid and chlorine. Mountain Pass has also procured the necessary offsets within the air basin to compensate for certain emissions increases that will occur on-site with the larger operations being constructed under Project Phoenix, in accordance with the requirements of California's air quality regulations.

* Percentages were determined as follows: The fuel use, GHG emissions, steam production, and electricity production of the cogeneration facility were calculated at full load. These GHG emissions were then compared to the GHG emissions should that steam be produced from a diesel boiler operating at 85% efficiency and that electricity be generated from Southern California Edison assuming that 33% of the electricity is from renewable sources.

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SUSTAINABILITY MAKES BUSINESS SENSE

Molycorp's Mountain Pass facility is becoming a leader in sustainability through the same engineering decisions that make business sense. For example, by creating an integrated cradle-to-cradle reagent-and-water solution and using one of the most energy-efficient and clean sources for power, the Mountain Pass facility is becoming a leading environmental steward while at the same time freeing itself from power and reagent price fluctuations. Molycorp engineers integrated three technologies—paste tailings disposal, water and reagent recycling, and on-site power—and combined them into a single unified business and sustainable mine upgrade initiative. The Mountain Pass approach, if successful, will conserve water, protect surrounding water resources, reduce GHG emissions, protect habitat, and reduce raw material use.

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CHAPTER 13

Geothermal Energy Recovery from Closed Underground Mines

John Ashley Scott and Andrew Hall

INTRODUCTION

It has been estimated that the number of closed and abandoned mines worldwide is well over 1 million (Wolkersdorfer 2008). Mines are extremely capital intensive, but despite this investment, the traditional view has been that they have little useful value after mine closure. A significant step toward sustainable mining would be nontraditional uses for mines and their surrounding lands that would allow sites to continue to provide value and jobs to the community after mining operations cease.

The alternate use of mine infrastructure following closure of ore-extraction activities would contribute to community sustainability and improve the morale of those who historically relied on the mine and its suppliers (Demollin-Schneiders et al. 2005). One option is to consider using these sites for energy storage and/or recovery schemes that would offset fossil fuel consumption and reduce greenhouse gas (GHG) emissions.

Certain disused underground mines have the potential to be used for energy storage (Evans et al. 2009) such as by a compressed air energy system, or CAES (Evans 2009). The aim of a CAES is to use electricity from renewable sources or off-peak output from utility power plants to compress air and store it under pressure underground. When there is a peak demand for electricity, the compressed air is withdrawn and used to power a turbine. CAES storage is commonly used where there are large voids, such as in salt mines and limestone caverns (Evans 2009). Use of warm mine water (Scott et al. 2009) to support the growth of microalgae for on-site biodiesel production is also of interest. Other studies have looked at energy recovery from mine waste dumps (Molson et al. 2005; Raymond et al.

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2008), where a ground circuit heat pump system would collect energy from heat exchangers installed inside the dump and deliver it for space heating.

After the ore has been extracted from some closed underground mine sites, the resulting open voids once considered to be worthless may go on to be flooded (Antonijevic and Komatina 2011). Because the mine water would be heated by thermal energy in the surrounding rock, these mines could be a valuable geothermal energy resource that can be recovered by heat pumps. During the winter, heat could be extracted from the mine water and supplied for community or business heating. In the summer, the process could be reversed to provide cooling, where the heat would be transferred back to the mine water.

Drilling and excavation for new geothermal installations can account for 33%–55% of the overall project cost (Kranz and Dillenhart 2010). The subsurface resources of underground mines that have passed their useful operational life span could, therefore, significantly help offset these costs and be a community partner for geothermal energy recovery. Consequently, the mine would provide additional economic value to the community beyond that of the mineral resource.

Around the world, there are only a few geothermal installations in place in closed mines, typically using mine water as a source of low-grade energy for space heating (Hall et al. 2011). Near the end of this chapter, an illustration is given showing how geothermal energy recovery from an abandoned mine can be estimated. The case study is centered on long-disused and flooded copper mines at Bruce Mines (Ontario, Canada). The desire by the local community was to investigate whether geothermal energy can be recovered from the mine water and used to support new business opportunities for the region.

GEOTHERMAL ENERGY RECOVERY

The usual methods to exploit geothermal energy contained within mine water are heat pumps in conjunction with open or closed loops (Ghomshei and Meech 2003; Milenić et al. 2010). The heat pumps can be used to provide space heating and cooling. In the winter, energy is taken from the mine water, and in the summer, energy is transferred back into the water (Malolepszy 2003). If the mine water is used only for heating, it will cause the temperature of the water to decrease over time. That is, the surrounding rock will slowly cool, resulting in a diminished heating capacity for the geothermal system. Therefore, a benefit of returning water with heat added for part of the year is to counter the steady loss in heat. In addition, maintaining the water level in the mine must be considered, not only to optimize the geothermal system, but also to minimize oxidization of the ore body and aid the stability of the old mine workings (Wolkersdorfer 2008).

Heat pumps operate by removing heat from the mine water and passing it into a refrigerant that distributes the heat to a space-heating radiator or under a floor system (Figure 13.1). Refrigerant circulating in the heat pump system collects heat

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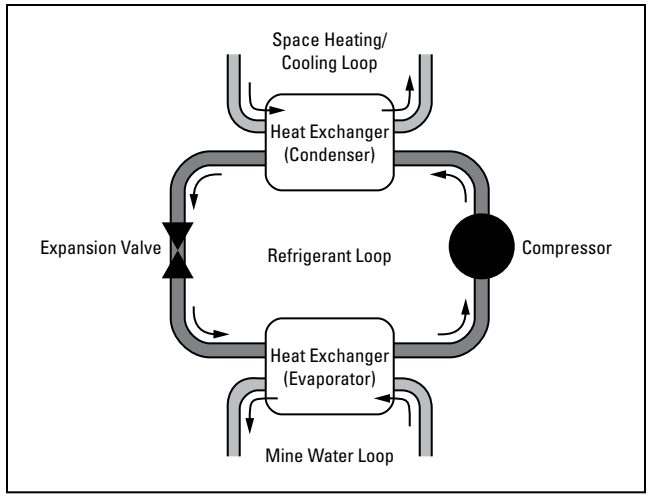


Figure 13.1 Heat pump flow diagram

from the mine water by a low-pressure heat exchanger. This causes the refrigerant to evaporate and change to a vapor. The vapor is then compressed with its temperature increasing with pressure to typically around 70–80°C.

Using a second heat exchanger, heat from the refrigerant is transferred to water circulating through the space-heating system (e.g., radiators). This causes the refrigerant to drop in temperature and condense back into a liquid that is passed through a valve which causes it to expand. This results in a further drop in temperature, and the now-cold refrigerant is passed back to the low-pressure side heat exchanger where it again absorbs heat from the mine water. By reversing the flow of the refrigerant, a heat pump system can also be used for cooling applications (e.g., air conditioning). In cool seasons during the heating cycle, mine water is, therefore, a heat source. In warmer seasons when heat is transferred into the mine water, it acts as a heat sink.

A key parameter in operating a heat pump is the coefficient of performance (COP), which is a measure of the efficiency of heat extraction or provision of cooling. For heating, the COP is the ratio of the input work (typically that from the electricity supplied to the heat pump system to operate the compressors and pumps) to the heat recovered from the mine water, plus the heat added by the input work. For example, if the heat pump produces 1 kWh of heating and in doing so consumes 0.25 kWh of electrical power, then 0.75 kWh must have been removed from the mine water. Therefore, the COP will be

$$\text{COP} = (0.75\ \text{kWh} + 0.25\ \text{kWh})/0.25\ \text{kWh} = 4$$

The typical range of COP for commercial heat pumps is 3.5 to 5.5, but the overall amount of energy recovered will depend on the size and number of installed

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heat pumps. These in turn will be based on the temperature and flow of water from, or back into, the mine. If the water is to be discharged at the surface (e.g., into a surface water body such as a river or lake) following the removal of energy, then regulations on water chemistry and water temperature must be adhered to. For instance, in Ontario, Canada, regulations state: "The natural thermal regime of any body of water shall not be altered so as to impair the quality of the natural environment. In particular, the diversity, distribution and abundance of plant and animal life shall not be significantly changed" (MOE 2013). These guidelines limit water discharge to a maximum of 10°C above the local ambient temperature, although they lack a guideline for cool water discharges.

If the water is to be returned underground following energy recovery, then it is imperative that the geothermal capacity of the mine be determined. That is, if too much cooled water is returned for the geothermal resource underground to heat it back up, then the temperature of the water pumped back out can quickly decline until recovery of energy is no longer sustainable. If the heat pump system is reversible and provides space heating and cooling, then the size of the system can increase compared to a system used solely for heating (Malolepszy 2003). The addition of energy to the water during the cooling season counters energy removed during the heating season. This can greatly reduce temperature degradation of the mine water.

Unless a geothermal energy recovery system is being considered for a mine that is being continually dewatered after closure, the usual strategy is to return the water back into the mine after heat extraction or addition. To achieve this, there are two types of geothermal loop systems coupled to a heat pump that can be employed.

Most residential geothermal setups use closed loops (Haehnlein et al. 2010), with the loops placed in the ground in a variety of ways. The loop system may also be located in a pond or lake if there is one in close proximity. Closed loop systems will be used in mines if the source of water is contaminated and poses a negative environmental impact and/or potential damage to the heat pump's heat exchangers (e.g., from high-acidity-related corrosion or high levels of abrasive solids). Operating under acceptable conditions, heat pumps can be expected to function for 10–15 years.

The most likely type of closed loop for a flooded mine is an in-shaft system, as illustrated in Figure 13.2. This simple closed-loop system features an in-shaft heat exchanger coupled to a heat pump to provide space heating/cooling for nearby buildings (Ghomshei 2007).

Open-loop systems are generally less expensive because of a simpler and typically shorter piping arrangement. These systems are appropriate when there is a large volume of water available that is of reasonable quality. Therefore, this type of geothermal installation is found in closed, flooded mines when the water does not have any problematic characteristics to the environment or heat pumps.

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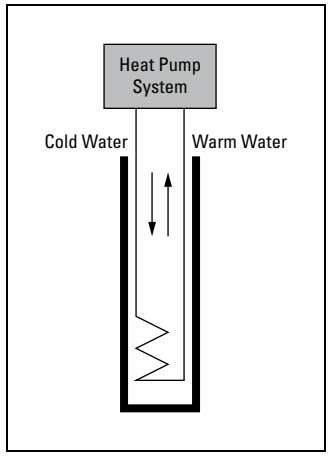


Figure 13.2 Closed-loop geothermal system

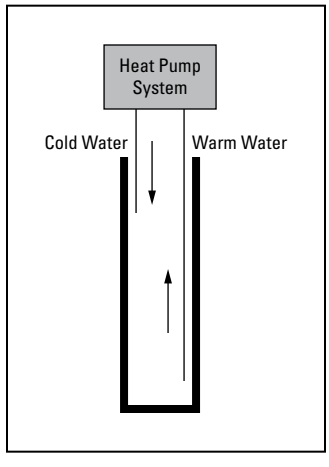


Figure 13.3 Open-loop geothermal system

As shown in Figure 13.3, an open-loop system has pipes at different elevations or in separate parts of the mine. During the winter, the water is taken from the deeper part of the loop where it is warmer and injected back in at a higher elevation. In the summer, this is reversed, with cool water taken from higher up and discharged back into the deeper well.

APPLICATIONS FOR GEOTHERMAL ENERGY RECOVERED FROM MINES

The installations worldwide that recover energy from mine water have a similar profile in that their primary focus is to utilize water from closed and flooded mines, upgrade the heat with heat pumps, and then use it for space heating (Hall et al. 2011). This may only be an option, however, for mine sites with large enough

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heating and/or cooling demand in relatively close proximity to the mine (Raymond and Therrien 2008). The space heating is typically achieved with hot-water, in-floor heating loops and radiators, although a heat exchanger can be used following the heat pumps to provide forced air heat for retrofits in buildings (Banks et al. 2004). Some of these installations have also been designed so that in the summer the direction of flow can be reversed to provide space cooling.

The majority of existing installations use abandoned coal mines, although there are a few based on metal ore mines. Uses for the recovered energy vary from single buildings to district heating and cooling systems. Geothermal district heating systems provide space heating to a large number of buildings. It is preferable to design and install district heating and/or cooling systems early in the development of a community near an abandoned mine site (Waziaf and Ackman 2006). For a district heating system in Shettleston (Scotland), energy recovery is from flooded coal mines (John Gilbert Architects 2013). Mine water is taken from a depth of 100 m to supply two heat pumps that heat water to 55°C. The water is stored in a tank before distribution to end users for space heating. The end users are 16 houses that were also upgraded to be more energy efficient as part of the project. The use of a buffering tank reflects electricity economy tariffs, which limit economic operation of the heat pumps to 18 hours a day. Therefore, the buffering capacity with a reserve of hot water is required for the other 6 hours a day. District heating using geothermal resources from mines can be also extended to include development of commercial or industrial parks (Banks et al. 2004).

One study that examined the relationship between district heating utilities and industry looked at industry providing waste heat for district heating as well as the district heating providing energy for industrial operations (Holmgren and Gebremedhin 2004). The authors concluded that substantial savings can be made through a partnership between district heating operations and industry, but the potential downside is the "uncertainty concerning the future of the industry providing the waste heat." When a mine is providing waste heat to district heating operations, no such uncertainty exists, because mines can remain an independent sustainable source of energy long after the closure of mining activities.

A potential barrier to successfully developing a geothermal district heating system is competition with "relatively affordable gas and oil supplies and separate, well-developed electricity and fuel delivery infrastructures" (Thorsteinsson and Tester 2010). This is not the situation in cases such as the Con mine geothermal energy study in Yellowknife (Northwest Territories, Canada) where alternate energy sources such as natural gas are not available (Ghomshei 2007). Furthermore, with rising fuel costs and demands to reduce GHG emissions, such a barrier is likely to become less relevant.

Following the installation of a district heating system, analyses have been used to determine what aspects are contributing to system inefficiencies (Ozgener et al.

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Table 13.1 Examples of existing geothermal energy installations in abandoned mines

Mine Site	Depth, m	Type	System Capacity	End Use
Park Hills, Missouri, United States	133	Coal	113 kW	Space heating
Springhill, Nova Scotia, Canada	1,350	Coal	45 kW	Space heating/cooling
Shettleston, Scotland	100	Coal	16 houses	Space heating
Lumphinnans, Scotland	170	Coal	18 houses	Space heating
Heinrich, Germany	N/A	Coal	350 kW	Space heating
Zollverein, Germany	N/A	Coal	N/A	Space heating
Folidal, Norway	600	Copper, zinc, sulfur	18 kW	Space heating
Heerlen, The Netherlands	700	Coal	700 kW	Space heating/cooling

Source: Adapted from Hall et al. 2011.
N/A = not available.

2007). In systems that were studied, the most significant wastages of energy were due to hot-water losses in the distribution system. Not only can such studies help to improve existing systems, but they can also provide guidance for the design of new systems.

An energy recovery system has been implemented at the abandoned Ropak Can Am coal mine in Springhill, Nova Scotia, Canada (Jesop 1995), and was one of the first installations in Canada. A heat pump system provides space heating but can be reversed to provide space cooling in the summer. The system uses an open-loop design, taking water from one part of the closed mine at a depth of 140 m and dumping it into another part at the water surface. As a result, 14,000 m^2 of buildings use geothermal energy at a maximum of 111 kW for heating and 159 kW cooling (cooling cycles are generally less efficient than heating).

The use of an abandoned metal ore mine includes the Folidal mine in Norway. This mine produced copper, zinc, and sulfur from 1748 to 1941 (Banks et al. 2004), and a community became established nearby. Following mine closure, the underground Wormshall cavern continued to be used by the community for concerts and banquets. In October 1998, a heat pump system was commissioned to upgrade heat from mine water and use it to heat the cavern. A 600-m-long closed loop was installed and coupled to a single heat pump to generate air at 22°C for space heating. The energy recovery system and the cavern continue to provide value to the community, even though the mine itself has been long abandoned. Table 13.1 presents a summary of major existing geothermal installations, a majority of which are in Europe and utilize water from abandoned coal mines primarily for space heating.

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Warm waters from underground mines can also be used for melting snow. Traditional use of salt on roads can greatly increase concentrations of contaminants in the environment, as well as cause road surfaces to deteriorate and vehicles to corrode (Godwin et al. 2003). Underground thermal energy has been utilized in Japan for more than 20 years to melt snow from roads on bends and steep gradients by using embedded pipes carrying warm water (Iwamoto et al. 1997). If the mine water has a heavy sediment load, then removal systems may be needed to avoid reducing the life of the pumping equipment; otherwise, closed loops and a heat exchanger could be used (Vutukuri and Singh 1993).

Mine water could be also used to provide heat for fish farms (Miller 2008) and greenhouses (Mahmoudi et al. 2010). Similarly, the energy from mine water could be used to regulate the temperature of raceway ponds for biofuel and nutraceutical-producing microalgae, thereby allowing a lengthened growing season for cultivation (Shang et al. 2010). Therefore, for mines in locations without significant local residential heating needs, end-of-life use may be in supporting one of these industries, thereby providing new employment opportunities to the postmining community.

BRUCE MINES CASE STUDY

Bruce Mines is located in Ontario, Canada, on the north shore of Lake Huron and was the second copper mining town in North America, after the Cliff mine in Michigan's Copper Country. Copper mining started in 1846 with the area named after James Bruce, the governor general of Canada, who was appointed that same year. In 1876, the mines were closed because of declining profits, floods, and cave-ins. Mining resumed between 1915 and 1921. Despite occasional surveys, however, the mines have been effectively inactive since then and were finally decommissioned in 1944. This demise left agriculture, aggregate extraction, and tourism as the region's main economic activities. The land around the closed shafts is currently fenced off and under the stewardship of the province of Ontario.

Bruce Mines is situated on a major transportation highway and rail route that facilitate rapid transport to key markets, such as the Greater Toronto Area (around 600 km away) and the United States via Sault Ste. Marie (75 km away). The aim of local councils and the community was to assess the possibility of creating new opportunity supported by energy recovered from the closed mines' waters to exploit the transportation access.

In summary, the main potential applications for recovered geothermal energy are

- Building space heating and cooling,
- Heating in greenhouses,
- Snow melting of paved areas,

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- Maintaining water temperature for fish farms or microalgae growth, and
- Preheating for industrial process streams (e.g., for an industrial park).

However, the primary motivation was to create a new business opportunity for the community, as opposed to offsetting the energy costs of existing infrastructure. Consequently, the preferred application for recovered heat was in greenhouses. The intent would be year-round growth of specialty fruit and/or vegetables, possibly using hydroponics, which would be sold to markets served by the transportation network.

Ideally, energy recovery systems should be designed during the planning stage of a new mine and incorporated during construction; however, this is not the current practice. The galleries of a closed mine are typically analyzed prior to flooding. This analysis can at least ensure that heat exchanger design is optimized and a unit installed prior to flooding. However, the mines were originally developed in the nineteenth century, and even the most recent operations have been abandoned for more than 90 years. This was well before the consideration of significant postclosure rehabilitation or uses of underground mines. Consequently, mine layouts are not as detailed or as comprehensive as would be available for more recently closed mines.

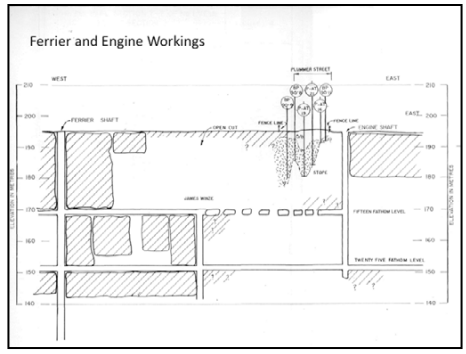
The primary information currently available is from a report conducted by a consulting engineering company (Golder Associates 1991). The goal of the survey was to identify areas where shallow or poorly supported shafts and stopes may negatively impact the stability of surface structures such as roads or buildings. Nevertheless, by using the provided information, three distinct sections within the overall Bruce Mines complex were identified in which there are likely to be substantial pools of mine water: Caribou, Taylor, and Ferrier Engine.

In all cases, the mine shafts were either capped or had been the subject of subsidence. Therefore, the mine water could not be directly sampled to assess temperature and chemistry (e.g., pH, hardness, metal ion concentration). However, surface water from open cuts was measured and found to have a relatively neutral pH. Although this suggests that open loops may be feasible, there is no guarantee that water at depth will be similar to the water accessible on the surface.

Estimating Water Volumes

Figure 13.4 is a typical diagram that shows how the 1991 report presented underground information. From the diagram in Figure 13.4 and similar ones for other parts of the mine complex, potential mine water volumes (from given dimensions of stopes and shafts) for the three identified sectors were estimated (Table 13.2). The estimated total available volume is, therefore, around 31,000 m^3, assuming that ground conditions have not changed since the figure depicting the workings was produced.

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Source: Golder Associates 1991.

Figure 13.4 Example of mine shaft and stope layout for operations at Bruce Mines

Table 13.2 Dimensions and depths of analyzed workings at Bruce Mines

Location	Shaft Depth, m	Shaft Width, m	Known Stope Area, m^2	Deposit Thickness, m	Total Volume, m^3
Taylor	50	4	820	3	8,800
Ferrier Engine	113	2.5	1,430–2,400	5	10,800–15,700
Caribou	357	2	1058	3.6	6,500

Source: Adapted from Golder Associates 1991.

Estimating Mine Water Temperatures

As previously mentioned, access to the mines to measure water temperatures below the surface was restricted because of shaft capping. But it was possible to take temperature readings south of Ferrier and Engine shafts because water was pooled in open cuts to a depth of 14–16 m at these locations.

Temperatures were also taken at Scott's shaft, which has pipes mounted on the side of the shaft that are open at the surface. At this location, water temperatures could be taken to a depth of 16 m before an obstruction stopped the probe's descent. Crazes pond is an open cut where historically the Crazes and Glanville's shafts were once located. The open cut has flooded to resemble a pond, and although the probe only descended to a depth of 14 m, the "pond" is connected underground to Scott's shaft.

At locations where there was open water, the temperatures recorded during September and October 2011 indicated a leveling out at 6–7°C at a depth of around 15 m. Because of the relatively small cross-sectional area of the locations where this sampling took place as well as very limited agitation of the water, it was considered reasonable to take temperatures at this depth to represent those of the rock.

The typical vertical geothermal gradient value for the Canadian Shield is only 15°C/km (Ivanov 2008). Using this value and the water temperatures measured

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Table 13.3 Estimated water temperature at the bottom of the three workings

Location	Water Temperature at 15 m, °C	Maximum Depth, m	Maximum Water Temperature, °C
Taylor	6.5	50	7
Ferrier and Engine	6.5	66	7.3
Caribou	6.5	103	7.8

at around 15 m, the temperatures of the water bodies further underground can be estimated (Table 13.3).

For each of the three identified volumes, water should be available for recovery for heating in the winter in the range of 7 to 7.5°C, and for cooling in the summer in the range of 6 to 6.5°C. This assumes that an open-loop system is installed, with one pipe at a depth of 15–20 m and the other pipe close to the maximum depth of the mine.

A similar study was carried out for the Gaspé mines (Quebec, Canada), which are abandoned, flooded copper mines that are 670 m at their deepest (Raymond and Therrien 2008). The mean water temperature was 6.7°C with an estimated water volume of 3,732,300 m^3. Based on these findings, the calculated energy reserve of the mines was 765 kW. With the use of heat pumps, it was determined that this could provide space heating for an industrial park.

Potential Geothermal Energy Recovery from Bruce Mines

The level of energy recovered from the mine water for providing space heating will be related to the temperature difference between the water sent to the heat pump and the water that is returned. For cooling, the opposite applies. To calculate the potential amount of energy that might be recovered from Bruce Mines, the return temperature needs to be specified. In doing so, it is important that it is not too low, otherwise the heat available in the rocks and transferred to that water can be quickly exhausted.

The modeled energy recovery from the Gaspé mines study was based on an average water extraction temperature of 6.7°C and a return of 3°C. With this return temperature, the water and surrounding rocks were predicted to eventually reach a steady temperature of 4.5 to 5.5°C with a pumping rate of 49 L/s. The calculations were based on a water volume more than 10 times that of Bruce Mines. Therefore, the extraction rate at Bruce Mines could be around 4 L/s pro rata.

Regardless of the return temperature or the flow rate for water taken from the mines, use of the water for heating in the winter and cooling in the summer will help to preserve higher temperatures in the rock and water, and will ensure the sustainability of the project. This is because cooling in the summer will help (re)heat the mine water, thereby helping to slow the rate at which the heat reserve depletes.

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Table 13.4 Estimated volumes and heat reserves of the three workings

Location	Water Volume, m^3	Rock Volume, m^3	Heat Reserve, GJ
Taylor shaft	8,800	265,000	130,000
Ferrier and Engine shafts	13,000	140,000	160,000
Caribou shaft	6,500	133,000	95,000

To provide an estimate of how much energy, H, is available in the Bruce Mines mine water, the following straightforward equation was used:

$$H = (V_g \times G_g \times C_g + V_w \times G_w \times C_w) \times (T_g - T_m)$$

where

V_g = volume of rock (wall thickness of 10 m assumed)
G_g = specific density of rock (3,200 kg/m^3)
C_g = specific heat capacity of rock (0.8 kJ/kg°K for heavy rock [granite])
V_w = volume of water (as previously estimated)
G_w = specific density of water (1,000 kg/m^3)
C_w = specific heat capacity of water (4.2 kJ/kg°K)
T_g = average ground temperature (7.5°C)
T_m = minimum ground temperature (5°C)

Assuming an average temperature reduction of 1.5°C for the rock and 3.5°C for water, the heat reserve for the three known water bodies at Bruce Mines can be estimated as shown in Table 13.4.

The total heat reserve for the three volumes in Bruce Mines is, therefore, 385,000 GJ. For comparison, a study of the Con mine in Yellowknife estimated a total heat reserve of 1,000,000 GJ, and this was planned to provide district heating for the city (Ghomshei 2007). Given that there are almost certainly remaining volumes within the Bruce Mines complex that have not been accounted for, it is possible that the heat reserve for Bruce Mines may approach half that found in the Con mine study. If so, this means the mines could potentially be used for heating and cooling. An average energy utilization value obtained from a range of existing geothermal installations based on mine water is 145 W/m^2 (Hall et al. 2011).

Greenhouses as Potential Users of Recovered Geothermal Heat

To estimate the heating potential for greenhouses, the concept of "degree days" was used to assess the likely demand placed on the geothermal system. Heating degree days are a measure of the severity of the weather and can be used to help size a heat pump for a geothermal system. One heating degree day is counted for every degree

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Celsius that the average daily temperature is below the nominal base temperature of 18°C. Similarly, one cooling degree day is counted for every degree that the average daily temperature is above 18°C. For example, a day with an average temperature of 15°C would be credited with 3 degree-days.

The annual degree days are found by adding the daily totals for the entire year. The greater the number of heating degree days for a given location, the larger the heating system should be to provide adequate heating. Climate data for the region over 10 years indicated an average of 4,983 heating degree days and only 675 cooling degree days. Therefore, heating, not cooling, will most likely limit the capacity of the geothermal installation for a greenhouse.

The energy requirement for a greenhouse was calculated using an annual minimum outside temperature of –25°C, a maintained inside temperature of 18°C, and an R-value of the greenhouse covering material. The R-value is thermal conductance and is based on the amount of energy conducted per unit thickness, per unit time, per units area, per degree of temperature difference between the two sides of the material. The R-value of the insulator is defined to be 1 divided by the thermal conductance per inch. This means R is an abbreviation for the complex unit combination hr·ft^2°F/Btu. In metric units, an R-value of 1 equals 0.17611 square meter Kelvin per watt (m^{2}K/W).

The R-value is a measure of thermal resistance and is the ratio of the temperature difference across an insulating material and the heat flux (heat transfer per unit area, per unit time). The higher the R-value of a material, the higher its insulation properties. For 4-mm polyethylene (typically the thinnest material used to cover industrial-scale greenhouse units), the R-value is 1.2. Using these parameters, a commercial-scale 930-m^2 greenhouse would require a heating system with a capacity of 188 kW to maintain temperature throughout the winter.

As a very approximate estimate for the heat pump system for a 930-m^2 efficient greenhouse, a single commercial heat pump could be used similar to a WaterFurnace (Fort Wayne, Indiana) model NLV240 or NLV300. These two models require a water flow of 3.8 and 4.8 L/s, respectively (WaterFurnace 2011). If a heat loss value of 1.2 is used, the water requirements increase to between 9.5 and 12 L/s.

Using 7.6-cm standard-diameter piping the velocity for 3.9 to 4.8 L/s ranges from 0.7 to 0.9 m/s. The less-efficient greenhouse with 9.5 to 12 L/s flow rate of water provides a velocity of 1.7 to 2.2 m/s. A minimum velocity of 1 m/s is ideal for vertical pumping, while an exit velocity between 3 and 5 m/s helps to ensure maximum efficiency for centrifugal pumps. Thus, 7.6-cm-diameter pipe is likely larger than required for both scenarios of a 930-m^2 greenhouse.

Key parameters that will have an impact on system cost include the size of the heat pump(s), the proximity of the heat to the user, and the proximity to a source of electricity. Assuming a distance of 150 m between greenhouse and geothermal supply, a commonly used piping material is cross-linked polyethylene (PEX) tubing.

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Based on a closed-loop system, when buried and insulated, and assuming easy access to and into the shaft, PEX supply lines and the enclosing berm are likely to account for about $20,000 (2011 US$ prices used throughout). Any steps that can be taken to reduce the distance between the water source and the heat pump can serve to reduce heat losses and capital costs. Furthermore, if the location for the greenhouse is far from power lines, the extra cost associated with bringing power to the water circulation pumps, heat pump, and greenhouse may be significant. Electrical costs for wiring and controls are likely to be around $20,000. The complexity and cost for the controls will change based on the end use. A heat pump being used solely for space heating will have less control requirements than one providing heating and cooling.

At a cost of $0.08/kWh, a heat pump would cost $7,600 per year for electricity as opposed to $34,400 for utility-supplied electric heat. The energy savings using the heat pump would also provide a GHG reduction equivalent to 65 metric tons of carbon dioxide (CO_2) if utility electricity is sourced from a fossil-fuel-burning power plant. These calculations were done with a heat loss value of 1.2, roughly 10 times less efficient than a standard insulated building wall. Other options for greenhouse construction include 4-mm twin-wall polycarbonate (R = 1.4) up to 16-mm five-wall polycarbonate (R = 3).

The installed cost for the heat pump would be $15,000, with additional mechanical equipment totaling $25,000. The estimated cost range for a heat pump system for a 930-m^2 greenhouse is, therefore, $75,000 to $100,000. Multiple greenhouses that share infrastructure (e.g., water pumping from the mine and larger shared heat pumps) would reduce the per-greenhouse cost. This is possible at Bruce Mines because the estimated total capacity of the three mine workings (800 kW) would be able to support greenhouses from 3,700 m^2 (low R-value covering) up to 9,300 m^2 (high R-value covering).

However, for any system, a thorough analysis of capital and installation expenses (heat pump system and greenhouse), and purchasable energy costs (current and future), would be needed to determine the most cost-effective combination. Equally important factors that need to be considered for any potential mine site are the stability of the mine workings, ownership status, the potential for the mine to be reactivated in the future, and whether the mine water has reached a stable state.

CONCLUSIONS

The construction, operation, and closure of underground mines are extremely capital- and energy-intensive activities. Despite this significant investment, the traditional view is that mines have little or no useful value after closure. However, many mines flood, and the relatively stable temperature of this water can be exploited by the use of geothermal energy recovery loops coupled to heat pumps. During the winter, heat could be extracted from the mine water and supplied for

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heating. In the summer, the process could be reversed and the heat transferred back to the mine water to provide cooling.

However, despite increasing pressure to identify alternate, sustainable sources of energy to reduce fossil fuel consumption and their production of GHGs, there are still only a limited number of existing and proposed geothermal installations at disused mines. Nevertheless, those that exist demonstrate the potential value of this approach. The preliminary case study discussed suggests that this could be possible even for mines that have been long closed.

The assessment of geothermal energy recovery feasibility from a closed mine needs to be accompanied by potential local uses in the surrounding community. In the example discussed in this chapter, the preferred use for any recovered energy was to help support new business opportunities, including heating greenhouses for commercial vegetable production. However, the most significant opportunity may be in looking at geothermal energy recovery from planned and working mines. In particular, mine design engineers could investigate how integration of energy resource recovery loops can be incorporated at the initial stages of mine planning. Integration of energy recovery from waste heat from mine water into an operating mine could be a significant step toward greater sustainability for the industry. It could diminish running costs by reducing fuel imports and decrease environmental impacts from GHG emissions.

Geothermal energy recovery would also boost overall longevity of the use of the initial investment, because the mine could be set up to be stable enough to continue to support the well-being of the local community by generating green energy beyond ore extraction. This energy could also provide additional GHG offsets for the operational phase of the mine. Mines, especially proposed ones, demonstrating initial integration of beneficial investment in long-term sustainability are more likely to be regarded favorably by investors as well as community and legislative bodies.

ACKNOWLEDGMENTS

The authors of this report express their sincere thanks to the mayors, councilors, and members of Bruce Mines and Plummer townships, the Chamber of Commerce, and East Algoma Community Futures who supported and committed funds for the Bruce Mines geothermal energy feasibility project.

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CHAPTER 14

Optimal Mine Site Energy Supply

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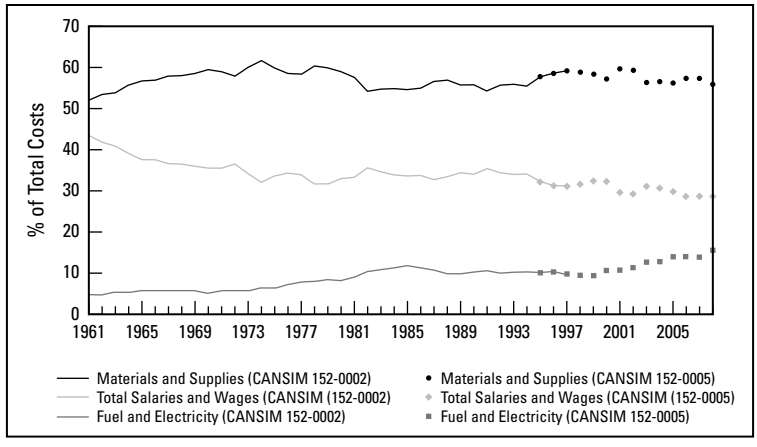
INTRODUCTION

This chapter reports and summarizes research-and-development efforts in the field of optimal mine site energy supply. The goal of this work was to find the optimal way in which the demand for energy by a mineral production facility can be met. The techniques do not just consider electricity, but are based on an extension of the well-known idea of cogeneration, termed *polygeneration*, because it permits consideration of multiple forms of energy consumed and used at mineral production facilities. Examples of such facilities include surface or underground mines, beneficiation plants, and mills, as well as smelting and refining facilities. However, we abbreviate the intent of being able to apply the technique to all types of minerals sector facilities through the adoption of the term *mine* in the expression *optimal mine site energy supply*, or OMSES.

Explained in this chapter are the OMSES framework, approach, and technique that lead to the identification of the best designs for mine energy supply. Auxiliary topics are also introduced and explained, such as (1) mine energy auditing that informs the OMSES framework through the specification of energy demand and (2) the use of graphical tools called *resilience maps* that permit assessment of the robustness of a particular OMSES solution to varying economic circumstances. The aim is to do this with sufficient transparency that industry practitioners and minerals industry researchers alike may adopt the work for their own use and maximize the benefits for the industry as a whole at a time when it faces great challenges.

The business need to reduce mineral production costs provides the motivation for a systematic approach to the problem of energy supply for the minerals industry. Energy costs are increasing. This is exemplified by an oil price that,

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Source: Statistics Canada 2013.

Figure 14.1 Historical annual costs for Canadian metal ore mining

in inflation-adjusted terms, is higher than it has ever been (BP 2012). For the Canadian mining industry, the effect of this trend in energy costs can be appreciated in Figure 14.1.

In the metal mines, on average, energy costs are now 16% of the total production costs, and rising; for nonmetal mines (potash, salt, coal, quarrying), the corresponding figure is 23%. For off-grid mines of either category, this fraction is higher. There has never before been greater need for robust treatment of energy in the Canadian mining industry, and there is no reason to think that this is not the case in other countries around the world where the mining industry is prominent.

Mathematical Programming Optimization Framework

The framework adopted to find optimal solutions to mine energy supply problems is the language of mathematical programming. "Optimality" is specified through the idea that some measure of "fitness for purpose" of the proposed designs can be formulated as an objective function that is to be maximized or minimized. The types of objective function allowed for in OMSES include minimization of the annual cost of energy supplied and maximization of the carbon emissions reductions, or both of these simultaneously with specialist formulations.

Decision Variables for Technology Selection

The objective function is expressed as a function of a set of decision variables. The decision variables reflect the selection of the available options for the mine energy supply system. As an example, this could be a design option where a mine can either be considered isolated (islanded) from an electricity distribution grid or it can be regarded as connected. Similar considerations could apply for gas transmission systems to which the mine is connected by pipeline.

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Polygeneration is an extension of the idea of cogeneration from a single prime mover, but more forms of energy are considered than just heat and electric power. The decision variables can be set up so that a choice between different prime mover technologies can be made. Such general choices can be exemplified by choosing one or more technologies from the following set:

{no prime mover (grid only), diesel engine, gas turbine,
gas engine, steam turbine, hydroelectric dam}

OMSES answers questions such as, "Which of these technologies is the best to adopt?" and "If gas engines are the best technology, what is the rating of each engine and how many engines should be installed?"

Decision Variables for Technology Operation

To evaluate the selection and configuration of equipment for mine site energy supply, one also has to know *how* a given set of equipment will be operated. This is not the same as simply specifying that the equipment is available to supply energy year-round. Rather, operation of one specific item of equipment may depend on diurnal, seasonal, and potentially interannual patterns of energy demand. Otherwise, its operation may be constrained in other ways such as energy or capacity tariff arrangements.

Consequently, the OMSES formulation simultaneously considers the energy supply system design and the energy supply system operation as a so-called "global optimization" problem. Returning to the mathematical programming theme, the way that such demand variability or tariff conditions become embedded into the framework is through the specification of mathematical constraints expressed in the decision variables.

Role of Mixed-Integer Linear Programming

Decision variables for the energy supply system operations may be of a discrete or continuous nature. For example, for a specific period of operation within a year (say, a specific hour), operation of parts of the system may be described using binary "switch" decision variables, meaning "on" or "off." Alternatively, the problem may describe the operational state of an item of equipment in the optimal design more continuously—say, as a proportion of the maximum (rated) capacity of the item to deliver energy. In this case, the decision variable would be real rather than binary valued. Such considerations are important in the work because they lead to mathematical programming problems of a different character: linear program (LP), integer program (IP), or mixed-integer linear program (MILP). These problems affect the computational methods that can be used to solve the programs defined. In general, one is confined to thinking that the OMSES problems are MILP problems with mixtures of decision variables that are binary, integer, or real. Where

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nonlinearities arise, if possible, the corresponding constraint or other part of the mathematical program affected is linearized.

OMSES Origin and Evolution

OMSES formulation was first presented in Carvalho and Millar (2012) as an application of the previous work developed in Carvalho (2011). The adaptation extended the formulation to deal with specifics to the field. For example, the technology database considered was extended to consider higher-rated equipment as well as technologies that had not been contemplated previously at all. The number of different energy forms was extended appreciably. In Carvalho et al. (2014), OMSES is extended to include energy storage, a detailed definition of *electricity connection costs*, as well as tariff complexities including demand charges and time-of-use charges. This extension permits a more complete and relevant analysis of the optimal energy supply system for mines.

ENERGY USAGE PATTERNS IN MINING OPERATIONS

Mining is an economic activity where the development of that activity is dependent on the resource quality and its location, as well as the technology available for its exploitation. In common with other aspects of mining engineering design, when the possible variations in mineralogical style, mining method, and climatic, economic, and political factors are taken into account, sometimes it is hard to find two mines that are sufficiently alike such that a design proven at one operation may be extended to another without modification.

The area of energy in mining is no exception. To a certain extent, such factors lead to variability in the amount and form of energy consumed. Naturally, this leads to variability in the demand for energy from individual mines. OMSES requires a fairly detailed description of the demand for energy. Three types of information concerning the demand for energy are required to support the OMSES methodology:

- What is the energy used for and what is its utility?
- What form is the energy consumed?
- How much energy is consumed and over what time scale?

What Is the Energy Used For?

Different Forms of Energy Can Provide the Same Utility

The amount of energy consumed in a given period must be known, but the form of energy (electricity, motive power, heat, steam, compressed air, etc.) supplied must also be understood. It is also important to know what the corresponding amount of energy is used for. This is because when one is considering a range of

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competing energy technology options to achieve a particular goal, it is possible that one method achieves the end purpose more efficiently than another. For example, it is commonly accepted that the conversion of electrical energy input into motive power applications, such as operating load-haul-dump (LHD) equipment, is more energy efficient than the conversion of diesel fuel into motive power for the same application.

If an optimal selection is to consider the substitution of diesel-powered LHDs with electric-powered LHDs, one must be able to characterize the fundamental work required in lifting, hauling, and dumping rock (the output) as well as the amount of electricity (one competing input) or diesel (another competing input) that is required to achieve the useful output. In general, a mine operator pays for the energy input as it comes "across the fence" of the mining operation but actually seeks the useful energy output "within the fence."

What Is the Difference Between Energy and Utility

Within the OMSES formulation, a discrimination is made between across-the-fence and within-the-fence energy. *Across the fence* energy is in the form of joules that are paid for. *Within the fence* energy is in the form of useful joules as "utility." Therefore, the overall objective of OMSES is to ensure that demand for utility is met with an optimal selection of technologies that converts the imported, paid-for *energy* into "on-demand" *utility* required to execute the production plan at minimum cost.

To illustrate this point, consider Table 14.1. It shows that for a remote underground mine that is grid connected, electrical energy is used to drive an electric motor that in turn drives a compressor to produce compressed air. In this case, the *energy* is that amount of electricity required to drive the compressor, and the *utility* is the indicated work available within the compressed air produced. Instead of using an electric motor to drive the compressor, the compressor could be driven by a diesel engine. In this case, the *energy* is that amount of diesel required to fuel the diesel engine, but the *utility* remains the indicated work available within the compressed air produced. The electric motor and its electricity, and the diesel engine and its diesel are competing options. Upon prolonged examination of Table 14.1, further competing substitutions can be conceived and a multiplicity of options to provide the various utilities emerges. Choosing the best technologies to adopt becomes harder.

Sometimes, despite best efforts, it is not possible to understand the utility demand because the process concerned is insufficiently well characterized to support this. A good example is establishing the utility demand profile for LHD equipment. The issue is not necessarily that this is impossible, but rather that it represents an unnecessary level of detail.

On other occasions, it is not desirable to understand the utility demand. Operators may wish to maintain a preference for a particular type of technology

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Table 14.1 Types of end-use utility for energy input into mining operations

	Open Pit Mine (remote, connected)	Underground Mind (remote, connected)	Underground Mine (not remote, connected)	Community / Mine Camp
Diesel is used to provide heat and work	Drill Blast Load Haul Generate electricity Produce steam Produce hot water	Drill Blast Load Haul horizontally Generate electricity	Drill Blast Load Haul horizontally	Heat homes and community spaces Transport personnel Generate electricity
Electricity is used to provide work	Processing ore Pumping Surface facilities Accomodation	Ventilation Vertical haulage Compressed air Pumping Backfill Ore handling Surface facilities Accommodation Processing ore	Ventilation Vertical haulage Compressed air Pumping Backfill Ore handling Surface facilities	Lighting Appliances
Gasoline is used to provide work	Transport personnel	Transport personnel	Transport personnel	Transport personnel
Propane is used to provide heat		Heating, ventilation, air		
Natural gas is used to provide heat			Heating, ventilation, air	
Aviation fuel is used to provide work	Transport personnel	Transport personnel		

for a variety of reasons: available skill and experience to repair and maintain a given technology and not an alternative one, or an over-riding desire for flexibility in equipment usage. In these cases, the objective of OMSES may be to consider whether the input energy demand can be met more cost effectively.

Energy Conversion Technologies Can Produce Multiple Utilities

OMSES supports extensions of such decision-making processes, motivated by an ongoing desire to drive down mineral production costs. It is recognized that some technologies may be inefficient at converting paid-for energy into useful utility, and that some of the inefficiently converted energy may end up in a form that is nevertheless useful.

To illustrate, the compression of air raises its temperature (whether the compressor is powered by an electric motor or a diesel engine), sometimes to a level where the associated grade of heat could be put to a useful economic purpose

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elsewhere at the mine. For example, compressor heat could be used to raise the temperature of feedwater supplied to heat a mine camp dormitory or to warm air that is supplied to a concentrate drier. The feedwater and the warm air are examples of additional utilities that could be produced by the compressor as well as the more obvious compressed air utility.

Although the mine camp dormitory may still require, say, a propane burner to heat the feedwater, displacing some of the propane burnt with recovered compressor heat provides value to the operation in fuel saved. If a sustained level of compressor heat can be relied on, further value may be realized in opting for a lower-rating furnace or fewer individual burners.

For simplicity's sake, compressor heat is frequently passed to a cooling tower or radiator and rejected to atmosphere, where any potential economic value in the secondary utilities is lost. The chapter authors firmly believe that this latter circumstance is undesirable and aim to provide the tools to permit mine operators to quantify the economic benefits of a heat recovery option. In the face of consistently rising energy prices, providing justification for slightly more complex technical solutions is becoming ever more essential.

Getting the most out of energy converted to multiple utilities lies at the center of the well-known concept of cogeneration, or more generally, polygeneration. Therefore, the question arises: Why do we need special tools to consider cogeneration options for mines? What makes mining operations "special" in this respect is that

- Typically the energy and utility demands are large,
- The types of utility demands are diverse,
- The number of utilities is large,
- The utility demands all arise in one place (the mine), and
- Domain-specific knowledge is frequently required to understand all the utilities.

Energy Benchmarking

There are two main reasons for producing an energy benchmarking metric for mines. The principal reason is to have a basis for estimating the amount of energy a mineral production operation may require, at the time that operation is being designed, so that the energy costs may be estimated and factored into the mine design process. Another reason is for comparison purposes, either to compare a single operation's consumption at various points in time, perhaps as part of a process of continuous improvement, or to compare the energy consumption of multiple operations against one another, perhaps to encourage a sector-wide improvement or to set levels of incentive.

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Energy Consumption at Underground Mines

Musselwhite mine is an underground gold-producing operation owned by Goldcorp Inc. It is located in Northern Ontario, Canada, and was opened in 1997 (Goldcorp, ca. 2011). After converting the quantities of energy consumed by this remote, yet grid-connected mine to consistent units of megawatt-hours (MWh) for the period between 2001 and 2009 (Goldcorp, ca. 2010), the total energy supplied to the mine can be estimated. Taken together with production data for the mine (Mason et al. 2002, 2003; Smyk et al. 2004–2010), one of the simplest energy benchmarks—the total energy consumed per metric ton of ore produced—can be plotted (Figure 14.2a). Inevitably as the mine ages, the depth of the workings increase and the specific energy consumption increases. The addition of mine depth (Goldcorp, ca. 2005; Scales 2007) results in specific energy consumption, expressed as kWh/(metric ton [t] ore × meter depth), and illustrated in Figure 14.2b. This chart shows that as the mine is extracting ore from greater depth, it is doing so more efficiently.

The data in Figure 14.2a are consistent with benchmark figures of 99.4 kWh/t ore mined for underground mining and 99.6 kWh/t ore processed for gold concentration (prepared by Natural Resources Canada and LCG Management Group in 2010) as the Musselwhite mine produces bullion. The same source reports that Canadian open pit mines and base metal processing operations require 11.8 kWh/t ore and waste mined and 81.4 kWh/t ore processed, on average, respectively.

A detailed investigation of energy consumption by mine activity is important to quantify the proportion of energy that is influenced by mine depth. This was not possible based on the published data for Musselwhite, but data were analyzed for another underground mine. Nickel Rim South mine, operated by Glencore, is an underground nickel, copper, and platinum-group-metals mine located northwest of Sudbury, Northern Ontario, Canada. The mine produces approximately 1.25 million metric tons of ore per annum from a nominal depth of 1,750 m (Bartsch et al. 2010). Assuming that the average electrical demand is 15.3 MW and using percentage consumption values reported by Bartsch 2011, a breakdown of the annual energy consumed by this mine can be estimated and is presented in Table 14.2. The proportion of the energy consumed by the mine in the form of electricity is 80.2%. Importantly, 49.8% of the energy is consumed by depth-related end uses (main fans, hoisting, and pumping—uses for energy that may be expected to rise as the mine depth increases).

If the depth of mining operations is accounted for at Musselwhite, then the result is Figure 14.2b, which shows that the energy management efforts being undertaken at Musselwhite mine are proving effective. If business-as-usual practices had persisted, it is estimated that energy consumption at Musselwhite may have been 15%–20% higher than measured in 2009. The dramatic effect on interpretation of the results due to a more refined selection of support variables for the calculation of specific energy consumption highlights the need to take great care in

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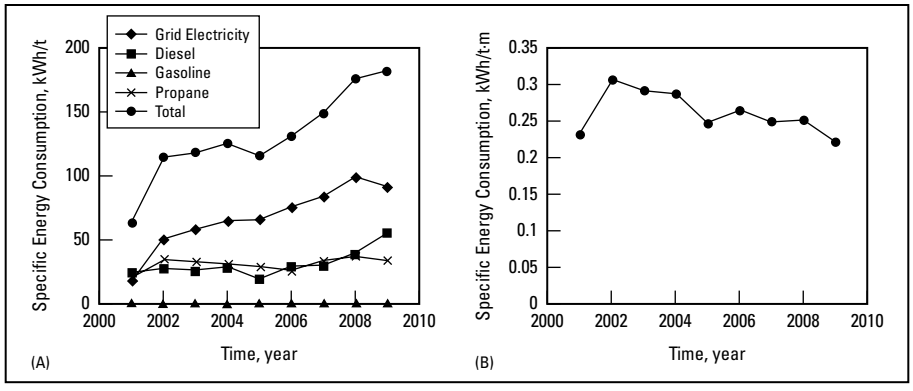


Figure 14.2 Specific energy consumption at Goldcorp's Musselwhite mine between 2001 and 2009: (a) kWh/t ore and (b) kWh/(metric ton ore × meter depth)

Table 14.2 Estimated energy consumed by Glencore's Nickel Rim South mine for 2011

Mine Activity	MWh/yr	%	Energy Type	kWh/t	kWh/(t·m)
Ventilation—Main fans	46,910	28.1	Electricity	37.53	0.0214
Ventilation—UG* auxilliary fans	8,042	4.8	Electricity	6.43	0.0037
Hoist ore	30,826	18.5	Electricity	24.66	0.0141
Fixed and mobile UG equipment	22,785	13.6	Electricity	18.23	0.0104
Surface facilities	8,042	4.8	Electricity	6.43	0.0037
Pumping	5,361	3.2	Electricity	4.29	0.0025
Ore handling	4,021	2.4	Electricity	3.22	0.0018
Backfill plant	4,021	2.4	Electricity	3.22	0.0018
Compressed air	4,021	2.4	Electricity	3.22	0.0018
Heat ventilation air	5,174	3.1	Natural gas	4.14	0.0024
Fuel UG LHD,† bolting, and drills	27,540	16.5	Diesel	22.03	0.0126
UG personnel transport	334	0.2	Gasoline	0.27	0.0002
Totals	167,077	100		133.66	0.0764

Source: Bartsch 2011.
*UG = underground.
†LHD = load-haul-dump.

choosing effective and sensible energy consumption metrics for energy management purposes in mines.

Energy Consumption at a Surface Mine

As should be expected in surface (open pit) mines, the proportion of total energy consumed in the form of diesel is significantly greater than for underground mines.

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Victor mine, operated by De Beers Canada Inc., is located in Northern Ontario in a climatic region similar to that of Musselwhite. Diesel consumption at the Victor mine accounts for half of the total energy consumed by the mining and ore processing operations. From 2008 to 2010, specific energy consumption (kWh/t ore mined and processed) at the mine declined from 89 to 75 kWh/t ore (De Beers Canada 2011), presumably as a result of energy management efforts and greater understanding of processes as the mine evolved into a full production phase.

After production rate, depth of the pit for surface mining operations in general is a significant determinant of the energy consumed by the operation, because this will have an important bearing on the amount of diesel consumed in haulage. The stripping ratio is also an important factor in specific energy consumption, especially if expressed in terms of kWh/t ore. Partial reporting of specific energy consumption data on open pit mines without reporting depth and stripping ratio could account for large variances that arise in comparing one open pit mining operation to another. For 2010 at the Victor mine, the total rock mined and moved was 9,612,000 t, of which 2,660,000 t was ore; 2,773,000 t of ore was processed (De Beers Canada 2011). Energy quantities and types for 2010 are reported in Table 14.3. This table shows that diesel for mobile equipment and fuel oil for blasting energy consumption together account for 9.9 kWh/t rock mined, a figure consistent with that quoted earlier from Natural Resources Canada and LCG Management Group (2010). These items account for 45% of energy consumed, with another 45% of the total being used to operate the processing plant.

Energy Intensity Benchmarking Metrics and Their Problems

Measuring energy utilization effectiveness by relying on the quantity of MWh/t of ore produced ignores many of the complexities of mining operations. As can be appreciated from Figure 14.2, a headline energy intensity of MWh/t may not be a static value appropriate to a given operation throughout its operating life, and thus

Table 14.3 Estimated energy consumed by De Beers' Victor mine for 2010

Mine Activity	MWh/yr	%	Energy Type
Processing plant and surface facilities	96,195	45.4	Electricity
Mobile equipment	92,690	43.8	Diesel
Blasting	2,599	1.2	Fuel oil
Stationary fuel combustion	2,483	1.2	Diesel
Boilers	17,155	8.1	Diesel
Aviation	497	0.2	Jet A1
Personnel transportation	143	0.1	Gasoline
Totals	211,763	100.0	

Source: De Beers Canada ca. 2011.

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may be of limited value when trying to compare one operation against another. Adopting an enhanced set of support variables for the calculation of a benchmark quantity may improve the relevance of between-operation comparisons. For underground mines, an energy benchmark metric that aims to improve the potential of comparisons between different underground mining operations is

$$I_{UG} = \frac{E}{m \times D \times HDD} \times \frac{kWh}{t\ ore \times m\ depth \times °C}$$

where I_{UG} is the specific energy consumed by an underground mine, E is the annual total energy consumed, m is the annual ore production tonnage, D is the average depth of producing areas, and HDD is the number of heating degree days per annum. Clearly, m tries to take account of operations of different scales, D tries to take account of the depth of mining, and HDD is a measure of the climate in which the mine is located. For the Musselwhite data, 97% of the estimation variance in a model for the energy consumed was related to these three variables. For surface mines, the chapter authors are investigating a revised energy intensity metric, I_{OP}, proposed as follows:

$$I_{OP} = \frac{E}{m \times D \times HDD \times SR} \times \frac{kWh}{t\ rock \times m\ depth \times °C}$$

where m remains an annual ore production tonnage, and SR is a stripping ratio defined as metric tons waste per metric tons ore. For milling plants, a revised energy metric, I_M, is being investigated, proposed as follows:

$$I_M = \frac{E}{m \times HDD \times \delta \times LF} \times \frac{kWh}{t\ ore \times \mu m}$$

where m is the ore throughput, and δ is the liberation size of the valuable mineral. This benchmark metric aims to account for energy used in comminuting the ore in crushing and (predominantly) grinding. Analyses have shown that the degree to which a plant is operating below the nominal capacity for which it was designed is a strong determinant of the energy consumed by that plant; hence, a load factor, LF, is included in this benchmarking metric.

Trying to establish the three measures just described for general use is ongoing. Progress on their development is hampered by low volumes of poorly disaggregated data. Generally, mine operators are not willing to provide details of energy usage into the public domain in such a way that it may reveal what a given operator may perceive to be its competitive advantage over other operators in the sector. As the proportion of direct production costs that are attributable to energy increases

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(Figure 14.1), the availability of information that permits calculation of meaningful energy benchmarks may be expected to decline. This means that use of the above metrics may be confined in-house as part of continuous improvement initiatives.

Diurnal Load Profiles

The production plan, defined by long-term and short-term planning engineers, is what ultimately determines the energy-consuming activities that are going to take place at each moment of the mine life and, therefore, the energy per unit of time consumed by each activity or process. These plans normally involve several shifts. Within each shift, some operations are repetitive and define identical cyclical energy and utility demand patterns. Shift patterns, particularly shift changeovers, can have a strong effect on the pattern of utility and energy consumption.

For underground mines, some important, high energy intensity processes that support production are not necessarily continuous; examples include hoisting of ore and waste, ventilation, and mine dewatering. Frequently, an ore storage bin will feature in-shaft bottom arrangements, so that hoisting does not have to take place throughout a complete shift nor an entire day. The electrical energy demand for hoisting, although very cyclical, is also highly variable within each cycle. In contrast, main fan operation presents a broadly continuous requirement for electrical energy, when the time period considered is of the order of a day and thus would comprise a component of base load demand for electricity. Auxiliary fans operated under "ventilation-on-demand" control may not form part of the electrical base load due to their intermittent or modulated operation. The use of a sump at the shaft bottom, and potentially at intermediate shaft pumping stations, provides storage capacity for groundwater and service water, such that dewatering need not arise continuously throughout a day nor a shift. The nature of the dewatering control system may be the strongest factor affecting electricity demand patterns for pumping. An on-demand control system that actuates pumps when sump levels exceed a given level may present a predictable, cyclical demand pattern but not one that is sensitive to times of the day when the price for power is high according to the tariff. Groundwater inflow may be highly unpredictable affecting the proportion of pumped water that depends on climatic conditions. Ventilation may bring an additional asymmetry between the two-shift operation. Day to night ambient temperature variations may induce or increase heating demand during the night and cooling demand during the daytime hours, but such patterns may only apply for days in a given month. In summary, demand patterns will depend on, inter alia,

- Production planning,
- Number of shifts,
- Base-load demand items,
- Peak rates for energy (particularly electricity), and
- Control systems applied to specific processes that support production.

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These factors determine the usual diurnal load profiles in underground mines, giving the first stage of the demand characterization.

Seasonal Load Profiles

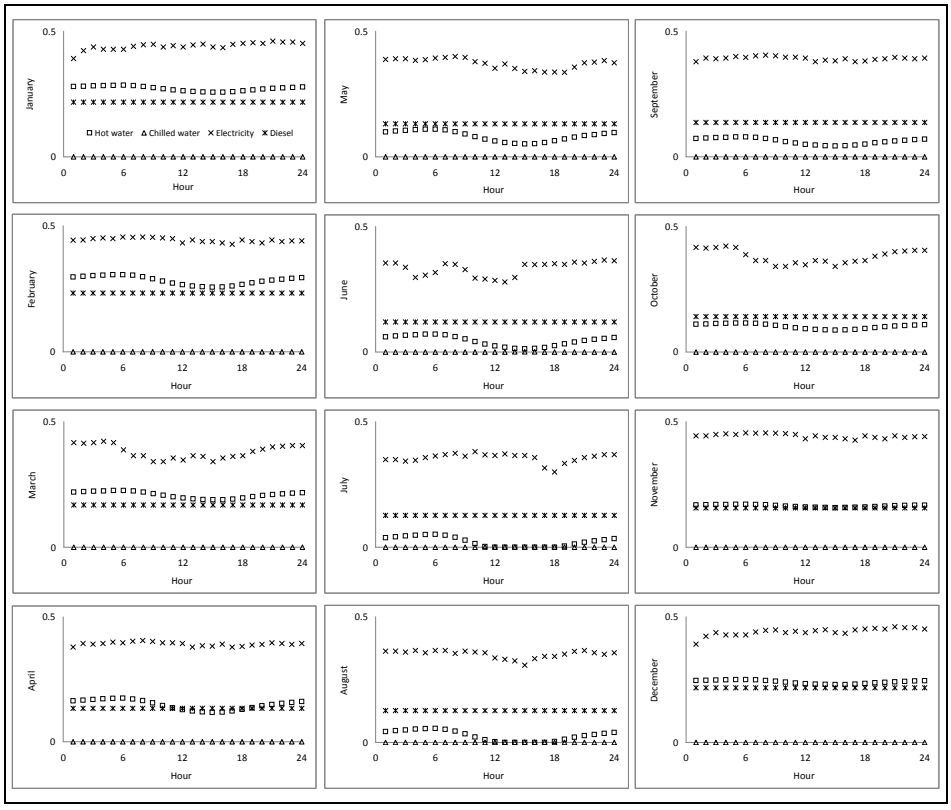
Geographical location can introduce seasonal load variation. This can be particularly important because energy needs to be consumed to maintain suitable working temperatures in the workplace. To prevent icing on shaft infrastructure in winter, which presents a safety hazard, the intake ventilation air in some Canadian mines is heated with natural gas or propane burners (depending on proximity to the gas grid). The same mines in summer months may have to refrigerate the intake ventilation air to keep the temperature of the working environment low enough that work–rest regimes for workers do not have to be implemented.

The mathematical programming formulation for OMSES is detailed in this chapter, and its application is illustrated with examples. The examples will draw on synthesized utility demand curves for four forms of energy: hot water, chilled water (to provide cooling), electricity, and diesel. These curves are informed by data from real mining operations: one underground mine (Figure 14.3) and one open pit mine (Figure 14.4). These curves are presented as the hourly energy requirements for one typical day of each month of the year. Therefore, the results of the optimization exercises will reflect diurnal and seasonal energy demand. For confidentially reasons, the data have been normalized. However, the annual totals are presented in Table 14.4, and the relative variability of hourly energy across this all-fuels energy mix for mining operations are preserved. Table 14.4 also shows annual totals for a "community" with load profiles presented in Figure 14.5. These data are applicable to either a worker village or mine-associated accommodation facility, or, alternatively, a mine-independent community located within or around a mining district that may be seeking infrastructure assistance as a result of mine developments. "Coolth" in Table 14.4 means demand for cooling. The load has been disaggregated for heating and cooling purposes from raw data on electrical demand that is currently used to meet this utility. Therefore, the optimization process may consider alternative technologies to meet these demands for thermal energy, such as heat recovery systems or absorption chillers.

Interannual Load Profiles

Figure 14.2 clearly illustrates that as a mine ages, the all-fuels energy consumed by the operation may be expected to increase. For underground and open pit mines, an important parameter governing this increase is the depth at which ore extraction is undertaken in any given year of the mine life. Consequently, the daily demand profiles for mining operations, presented in Figures 14.3 and 14.4, will migrate up the vertical axis as the producing life of the mine ages. For underground mines, the electricity curves will migrate most, reflecting predominance of electricity use

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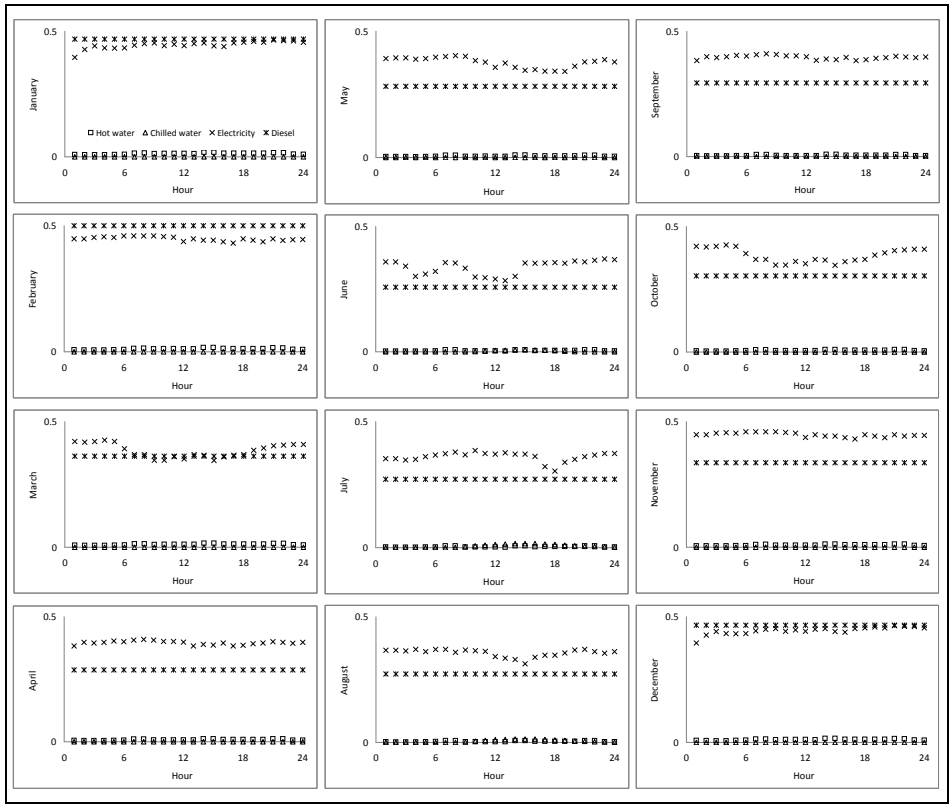
NOTE: Data are normalized by the total of the annual maxima of hourly demand levels. Raw data are expressed as MWh/h.

Figure 14.3 Synthesized daily demand profiles for typical days in each month of the year for an underground mining operation

for vertical haulage and vertical services such as main ventilation fans and dewatering pumps. The demand for diesel for an underground mine could be expected to remain relatively constant year to year if horizontal tramming distances remain steady. Given that the dominant form of energy for open pit mines is diesel (at least for the example curves synthesized) and diesel is used for vertical haulage, in this case, the diesel curves may be expected to be subjected to the most vertical displacement on the demand profile charts as the pit deepens. The ore production rate may be varied from year to year, which will also lead to significant interannual variations in energy consumption.

Energy management practices for mining operations have not yet matured to the point where they are considered in the development stages of the mine life. The energy consumed in bringing a mine to the point that it starts to produce has not yet been quantified in the literature, but it is suspected of being substantial.

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NOTE: Data are normalized by the total of the annual maxima of hourly demand levels. Raw data are expressed as MWh/h.

Figure 14.4 Synthesized daily demand profiles for typical days in each month of the year for an open pit mining operation

For this reason, this portion of the total energy consumed over the mine life is not considered in the example optimization runs used to illustrate OMSES.

TECHNOLOGY AND ENERGY RESOURCES

Generally, mining operations rely on an electrical grid connection unless the remoteness of its location makes this impossible. This does not mean that OMSES need not be applied; depending on the tariff arrangements, substantial savings for operators may nevertheless be realized. It is also possible that even when an electric grid connection point is readily available, tariff arrangements are such that provision of energy utility in an islanded arrangement may be preferable on the grounds that the demand can be met at lower cost. Frequently, mines already have, or are required to have, electricity generation capacity installed onsite for

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Table 14.4 Annual summary of utility demand for mining operations and communities for example OMSES optimization scenarios

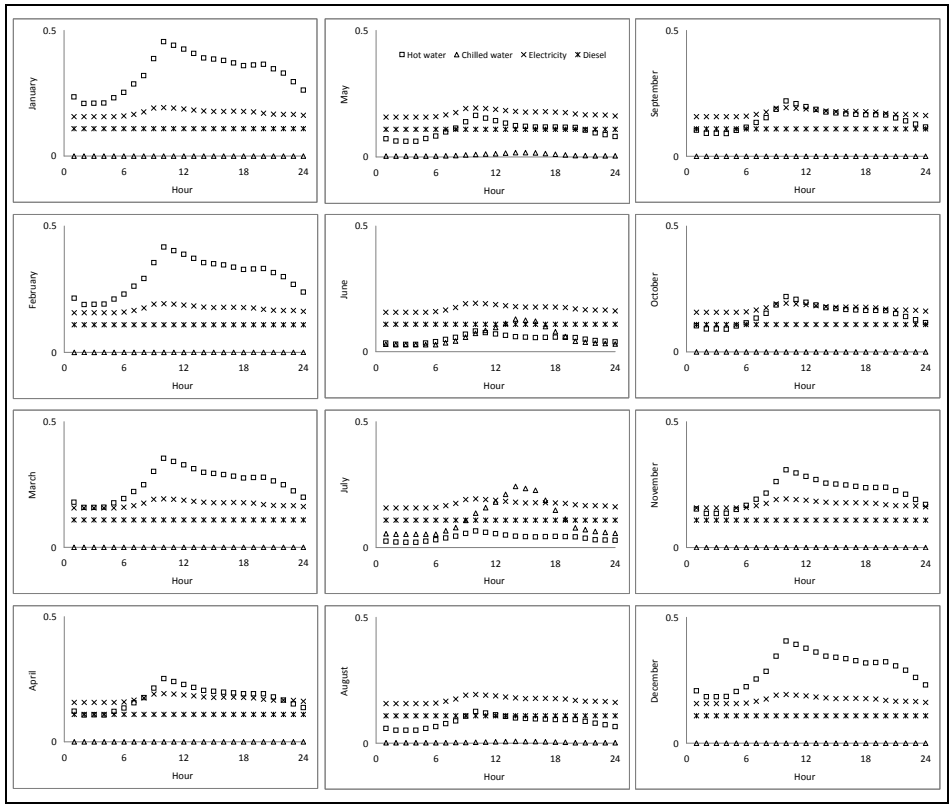
	Underground Mine	Open Pit Mine	Community
Fundamental demand for energy utility			
Heat, MWh/yr	43,758	2,356	6,186
Coolth, MWh/yr	20	354	545
Electricity, MWh/yr	125,224	119,730	5,965
Fuel for motive power, MWh/yr	50,539	102,666	3,786
Defining parameters:			
Production, t/yr	1,290,000	2,700,000	—
Depth, m	800	—	—
Ore: Overburden, t/t	—	2.61	—
Number of dwellings	—	—	85
Energy intensity:			
Mines, kWh/t	170.2	83.4	—
Communities, kWh/(dwelling yr)	—	—	193.9

emergency purposes so that critical facilities can be operated in the face of planned outages or unplanned service interruptions. OMSES permits consideration of the optimal design, selection, and utilization of these assets in energy-and-cost saving roles while preserving their emergency roles. This can be advantageous because the capital costs of procuring the prime mover(s) are either already sunk or, nevertheless, must be allocated.

During mine feasibility studies, a design choice of "to connect" or "not to connect" is always considered rather than considering a determination of "easy to connect" or "impossible to connect" alone (i.e., a design policy to always connect if it is easy to connect). Depending on circumstances, the role of a grid connection can change from one where its prime purpose is to provide the main source of electricity to one where its prime purpose is to provide emergency electrical "generating" capacity. Conventionally, the installed capacity of backup generators is substantially lower than that required to support normal operations. Therefore, if a prime mover operating in a semi-islanded environment is to be considered, the installed capacity of such prime movers will be substantially higher than if they were being used for backup alone. Within OMSES, the grid connection becomes a technology *option* for the supply of electric utility and then must compete, on cost, against other prime mover options.

When the possibility of generating some or the entire power demand is considered, the following technologies present themselves as options as the prime movers (USEPA 2013):

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NOTE: Data are normalized by the total of the annual maxima of hourly demand levels. Raw data are expressed as MWh/h.

Figure 14.5 Synthesized daily demand profiles for typical days in each month of the year for a community peripheral to a mining operation (e.g., a worker accommodation facility)

- Gas turbine
- Micro-gas turbine
- Spark ignition reciprocating engine (gas engines)
- Compression ignition reciprocating engine (diesel engines)
- Steam turbine
- Fuel cells

The use of diesel generators is predominant in remote locations. They are also the preferred solution when renewable energy is installed because of their fast start-up time compared with gas turbines and steam turbines.

Storage Systems

If aiming to meet the demand for energy utility in an islanded or semi-islanded fashion, energy storage systems are essential to provide the variability or diversity

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associated with production processes that cannot be accommodated through the modulation of the prime mover plant. Storage systems present at operations fully connected to energy grids provide opportunity for peak-clipping, valley-filling, and load-shifting energy management practices that can deliver substantial value for mining operations with demand charging elements in their tariffs.

Distributed energy storage within mining operations may be a reality in the near future. In some jurisdictions with prominent underground mining sectors, strong interest in electrically driven loading and hauling equipment equipped with battery packs or fuel cells is reemerging. This is principally driven by a prospect of new regulations pertaining to the use of diesel in the subsurface, arising as a consequence of now-proven mutagenicity of diesel particulates. Regardless, the present expansion of installed diesel capacity in the subsurface of mines introduces additional demand for electrical utility for surface ventilating fans that must deliver more air to dilute airborne contaminants. This load would be substantially reduced with a switch to electrically driven underground production equipment.

Within OMSES, storage systems for different forms of energy are included. (See Carvalho et al. 2014 for mathematical details of the formulation.) Electricity storage, gasified biomass (syngas) storage, and bunkering of liquid and solid fuels such as diesel and biomass are a significant part of utility balance constraints. If included, thermal storage could consider technologies that store heat or cold through materials that change phase (such as water, paraffin, or even air), or through the storage of sensible heat in materials that do not.

Energy storage systems can be classified as follows (IEC 2011):

- Mechanical storage systems
  - Pumped hydro storage (PHS)
  - Compressed air energy storage (CAES)
  - Flywheel energy storage (FES)
- Electrochemical storage systems
  - Secondary batteries (Lead acid/NiCd/NiMh/Li/NaS)
  - Flow batteries
  - Chemical energy storage
  - Hydrogen (H_2)
  - Synthetic natural gas (SNG)
- Electrical storage systems
  - Double-layer capacitors (DLC)
  - Superconducting magnetic energy storage (SMES)
- Thermal storage systems
  - Molten salts
  - Adiabatic CAES
  - Sensible heat storage (natural heat exchanger)

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This classification is representative of already commercial, proven technologies, although some are commercial only in specific economic environments. For the mining sector and many other industrial sectors, electrochemical storage is preferred because the technology is well established and scalable. Some of these technologies are currently opportunistic. Sensible heat storage requires large volumes of fragmented rock and a means of drawing a heat-carrying medium through it. Conventional PHS relies on topographic opportunity; however, any surge capacity of sumps in mine dewatering systems can effectively be used as pump storage by deferring pumping loads until more favorable times as defined in the tariff.

Another type of energy storage is the bunkering of fuels. Diesel is the most common stored fuel in mine sites. It is mainly used for heavy vehicles but also for self-generation of electricity. Fuel logistics and management are considered key tasks that underpin assured operation of many mines. Mines situated in remote locations are usually affected by constraints on fuel supply. It is not necessarily just distance that is the issue. In Canada, road access for bulk materials may be confined to one or two winter months a year when ice roads are dependable. Therefore, diesel inventory has to be monitored to avoid shortages and the rather expensive prospect of flown-in bulk fuel.

Renewable Energy Technologies

At the Renewable Energy and Mining Summit held in Toronto in September 2013, it was recognized that many of newer renewable energy technologies (wind, solar) have improved substantially such that many of the former criticisms about them are now untrue. They are no longer quite so expensive, their reliability has significantly improved (in terms of their equipment/component life and their ability to provide a more continuous source of power), and the technologies have been proven at various scales and in diverse environments. Not unexpectedly, economic benefits are highest when mining operations are furthest from energy distribution infrastructures.

Hydroelectricity

Hydroelectric power plants are classified as a form of renewable energy, and the number of mining companies investing directly in the construction of hydroelectric plants to support their operations is appreciable. Thus, the idea that mining companies can exploit renewable energy technologies for benefit is not new. Payback times for hydroelectric plants are long, internal rates of return are low, and net present value/capital expenditure ratios are low too, which could demonstrate the importance of resilience to electricity price volatility for mining companies. With the exception of micro-hydro run-of-stream installations, hydroelectric plants essentially represent an integration of energy storage (in the form of water backed up behind damming structures and in water courses) and generating capacity, which

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means that output from the plant can be controlled and is relatively predictable. In other words, the supply of energy is said to be relatively "firm."

Solar Energy

In contrast to hydroelectricity, solar photovoltaic power plants—now treated as mature technologies—have cost-effectiveness subject to the solar irradiation of the location, which is intermittent. Consequently, any "firmness" of energy supply from this technology must arise from it being coupled to a storage technology. Through seasons and years, the output of these systems is relatively predictable with known levels of uncertainty. Resource assessment over the short term is possible, although it is necessary to consider uncertainties due to meteorological factors.

Large-scale concentrating solar thermo-electric technologies have been deployed at production operations such that sustained levels of power can be maintained for up to 20 hours per day for "low teens" of cents per kilowatt-hour long after the sun has set (Smith 2013), because they have been coupled to heat storage systems containing phase-change materials. Direct use of solar thermal energy has been successfully employed to maintain leach productivity in heap leach systems in Chile (Piraino et al. 2012).

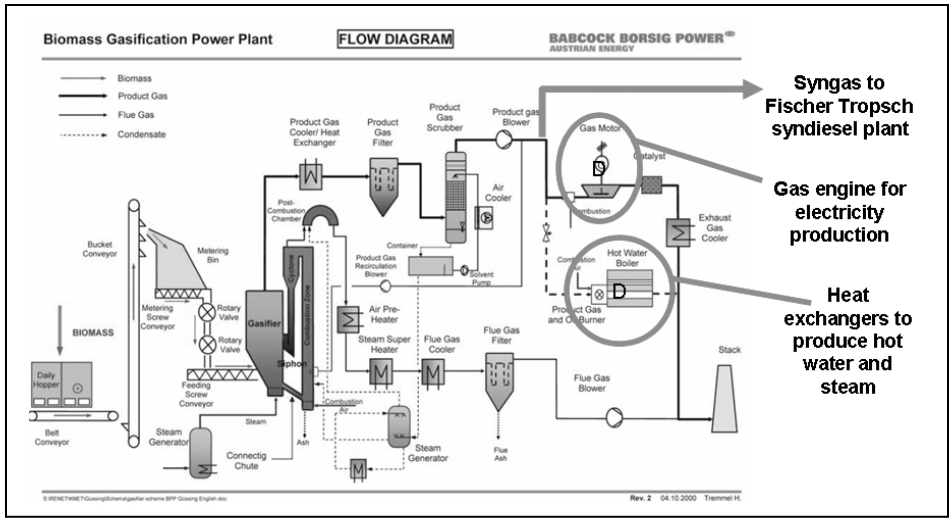
Wind Turbines

The pioneering exemplars of utility-scale wind energy integrated into mine energy systems, grid connected and islanded, are those at Veladero in Argentina, Punta Colorada in Uruguay (Barrick Gold Corporation 2007), El Toqui in Chile (Gridley and Banto 2010), and Diavik in Canada (Rio Tinto 2013). In the case of Diavik diamond mine, the installed capacity (scale of wind turbine) of wind energy has been chosen such that power delivered by the turbines rarely, if ever, exceeds total electricity demand from the mine. Part of the motivation for installation of wind turbines was a planned step-change increase in electricity consumption due to a transition of mining operations underground from a former surface mining operation. The electricity generated by these wind turbines is expected to reduce diesel required for power generation by 10%, and the system is expected to have a payback period of around 8 years. The case is also interesting due to the extreme low-temperature conditions in which the turbines operate; turbine blades are heated to avoid the formation of ice.

Biomass

Biomass materials can be used for different purposes ranging from the less sophisticated to the complex. Suitably dried, it can be combusted as a heating fuel with a gross calorific value approximately half that of coal (Boyle 2004). Pelletized biomass manufactured from purpose grown and harvested biomass or woody residues is

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Source: Adapted from Hofbauer et al. 2002.

Figure 14.6 Schematic of a biomass gasification power plant for syndiesel synthesis

increasing its market share for building heating as well as for power generation as a substitute for coal.

As an alternative to straightforward combustion boilers that raise steam for power generation, a wide range of biomass feed stocks can be gasified to obtain syngas (USEPA 2007), which has been successfully demonstrated at the Güssing combined heat and power plant in Austria (see Figure 14.6) (Hofbauer et al. 2002). This synthetic fuel is quite versatile, because it can be used in boilers, process heaters, engines, gas turbines; distributed in pipelines; or even blended with other gaseous fuels. Without suffering significant changes to the process, gasification systems can use several types of biomass, from dedicated crops to wood and agricultural products. However, the economic viability of this technology is site specific because there are many localized economic variables to consider such as biomass farming, collection, and distribution (USEPA 2007). No onsite commercial or precommercial demonstration of this project is known to the authors.

Liquid biofuels, which are suitable replacements for diesel, can be synthesized through adoption of the Fischer–Tropsch synthesis (FTS) process, which is used at Güssing as reported by Sauciuc et al. (2011). This process converts syngas into a wide variety of hydrocarbon products, from gases to waxes, including liquid hydrocarbons of commercial interest such as syndiesel. Luque et al. (2012) note that "FTS processes from biomass-derived syngas have received a great deal of interest in recent years as a suitable alternative to produce various high quality (free of sulfur, nitrogen, and aromatics) fuels for different applications, since they are compatible

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and blendable with conventional fuels, thus offering the possibility to work with the existing fuel infrastructure."

Despite no noted precedent practice of the FTS process being adopted with a biomass gasifier on a mine site, OMSES includes this technology (Carvalho and Millar 2012) because the syndiesel produced by the process is of high relevance to mining operations, especially open pit mines. In the formulation, trucks, excavators, shovels, loaders, and static prime movers generating electricity can draw from the diesel/syndiesel utility. With suitable bunkering and drying facilities, biomass renewable energy technologies offer one very important advantage over some other forms: nonintermittent, steady supply.

Operational Considerations

Electricity Tariffs

Energy market characteristics totally depend on the country or region. The most repeated scheme today is a pseudo-competitive market that is partially regulated and seeks some competition while ensuring grid reliability. Under this scheme, the price of electricity that consumers pay accounts for two costs: time of use (TOU) and demand charge (DC). TOU arises from a competitive market where electricity producers make their offers until the overall demand is met. The price per kilowatt-hour of electricity paid by consumers can thus vary from hour to hour. DC includes all the costs that the electrical system requires for its own integrity, as well as some long-term fixed-price contracts signed by the corresponding authorities with specific generation plants, such as nuclear power plants and renewable energy producers (IESO 2014).

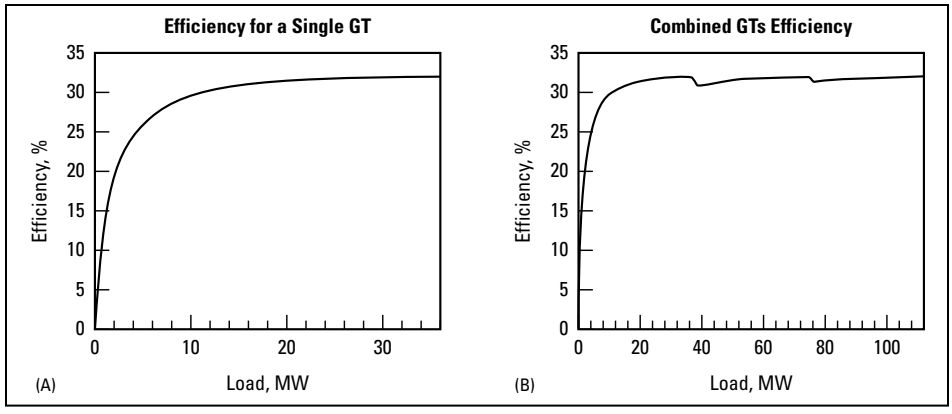
When they apply, TOU charges when consuming electricity are unavoidable, but the structure of formation of DC allows the consumer to design strategies to reduce the total cost of the electricity consumed. The latter generally depends on the peak electric power demand, whether it is the maximum consumed within a specific time interval (month, day, etc.) or just the power consumed in an unspecified time interval. Consumers can therefore face a charge per megawatt of peak power consumed.

Part-Load Performance for Islanded Systems

When studying islanded systems that generate their own electricity using thermal engines, part-load operation is an important issue. This is especially true when the electric load profile is not steady, or when a significant proportion of intermittent or variable electricity is admitted onto the system from renewables. Part-load operation is also important when heat is recovered from the waste flows (exhaust gases, cylinders, and oil refrigeration) of the prime mover appliance.

At part-load conditions, the relationship between the electric and the heat output changes. Furthermore, the fuel amount consumed per unit of electricity

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Source: Reprinted from Energy Conversion and Management, Vol. 67, by K. Trapani and D.L. Millar, "Proposing Offshore Photovoltaic (PV) Technology to the Energy Mix of the Maltese Islands," pp. 18–26, 2013, with permission from Elsevier.

Figure 14.7 (a) Efficiency curve for a single-unit, 37.5-MW gas turbine (GT); (b) aggregate efficiency curve for three 37.5-MW gas turbines units

output also changes. For these reasons, the operation of a system that demands, for example, electricity and heat can normally be run at more than one set point, especially when other sources of energy can meet some of the load. System integration problems with intermittent and variable renewables are most serious when there is only one prime mover unit installed. Under steady demand, renewable power admitted onto an islanded grid, on the basis of low marginal cost from renewable sources, can lead to an increase of the aggregate cost of power produced. This increase in cost is due to the operating condition of the prime mover being displaced from a portion of its part-load curve, where the efficiency is close to maximum, to a portion where the efficiency of the prime mover is substantially lower. The fuel cost of the prime mover operating less efficiently can be higher. This is most obviously appreciated through inspection of Figure 14.7a. However, when multiple, identical prime movers are installed (and operation cycled between them), the system of prime movers can accommodate much larger swings in load while holding the overall efficiency of fuel conversion to power close to maximum levels (Figure 14.7b). Such a conclusion only holds for prime movers that can rapidly adjust their operating points.

To achieve the best operation point subject to the satisfaction of the energy demands, optimization techniques can be applied. However, the traditional operational modes of cogeneration plants concern one of the following:

- Power tracking occurs when the engine produces the whole of the instantaneous demand of electricity and modulates accordingly. The engine is normally rated for the maximum electric demand, operating most of the

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time in part load. Most of the engines designed for electricity generation maintain a relatively high part-load efficiency. Any unused heat is released to the atmosphere, and any lack of heat can be met by an auxiliary boiler.
- Heat tracking occurs when the engine delivers as much heat as demanded. Therefore, this type of operation can be more difficult, unless any lack of electric power to meet demand can be delivered from another source.

Aside from array configurations of prime movers, cogeneration systems may also be balanced off through the adoption of energy storage systems. This results in an increase of the load factor of the combined supply of heat and electricity of the cogeneration plant. Thermal storage, electric storage, or both can be added to the system to provide the required operational flexibility for the prime mover appliance.

CONSERVATIVE CONVERSION GRID SUPERSTRUCTURES

Superstructure-based modeling of energy systems leads to simultaneous determination of the optimal set of technology components supplying multiple utilities as well as optimal operating conditions for each of the components. It forms the basis for expression of constraints in mathematical programming techniques (Yeomans and Grossmann 1999). The customized form of superstructure modeling first presented by Carvalho and Millar (2012) arose as a result of mining industry applications. The most general form devised to date is presented in Figure 14.8.

Representation of Utilities and Technologies

The horizontal lines in the superstructure shown in Figure 14.8 represent the utilities considered in the optimization. Energy conversion technologies, denoted with the vertical lines, can be a source of the utility ("+") or a consumer of the utility ("–"). The nonspecific site loads are gathered on the far right-hand side of the diagram in the "site demand" column. Annual load profiles for utilities presented in Figures 14.3 to 14.5 are consolidated and concatenated at these farthest right-hand nodes. Clearly, the number of utilities indicated in Figure 14.8 is greater than the number of utilities for which load profiles are available in Figures 14.3 to 14.5, which would thus represent an incomplete prescription of the loads required if applied to Figure 14.8.

If sufficiently important, individual site loads can be separately identified as a technology with a vertical line, which is the case for the hoist/winder shown in Figure 14.8. This is most likely for loads that may be chosen for manipulation, in either their timing of actuation or other similar energy management interventions that are motivated by reducing cost (e.g., when TOU charges are included in the tariff) or conserving demand (limited rating of grid connection, demand charging features in the tariff).

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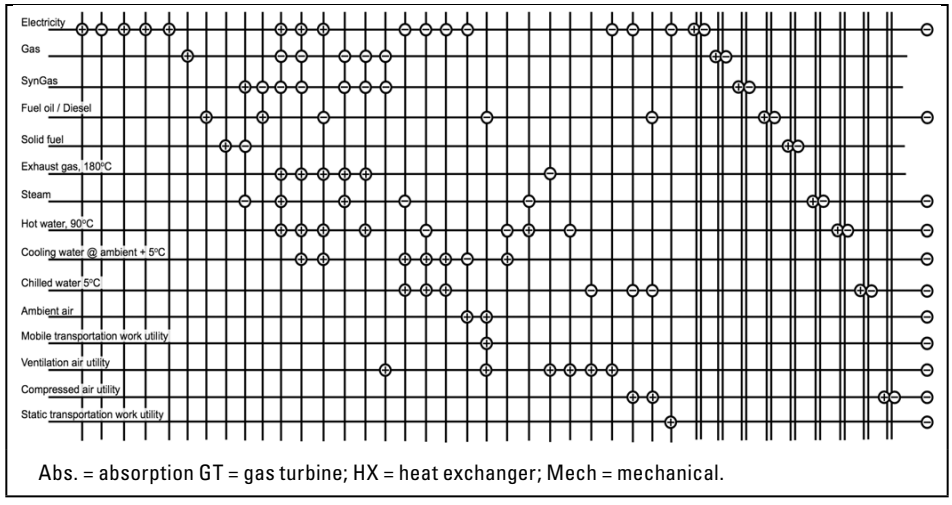


Figure 14.8 Mine site energy supply system superstructure showing utilities considered (horizontal lines), energy conversion technologies (vertical lines), energy storage technologies (double vertical lines), sources of a utility (circles with "+"), consumers of a utility (circles with "–"), and other site loads (right-hand side)

Utility Character and Interaction

The horizontal utility lines in Figure 14.8 can represent electrical power or electricity flow, thermal power, or heat flow manifest in associated mass flows of solids (e.g., coal [not shown], biomass), liquids (e.g., water of varying temperatures, diesel, syndiesel), and gases (e.g., syngas, exhaust gas, ventilation air), or mechanical power or work flow (mobile transportation work utility, static transportation work utility). In the case of liquids and gases, the horizontal line denotes that the mass flows carry either chemical energy, as in the case of fuels (e.g., gas, syndiesel), or thermal energy (e.g., cooling water, exhaust gas). Pressurized mass flows of thermofluids (e.g., steam, compressed air, ventilation air) are utilities carrying both thermal energy and work. The ambient air utility provides a thermodynamic reference state for the system and represents a sink for the mine site energy supply system into which energy with zero exergy may be discharged. This is not the case with mobile plant technology, which will discharge energy with exergy well above zero into the ambient air utility. This is because exhaust heat from the engines driving these machines cannot be recovered and directed toward a useful purpose. The exception is for an underground mine only where exhaust heat from a mobile plant is discharged to ventilation air and can warm it.

Electrical Grid Connection and Energy Storage

Some technologies feature only a "+", which denotes that they are a source of energy or utility that is obtained external to the mine site energy supply system (e.g.,

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hydroelectric, photovoltaic) power. One of the technologies in Figure 14.8 features only a "–", the electric grid export. In this case, it denotes that electrical energy or electric power can be exported from the mine site energy supply system to service external loads. Considering the two potential roles of the electrical grid connection separately effectively permits the electrical grid to be treated as an electricity store from which electrical power can be drawn or supplied. This could only occur simultaneously with two distinct sets of physical power lines. Storage technologies are introduced into the superstructure in a similar, though not identical, manner. An onsite storage technology can behave as either a source or a consumer of utility (generally, not at the same time, but some electrical power conditioning systems, AC → DC → AC, do work with simultaneous input and output flows). These technologies are stores, and this is denoted by their source and consumer nodes being brought into contact. The ratings of storage technologies interacting with a given utility need not be symmetrical; that is, the charge rating need not be the same as the discharge rating.

Developing Visual Understanding of the Optimization

The general description of mine site energy supply systems shown in Figure 14.8 is useful because it forms the basis for thermodynamic and thermoeconomic descriptions of energy supply systems. The approach presents several advantages (Smith 2005):

- Many different design options can be considered at the same time.
- The complex multiple trade-offs usually encountered in energy supply system design can be handled.
- The entire design procedure can be automated and is capable of producing designs quickly and efficiently.

In terms of OMSES, Figure 14.8 provides a useful visual prompt for the first part of the optimization process. The problem of optimal design of the mine energy supply system can be visualized as a decision: *From the set of available technologies admitted for consideration, which subset leads to a minimum discounted cost of utility supplied, given that the loads present on the far right-hand nodes must be met?*

The horizontal lines provide a prompt for constraints to the optimization process: each utility must be balanced. As the load profiles are taken to apply at the far right-hand nodes, there is a reminder that these constraints apply for each time period (say, each hour) of the whole optimization period. The vertical lines also provide a reminder of constraints on the optimization process: particular technologies only interact with certain utilities, and the conversion of one form of utility to another is dictated by a set of conversion coefficients that is characteristic of the technology. Figure 14.8 says nothing explicitly about the rating of a technology

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or the number of units of a technology that are installed; these variables are taken as implicit to the technology represented in Figure 14.8 and are part of the optimization process.

The second part of the optimization process addresses the auxiliary problem. Having chosen a set of technologies, there will be multiple ways in which the equipment can be deployed for any given time period. Therefore, what is the optimal deployment of the equipment for that time period? And what are the optimal deployments for the remaining time periods? Variables representing the operational state of selected technologies are introduced for each technology and for each time period considered, and the problem statement becomes: *Having chosen a set of technologies, what are the values of the operational state variables that lead to the minimum discounted cost of utility supplied?*

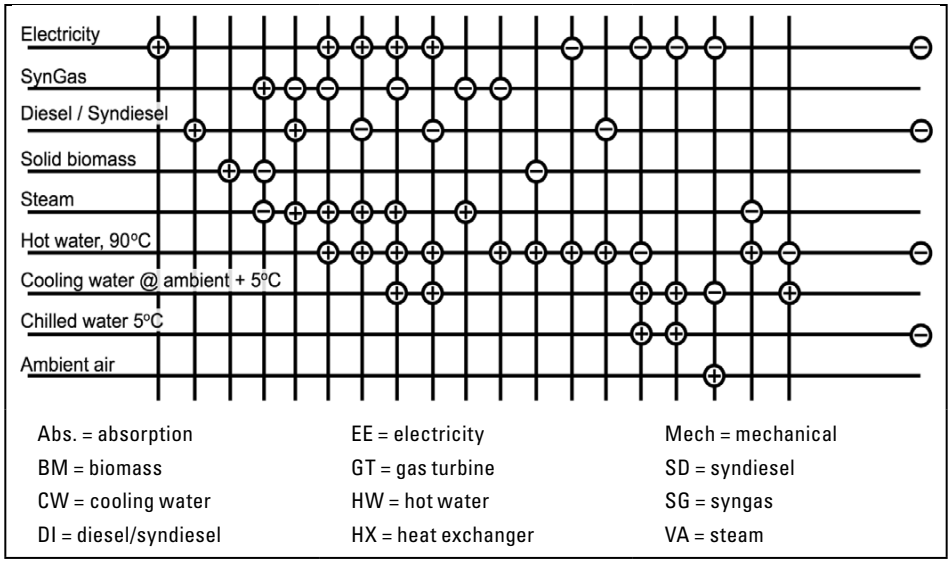
Clearly, the two optimization problem statements are related. The optimal values of the state variables will depend on the technologies selected. Whether the loads of the far right-hand nodes are met will depend on the operational state of the equipment. OMSES solves both subproblems simultaneously. To reflect the conservation constraints implied in the vertical and horizontal lines that may not always be implied in alternative superstructure modeling approaches, Figure 14.8 is referred to as a conservative conversion grid (CCG) superstructure. It represents an ideal system that takes advantage of all the possible sources of energy and all the existing technologies in unlimited quantity so the system can meet the defined load profiles at the lowest (global optimum) cost (economic, energetic, or environmental).

EXAMPLE OMSES APPLICATIONS

CCG Superstructure Modification for Specific Mining Operations

For application to a specific mining operation, client or user interventions may preclude, a priori, particular technologies from consideration on the basis of a variety of factors, including limits on the maximum cash exposure, cost, corporate preference, and perceived risk. Dropping a particular technology may lead to the omission of a particular utility. For example, without the need for refrigeration systems, it is unnecessary to consider a chilled water distribution system. In a similar fashion, specific utilities may be omitted from consideration. For instance, an all-electric mine would have little need to consider fuel utilities. With these considerations for specific sites, the number of technologies and utilities reduce in comparison to Figure 14.8, and one is left with a mine-specific CCG superstructure, as presented in Figure 14.9. Because the number and type of utilities are congruent, the load profiles in Figures 14.3 to 14.5 may be applied in turn or in combination to the far right-hand nodes of this CCG superstructure.

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Source: Carvalho and Millar 2012.

Figure 14.9 CCG superstructure adopted for example cases

The optimal technology combination is the result of an evaluation of investment and procurement costs of across-the-fence energy resources from the environment. Some of these may themselves be constrained (limited supply capacity).

Table 14.5 represents an example of utility exchange relationships for each technology included in Figure 14.9, where the coefficients that define these relationships are normalized so that the main product takes the value of 1. Table 14.5 also includes the corresponding investment cost, operation and maintenance (O&M) cost, and the nominal power of each piece of equipment.

The mathematical formulation presented in Carvalho et al. (2014) was partially adapted to a mine in Northern Ontario, Canada, in the sense that the technology selections (Figure 14.9) were particularized to match the natural energy resource availability of the region and it included a section that exemplified the way demand charges are accommodated in the formulation according to Ontario regulations. This formulation is the basis of the examples contained in the following section, through which the benefits of using OMSES can be better understood.

The formulation is common to the four examples, although energy storage, electrical connection costs, and electrical demand charges are only considered in the second example. The first example introduces the use of OMSES in comparison of two competing scenarios for OMSES for a given mining operation: grid connected and not grid connected. The second example discusses how the configuration of the optimal solution changes when the connection distance from the existing grid is increased. The third example introduces a graphical concept for sensitivity analysis,

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Table 14.5 Selected equipment and matrix of production coefficients

Equipment	Nominal Power (MW)	Capital Cost (10^3 $)	O&M Cost ($/MWh)	Biomass (BM)	Electricity (EE)	Syngas (SY)	Diesel/Syndiesel (DI/SD)	Steam (VA)	Hot Water (HW)	Cooling Water (CW)	Chilled Water (RW)	Ambient Air (AA)
Gasifier	3.0	3000	4.0	1.54		1		0.06				
Fischer–Tropsch	3.0	4000	6.0			1.25	1	0.60				
Gas turbine	3.6	4000	7.5		1	3.03		0.59	0.66			
Diesel turbine	3.6	4000	10.0		1		3.00	0.60	0.60			
Steam turbine*	5.6	2500	5.0		1			3.00	2.00			
Gas engine	3.6	3600	10.0		1	2.44		0.70	0.41	0.33		
Diesel engine	4.4	4400	5.0		1		2.27		0.80	0.20		
Steam boiler	3.0	144	1.0			1.18		1				
Hot water boiler	3.9	150	1.0			1.22			1			
Biomass boiler	3.5	492	4.0	1.25					1			
Electric boiler	3.5	144	1.0		1.11				1			
Diesel boiler	3.0	130	1.0				1.15		1			
Absorption chiller	1.5	280	5.0		0.01				1.36	2.36	1	
Mechanical chiller	2.7	185	2.0		0.21					1.21	1	
Cooling tower	5.0	82	5.0		0.02					1		1
VA-HW HX	5.0	50	1.0					1.1	1			
HW-CW HX	5.0	35	1.0						1.1	1		

*Steam turbines are only considered in the parametric analysis of grid connection distance.

and finally, the last example aims to explore demand consolidation benefits when more than one mine/consumer is considered in the optimization problem.

Example 1: Basic Run of OMSES for an Open Pit Mine

In this basic run, some results obtained through the implementation of OMSES are examined. The proposed case is an open pit mine with the utility demands known, as depicted in Figure 14.3. Two scenarios for the mine are proposed. In Scenario 1, there exists a grid connection (electric imports available), heat cannot be recovered (should prime mover generators be installed), and biomass import is forbidden. These (rather restrictive) constraints introduced for Scenario 1 were

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applied so a conventional grid connection and trucked diesel solution would emerge from the optimization process. In Scenario 2, the mine is forced to operate off-grid (electric imports forbidden), waste heat recovery is allowed, and biomass is available although annually restricted for logistical reasons (storage capacity and transportation capacity) and with prices as reported in the Western University Research Park (2012) document.

The installed equipment, annual imports, and the main economic results are shown in Table 14.6. In both scenarios, utility demands are identical, but the different constraints and contour conditions imposed lead to different solutions. Table 14.6 reveals the following, for example:

- Under the defined conditions, nonconventional technologies emerge through the optimization process, such as biomass gasification and liquid fuel synthesis.
- If the considered mine is located far enough away from the closest connection point of the electric grid, the resulting cost of the infrastructure required may lead to off-grid solutions.

Figures 14.10 and 14.11 illustrate the solutions obtained for Scenarios 1 and 2, respectively, on the CCG superstructure. The technologies installed (see Table 14.6) maintain the original "color" in the superstructure represented in Figure 14.9; technologies taking the lightest gray color (vertical lines) are not part of the optimal solution. Utilities that are not part of the optimal solution under given scenario conditions are also colored gray in this postoptimization representation.

In Scenario 1 (Figure 14.10), the whole electric utility demand is imported from the grid, including that required to meet consumption from the electric boiler, the single-effect absorption chiller, and cooling tower feed pumps. Figures 14.10 and 14.11 present the total utility site demand met at the far right-hand nodes, and these totals are the same for both cases, which is to be expected. The manner in which these site demands have been met is clearly different, as is evident from the intermediate annual energy flows that are shown next to the corresponding nodes on both diagrams. As an example, in Scenario 2 (Figure 14.11), the gasification plant produces 383,036 MWh/yr of syngas from steam and solid biomass.

The results (Table 14.6, Figures 14.10 and 14.11) do not necessarily indicate the "final solution" for the open pit mine being considered. Rather, they present the lowest annual cost manner of meeting the site utility demand to support production, given the various constraints imposed in the scenario specification. Further considerations will be necessary to arrive at the right system for a given operator. For example, if a grid connection is not a practical consideration for the operation, Figure 14.11 indicates that at the given level of fuel pricing, installation of gasifiers and Fischer–Tropsch (FT) units to supply more than half of the (syn-) diesel required and to fuel gas engines to generate 122,882 MWh/annum electricity is more cost-effective than importing all the diesel and generating electricity

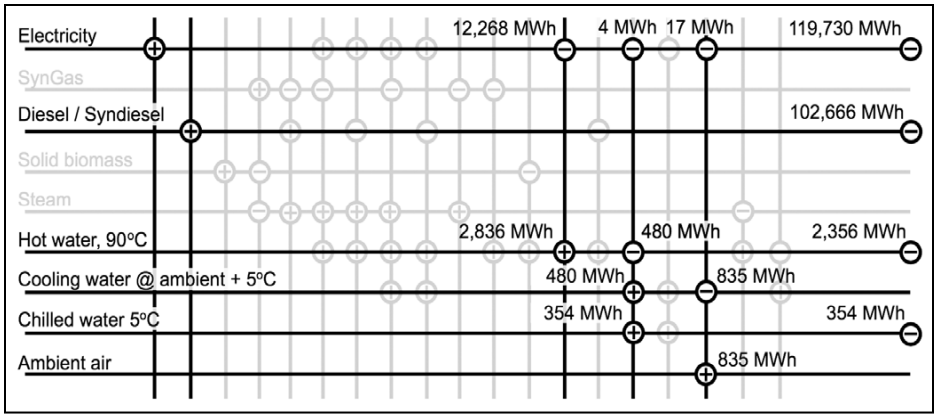
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Table 14.6 Results from the basic run considering two scenarios

	Scenario 1	Scenario 2
Electricity price ($/MWh)	100	—
Biomass price ($/MWh)	—	30
Diesel price ($/MWh)	130	130
Additional constraints	No heat recovery No limit on diesel stored Biomass not available	Waste heat recovery Diesel capacity limitation Off-grid (electricity)
System Composition	**Number (installed power)**	**Number (installed power)**
Gasifier	0 (0 MW)	15 (45 MW)
Fischer-Tropsch	0 (0 MW)	3 (9 MW)
Gas turbine	0 (0 MW)	0 (0 MW)
Diesel turbine	0 (0 MW)	0 (0 MW)
Gas engine	0 (0 MW)	5 (18 MW)
Diesel engine	0 (0 MW)	0 (0 MW)
Steam boiler (diesel)	0 (0 MW)	0 (0 MW)
Hot water boiler (diesel)	0 (0 MW)	0 (0 MW)
Hot water boiler (biomass)	0 (0 MW)	0 (0 MW)
Electric boiler	1 (3MW)	0 (0 MW)
Diesel boiler	0 (0 MW)	0 (0 MW)
Single-effect abs. chiller	1 (1.5 MW)	1 (1.5 MW)
Mechanical chiller	0 (0 MW)	0 (0 MW)
Cooling tower	1 (7.4 MW)	3 (22.2 MW)
VA-HW HX	0 (0 MW)	3 (15 MW)
HW-CWHX	0 (0MW)	4 (20 MW)
Electricity connection	Yes	No
Imported electricity	122,899 MWh/yr	—
Imported diesel	102,666 MWh/yr	36,392 MWh/yr
Imported biomass	—	589,875 MWh/yr
Production of syngas	—	383,036 MWh/yr
Production of syndiesel	—	66,274 MWh/yr
Capital cost of system	CAD 700,350	CAD 87,543,750
Annual cost of imported electricity	CAD/yr 12,289,864	CAD/yr —
Annual cost of imported diesel	CAD/yr 13,346,580	CAD/yr 4,730,930
Annual cost of imported biomass	CAD/yr —	CAD/yr 17,707,647
Annuitized cost of equipment*	CAD/yr 140,070	CAD/yr 17,508,750
Total annual cost	CAD/yr 25,636,444	CAD/yr 39,947,327

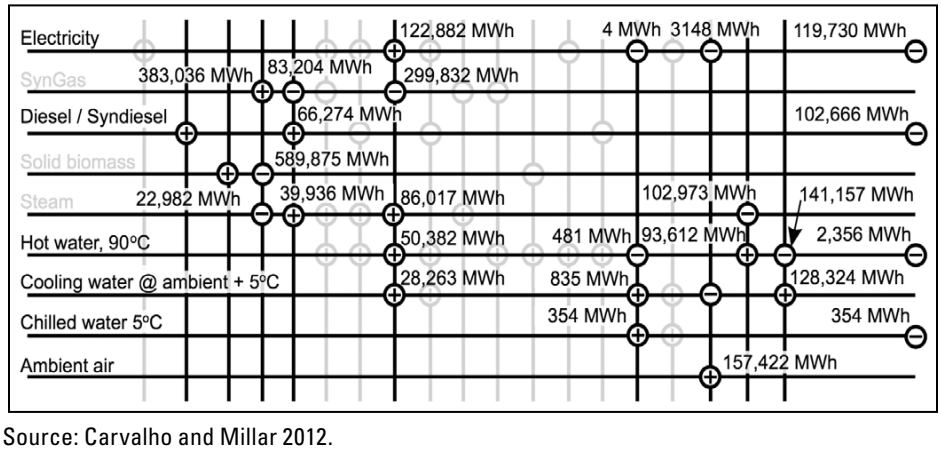
*Lifetime 20 years; discount rate 10%.
CAD = Canadian dollars.
HW-CW HX = hot water–chilled water heat exchanger.
VA-HW HX = Steam–hot water heat exchanger.

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Source: Carvalho and Millar 2012.

Figure 14.10 Scenario 1: Open pit mine with utility loads defined by Figure 14.3, grid connected (levelized cost does not include cost of cable), $100/MWh$_e$ (electrical), $1.35/L diesel, biomass not available, no heat recovery, no limit on heat wasted, no limit on diesel stored. Compare with Figure 14.9.



Source: Carvalho and Millar 2012.

Figure 14.11 Scenario 2: Open-pit mine with utility loads defined by Figure 14.3, not grid connected, $1.35/L diesel, $135/t purpose-grown biomass, engines with heat recovery, limit on fuel storage, limit on heat emitted. Compare with Figure 14.9.

with diesel engines (after capital procurement, installation, O&M, fuel costs, and discounting are taken into account).

The optimal solution indicated is clearly more complex than those normally selected for off-grid open pit mines, and this added complexity may be sufficient to deter an operator from this lowest-cost solution. Additional practicalities such as reliability, maintainability, and volume of precedent practice in mining contexts

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may be overriding factors that would deter an operator from selection of the lowest-cost solution found from the OMSES process.

For such reasons, OMSES can be referred to as a decision support tool. It will identify the lowest-cost equipment portfolio and operating strategies, but it will be up to the design team to decide whether these lowest costs for the scenario sufficiently compensate for the additional perceived risk of more integrated energy supply technology. Alternatively, operators may choose to offset perceived risk by subcontracting out the provision of energy supply to specialist corporations with sufficient experience, human capacity, and other resources such that they regard designing, building, and operating equipment specified in Table 14.6 and Figure 14.11 as routine. In such cases, the energy services company may choose to use OMSES to design the system, and the mine operator may use OMSES to establish the level of premium they are willing to pay to compensate for the lowering of risk perceived.

Example 2: Connection Distance Analysis for Remote Mines

Scenario 1 (Figure 14.10) did not consider the cost of the grid connection in its optimization process. Mining operations are often located in areas with challenging infrastructural access or are poorly connected to conventional energy infrastructure (electricity grids or natural gas pipelines). Building on the basic Scenario 1, a parametrical OMSES study is presented in this section that varies the distance to the closest location of electrical grid connection and takes account of its cost. Connection to a natural gas pipeline is not considered, but road access is assumed available only during the winter months such that biomass and diesel remains available and transportable to the mine. Energy storage is permitted for diesel, biomass, electricity, and syngas with storage capacities determined as part of the optimization process.

The infrastructure cost of an electricity connection, $C_{inf,EE}$, can be expressed as follows (Carvalho et al. 2014):

$$C_{inf,EE} = (\Gamma_{EE} \times a_{inf,EE} + D_{TRANS} \times \Gamma_{EE} \times b_{inf,EE})$$

where Γ_{EE} is the rating of the line and transformer system (a decision variable to be defined by the optimization procedure), D_{TRANS} is the distance between the mine and the nearest connection point, and $a_{inf,EE}$ and $b_{inf,EE}$ are cost factors and have units of \$/MW and \$/MWh-km, respectively. The connection cost equation shows that this is not only dependent on the distance, but also on the rating of the cable (a variable that is determined during the optimization process).

Variable electric demand charges are also included in the example, following the approach of Carvalho et al. (2014). These demand charges depend on the power imported during relatively small but unknown set of hours within a year.

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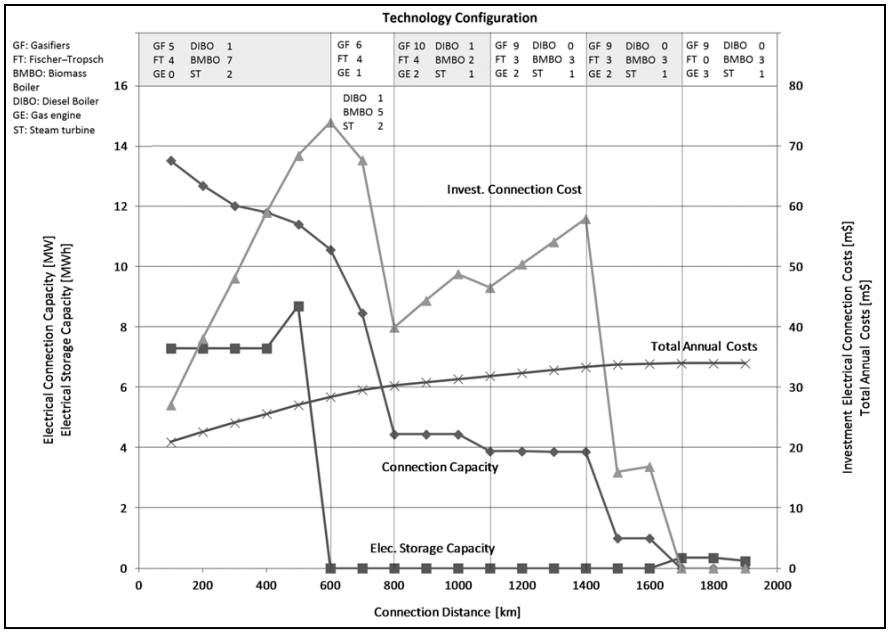


Figure 14.12 Connection distance parametrical analysis

The approach makes use of statistics to evaluate when these hours may take place so the energy supply system can avoid importing electricity during such hours.

Regardless of rating, a mine located at a far enough distance from the connection point will incur such high connection costs that the optimal solution will be an islanded system. Figure 14.12, which illustrates the results of such an analysis, shows that for the conditions considered, this distance is approximately 1,700 km.

In addition to the capital cost of connection, an equally strong determinant on the lowest annual cost energy supply system design is the electricity tariff available from the grid operator, in particular whether TOU or DC feature. In this parametric analysis, demand charging as detailed for Ontario in Carvalho et al. (2014) was included. As expected, when the distance from transmission or distribution infrastructure increases, the total annual costs of energy supply increase. However, it is instructive to examine how the design of the optimal energy supply system changes with increasing distance, and this is reported along the top of Figure 14.12.

When the connection distance is less than 600 km, the mine is grid connected with a high cable rating. The mine is principally powered from the grid, but electrical energy storage capacity is installed principally because it leads to an operational strategy emerging that will reduce the demand charges of the tariff. Gasified biomass-fueled steam turbines are also installed. At the time of peak transmission and distribution demand, the discharge rating of the storage and the steam turbine ratings combine to reduce the call on the grid to near zero, resulting

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in significant financial benefit through the avoidance of demand charges. The optimization process has arrived at a balance between storage discharge rating and steam turbine rating, based on the respective costs of the technologies (steam turbines are economical, storage is expensive) and the secondary ability of the storage system to mitigate TOU electricity charges. The rating of the connection to the grid is optimally chosen to allow mine operations to proceed as well as to permit the electricity stores to be charged (at night). The grid connection rating generally reduces with distance because once the capital cost of the cable is included in the cost of procuring electricity from the grid, it becomes more cost-effective to produce more electricity onsite.

The grid connection rating drops significantly between a distance of 600 km and 800 km, with corresponding drops in capital cost. Loss of electricity import capacity is met through the installation of a gas engine fueled by gasified biomass. The analysis indicates that it is not worth installing electricity storage capacity onsite to deal with demand charging from 600 km and farther; the secondary TOU mitigation benefits are also lost. Between 800 km and 1,400 km, the connection rating reduces slowly, and consequently, its capital cost rises. The lower connection capacity is compensated for by the installation of another gas engine, with the "remaining" steam turbine operating as a "bottoming" cycle in a combined cycle configuration. Beyond 1,400 km, the connection capacity drops sharply with greater load being placed on the combined cycle plant. When the OMSES system becomes islanded at 1,700 km, another gas engine is installed and electricity storage again plays an important role, operating as a demand "lopper" of peaks in the islanded system.

An interesting interaction takes place between the progressively greater reliance of biomass feedstock used for electricity generation with gas engines as connection distance increases and the number of FT units that are installed to produce syndiesel from gasified biomass. Figure 14.12 presents the possibly unexpected result that as the electricity grid connection distance increases, the number of FT units reduces; no FT units are installed at a 1,700-km connection distance. Up to 800 km, the solid biomass storage capacity is underused. At 800 km, the biomass store is completely restocked every winter. Beyond 800 km, there are two competing uses for gasified biomass on the mine site: it could be used to generate electricity in the gas engines or it could be used as the feedstock for the FT units and produce diesel for the haulage fleet. Any swing toward electricity generation means that less diesel can be produced and the diesel fuel must be imported to maintain the mine production capacity. Beyond 1,700 km, all gasified biomass is used for electricity generation and all diesel must be imported. The loss of FT units in the parametric analysis is a sole consequence of the fixed biomass storage capacity. Rerunning the analysis with the biomass storage capacity as a decision variable retains the onsite diesel manufacturing capacity.

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Example 3: Introducing OMSES Resilience Maps

In the previous section, the parametric analysis was predicated on the availability of grid electricity, diesel, and biomass at the given prices. In particular, the presence of the "more exotic" technology options of gasifiers and liquid fuel synthesis units depended significantly on the delivered price for solid biomass material relative to the delivered price for diesel. Peat, which is abundant in Northern Ontario (Gleeson et al. 2006), was the specific biomass feedstock conceptualized. As a consequence of price sensitivity, an important question to ask of an OMSES solution is whether the design remains optimal under varying input fuel prices. Such considerations particularly hold true when uncertainty about future fuel prices exist and the service life of the mine site energy supply design may be at least a decade.

To examine such price sensitivities, a parametric series of re-optimizations can be undertaken while the input fuel prices are systematically flexed. Each member of the series returns a technology configuration corresponding to the lowest annual cost of utility supplied. The resulting OMSES designs are then programmatically examined for similarity with other optimal designs, such that each optimal configuration may be classified and the classifications can be indexed against the corresponding input fuel costs. The classification adopted by the authors focuses on similarity of the set of technologies installed (e.g., of those listed in Figure 14.9) and ignores the number of each technology installed. A set of optimal solution categories results, and the categories can be used to "label" a grid corresponding to the flex ranges of input fuel costs. Such diagram is referred to as an OMSES resilience map, an example of which is presented in Figure 14.13.

An OMSES solution may be considered "resilient" to fuel cost uncertainty if the area occupied by its particular OMSES design classification is large on the resilience map compared with other classifications. For example, the solution FT + gasifier (with grid electricity) occupies a greater area in Figure 14.13 than other classifications and consequently may be considered the most resilient to changes in biomass price and diesel price. However, an OMSES resilience map provides a graphical context on which trajectories of past or future fuel price combinations may be plotted, and then a more appropriate prescription of resilience may be whether this trajectory makes excursions that cross classification areas. For example, using Figure 14.13, if the diesel fuel price is 140 $/MWh ($1.55/L delivered) and the biomass fuel price is $50/MWh ($220/t delivered), the open pit mine may consider use of a biomass boiler alone. With a diesel fuel price increase to $200/MWh, the open pit mine should consider installing gasifiers and FT units. For such a price excursion, when the OMSES design opted for was designed for the former diesel price (of $140/MWh), this design no longer remains optimal for the revised pricing.

Sensitivity to optimality has been illustrated through the adoption of resilience maps with reference to input fuel price fluctuations. Similar charts can also be prepared to explore the sensitivity of the OMSES design classification to variables other than fuel prices—for example, capital costs or bunkering capacities.

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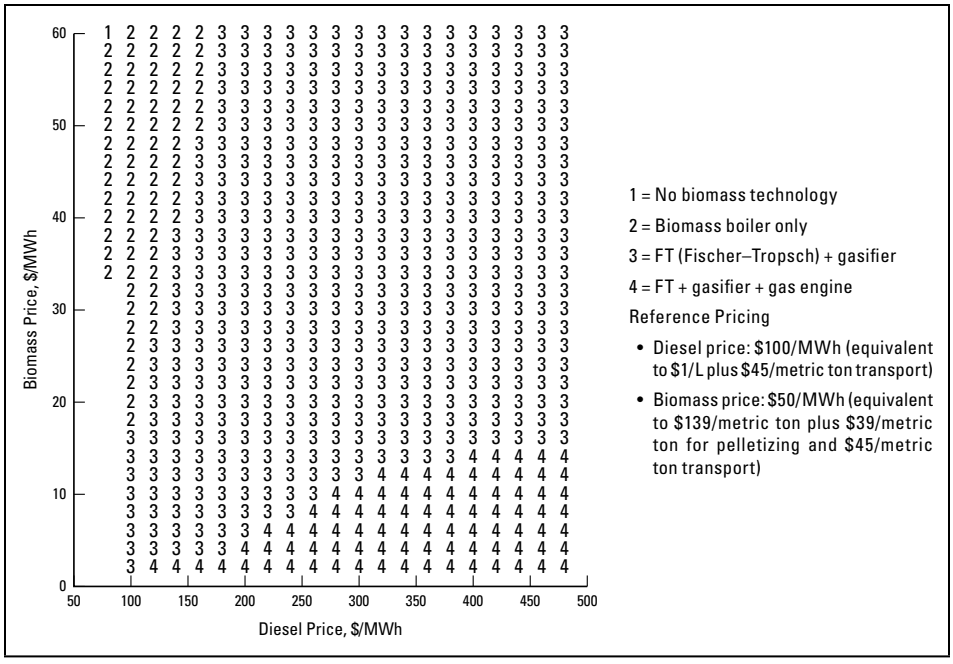


Figure 14.13 Resilience map for the open pit OMSES problem

Example 4: Demand Consolidation

Mines can be energy consumers that are isolated, but multiple mining operations frequently exist close to each other. When utility demand of several nearby operations or utility consumers are aggregated, an OMSES solution can be computed for all consumers simultaneously. In addition, the larger scale of demand can lead to the economic benefit of a lower cost of utility supplied for all parties to the load aggregation.

When demand from multiple consumers is aggregated, the optimal solution may lead to higher load factors for every unit of each technology installed, and hence, lower costs. It may also lead to combinations of technologies that were not considered in the separated problems. A straightforward example to visualize is of one mine with predominantly thermal needs and another with predominantly electrical needs. Aggregation of the loads from both operations will permit cogeneration technologies to emerge from the OMSES process.

To illustrate this idea, the utility demand of one or more neighboring communities (Figure 14.5), an underground mine (Figure 14.3), and an open pit mine (Figure 14.4) can be considered for aggregation. Table 14.7 shows the results of considering each load independently and aggregated with loads of one or more of the neighboring parties. As more load is aggregated, the total annual cost of all utility supplied decreases. In Table 14.7, the "Acting Together" column establishes

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Table 14.7 Total annual cost of energy supplied under various demand aggregation strategies*

Scenario	Acting Together	No. of Communities	No. of Underground Mines	No. of Open Pit Mines	Total Annual Cost, M$	Savings due to Aggregation, M$ (%)
1	No	1	—	—	1.783	—
2	No	—	1	—	22.821	—
3	No	—	—	1	26.746	—
4	No	—	1	1	49.566	—
5	Yes	—	1	1	49.335	0.231 (0.47%)
6	No	1	1	1	51.349	—
7	Yes	1	1	1	51.013	0.336 (0.65%)
8	No	5	1	1	58.480	—
9	Yes	5	1	1	57.161	1.319 (2.26%)

*Diesel prices: $140/MWh ($1.55/L). Biomass prices: $50/MWh ($220/t).

whether the total annual cost is the result of the sum of separated problems (No) or the solution of the aggregated problem (Yes).

The savings arising from the aggregation of demand are revealed in the rightmost column of Table 14.7, which shows increasing savings when more consumers' loads are aggregated. In practice, the additive effect of the demand increasing the utilization of the technologies purchased is not the only result that drives the annual cost down, although it is the only one considered. The effect of economies of scale can play an important role if the aggregation of several mines and communities is contemplated. This can can be considered in subsequent steps of the analysis, because equipment of larger rating can be included for consideration in the technology database (Table 14.6), but this is beyond of the scope of the present work.

SUMMARY AND CONCLUSIONS

OMSES brings together aspects of supply-side and demand-side management to identify the optimal design of the energy procurement system for mineral production facilities. This may involve production or conversion of energy from the form supplied to the form required onsite or direct import of the energy in its end-use form. The authors' formulation can accommodate the real-world complexities associated with mine energy supply such as pricing tariffs and regulatory constraints. For remote mines, this may involve whether the operator should invest in a grid connection. The framework allows for great flexibility in technologies considered

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alone and in combination, whether for generation, conservation, or enhancing conversion efficiency. It is a framework that assimilates energy demand from mobile plant as well as demand from stationary facilities.

Bush (2013) states that "successful integrated resource planning [of energy for minerals operations] also requires detailed knowledge of how and when energy is being used by each of the company's operations. This necessitates improved information management and data collection at the operational level." The information technology tools and sensors that are required to gather, maintain, and interpret energy data have been available for many years. Yet how and when energy is consumed at mines remains unknown by some operators, other than they know what they pay. The information requirements to explore designs for energy supply for mineral operations using OMSES, such as those in Figures 14.3 and 14.4, are extensive and may be beyond the present ability of minerals operators to provide.

Consequently, what is the point of developing a framework for OMSES when the availability of input data may be sparse? The authors believe that the central benefit of the optimization framework which has been developed is that even now it may be applied to mine site energy supply design tasks. This can be accomplished using provisional utility demand profiles and complete knowledge of the expected tariffs, producing valuable insights into the energy supply system design options. Energy management strategies are not prescribed within the OMSES framework, but they emerge in the analysis of OMSES solutions, guided by one rule: find technologies and operational modes that lead to the lowest total annual cost of energy supplied. This is because the framework considers energy supply in a fully integrated manner, which, on occasion, produces counterintuitive results that, upon analysis, ultimately make good economic sense for the operator. To help with interpretation, the sensitivity of optimality must be assessed through parametric explorations so that design resilience may be tested and accepted.

At present OMSES exists as a series of rather weakly coupled research analyses and work flows. Current work involves development and integration of these tools and procedures to render a turnkey, user-friendly software product that can be customized to the needs of mining industry energy professionals.

ACKNOWLEDGMENTS

This work was developed inside the framework of research projects within the Smart Underground Monitoring and Integrated Technologies for Deep Mining program, funded by Ontario Research Fund for Research Excellence Funding Round 5, and the OMSES project funded by the Natural Sciences and Engineering Research Council of Canada through an Industrial Research and Development Fellowship for Monica Carvalho. Michelle Levesque's doctoral candidacy is supported by Vale. All support is gratefully acknowledged by the authors. Figures 14.9 to 14.11 are taken from Millar and Carvalho (2012) and are reproduced herein under the

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PART V

MINE WATER MANAGEMENT

Michelle E. Jarvie-Eggart

Water is one of the most important global environmental issues of the twenty-first century. The availability of freshwater for human use is such a concern that the United Nations includes sustainable access to safe drinking water among its Millennium Development Goals. Freshwater resources must supply not only drinking water but also irrigation and many industrial uses, including mining. Lakes and rivers may also have cultural or recreational importance to local populations.

Water is also one of the most important resources for a mining operation. Mining, mineral processing, and tailings disposal all require significant volumes of water. In arid regions, mines competing for scarce water look for engineering solutions to reduce water use. In areas with abundant freshwater, mines with excess water look for engineering solutions to avoid polluting local surface water or groundwater. For new and expanding mining operations, a comprehensive plan for responsible water management is fundamental to obtaining environmental approvals and permits. Thus, responsible miners take proactive steps to conserve water, prevent water pollution, and collaborate with local communities to ensure water access and water quality for all stakeholders.

Chapter 15 on sustainable mine water management summarizes the myriad of ways water is used in a mining operation, describes typical water sources, and discusses the importance of mass balances for water. This chapter also discusses case studies on the development of a zero surface water discharge strategy in northern Minnesota; the Olympic Dam, a copper, gold, silver, and uranium mine in Australia; the Argyle diamond mine in northwest Australia; and the Homestake gold mine near the western border of South Dakota.

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Chapter 16 on mine water treatment discusses water quality issues for mine water, as well as various treatment techniques including physical, chemical, biological, and passive processes. The authors highlight the possible use of vacuum membrane distillation (VMD) in mine water treatment, detailing the mass transfer process, VMD setup and operation, and VMD performance. They present the results of a study on VMD water treatment at two coal mines and discuss the potential to use solar power to drive VMD processes.

Chapter 17 highlights water planning and management in a pit lake at the Meirama brown coal mine in Spain. This case study illustrates collaboration between a mining company and the local community to manage environmental impacts in a pit lake and supply drinking water to the city. The mining company needed to find a way to stabilize the Meirama pit lake banks, diffuse acidic seepage, and minimize weathering of exposed rock. The city of A Coruña needed to find additional water supplies to support a growing population. Forced flooding of the pit using river water was selected as a solution to achieve the environmental objectives and supply additional water to serve municipal water demand.

From the overall management of water at mine sites to the treatment of mine water and its use as a potential community water source, these chapters highlight the importance of careful planning for the long-term use and protection of water resources from concept to closure of a mine project.

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CHAPTER 15

Responsible Mine Water Management: Water and Mass Balance Modeling, and Creative Mine Water Management Solutions

Christie Kearney and Kelly Matson

INTRODUCTION

Responsible water management is critical to positive social, environmental, and economic outcomes for any mining operation. Regulators, water resource managers, and local communities are increasingly apprehensive about mining's potential impacts on water availability and water quality. Water security is recognized as a key concern in sustainable development (United Nations Millennium Development Goals; UN-Water 2013), with population growth, economic development, and climate change adding pressure to global freshwater resources.

The mining industry is responding to these concerns. A recent study commissioned by the International Council on Mining and Metals (ICMM), *Summary of International Water Issues for Mining*, concluded that water management is one of the top priorities for the minerals industry worldwide (Moran et al. 2009). Mining companies are finding that regulatory approval for new mining projects, project expansions, or process improvements requires that they understand the water needs of other stakeholders, respect the local cultural values related to water, and prevent the degradation of surface water and groundwater resources. As climate change science predicts increasing severity of droughts and storm events, water management on mine sites will become increasingly important in the future.

Over the last decade, many mining operations have instituted responsible mine water management measures, including water recycling and use of low-quality

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water, to continue to operate and even expand while facing global competition for water. For example, Rio Tinto, a world leader in mining, set a target to reduce the amount of freshwater used per ton of product by 6% from 2008 to 2013 (Rio Tinto 2013a). This goal was set after Rio Tinto was able to reduce water use by 6.3% per ton of product between 2003 and 2008 (Rio Tinto 2013b). Many other mining leaders are setting similar targets.

Any mining operation seeking to reduce water use and minimize water quality impacts needs to consider its comprehensive water balance. Water usage in each mine process must be accounted for, as must the mass balance of chemical constituents in the water for tracking water quality. Accounting tools range from simple spreadsheets to more complex statistical predictive modeling software tools like GoldSim, a Monte Carlo stochastic simulation software, depending on the operations. Once the water quantity and mass balances are understood, creative solutions can be designed to reduce water use and minimize water quality impacts.

This chapter outlines the main uses of water within mining operations, discusses water accounting techniques, and examines innovative techniques that mining companies are using to reduce impacts to water resources.

MINING AND WATER: OVERVIEW

Mine water balances and responsible mine water management solutions are based on understanding the need for water in mining and mineral processing, the sources of water available to the mining operations, and the necessity for water treatment prior to reuse or discharge.

Water Uses in Mining and Mineral Processing

Water plays an important role in most mining and extractive processes. Understanding the main uses of water, the quantity and quality of water that are required for each use, and the water losses associated with each use are the first steps in making decisions on how to best manage water at mining operations.

Water usage and the resulting mass balance vary depending on the type of mining and mineral processing used for the operation. For example, an underground mine will typically be required to deal with more groundwater inflows than an open pit mine. An example of varied mass balance occurs in hydrometallurgical processing, which will typically result in water laden with higher concentrations of soluble metals than an operation ending at the concentrator. The main water uses in mining operations, listed in order of typical quantities, include the following (METS 2011):

- Conveyance of the ore or wastes (slurries or suspensions)
- Mineral processing and separation (grinding, flotation, gravity separation, leaching, hydrometallurgy)
- Mineral extraction (hydraulic or solution mining)

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- Cooling
- Dust suppression
- Washing of equipment
- Dewatering
- Human use and consumption

The conveyance of ore and wastes in the form of slurries or suspensions is typically the largest water demand at a mine. Tailings disposal, in particular, can require a significant volume of water and can result in losses of large volumes of water. In conventional or slurry tailings disposal, tailings are sent to an impoundment area with approximately 50% water by volume (±10%) in the conveyed slurry. Some of the water used to transport tailings can be recycled from reclaim ponds in the tailings basin. However, over time, constituents can build up within the water, resulting in decreasing water quality for the operation. Some of the water used for tailings transport can be lost to evaporation within the impoundment, infiltration or seepage through the impoundment, and permanent storage in the voids between the tailings particles. Methods of tailings disposal are available that use substantially less water, such as thickened tailings, paste tailings, dry tailings, and cemented tailings, but these methods typically have significantly different capital and operating costs that need to be considered (Spitz and Trudinger 2009).

Mineral processing uses water during several steps in its procedure to separate the ore from the gangue and to produce concentrates. This is typically the second highest water demand at a mine. Grinding, flotation, leaching, and hydrometallurgy are the main water users in typical mineral processing; however, the water used in these processes can often be captured and reused. The use of recycled water in mine processes results in a buildup of constituents within the water, which causes a decrease in water quality over time. Reuse of low-quality water without some treatment or dilution can lead to scaling or corrosive water. The flotation and leaching processes can be adjusted to use this lower-quality water, or other low-quality water such as seawater, brackish water, or saline groundwater, without prior treatment. However, many mineral processing steps require high-quality water, and water treatment plants are becoming a required process for mines around the world. Water losses in mineral processing can be due to evaporation from heap leach piles or ore drying, or moisture retention in the concentrate or other end products. For an in-depth description of the amount of water used for each step of the mineral processing circuit, including a breakdown of varying ore types, see *Water in Mineral Processing* by Drelich (2012).

Compared to mineral processing and ore or waste conveyance, there is relatively little water used in mineral extraction. Exceptions are hydraulic mining and solution mining, both of which are specialized practices for a mining operation. Hydraulic mining is the process of using jets of high-pressured water to cut through the waste rock or sediments to get to the ore body. This type of mining has been used for centuries and is still employed in underground coal mining operations.

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Solution mining, also referred to as in-situ leaching or in-situ recovery, is the process of recovering soluble minerals such as uranium and sometimes copper by leaching the metals in place, typically through boreholes drilled to the mineral deposit. This type of mining is most commonly used for uranium deposits. As of 2010, solution mining accounted for 41% of the world's uranium extraction (World Nuclear News 2011).

Cooling, equipment washing, and human use require relatively little water (compared to uses such as tailings transport and mineral processing), but they usually result in permanent water losses because typically, no recycling options exist for these water uses. The four main losses of water at any mine are usually associated with evaporation (ponds, wetted surfaces), cooling (machines, products), storage of materials (within the tailings voids), and dust control (Hutchison et al. 2013).

Water use in coal mining and other soft-rock mining (e.g., salts, oil sands) is very different than its use in hard-rock mining. Water is often used to aid in extraction of soft-rock mining. For coal mining, water jets are used to break up a coal seam or to wash away sediments along the seam. Similarly, water is often used to wash the coal free of impurities and sulfur as part of the processing of the coal. Based on a study by the U.S. Department of Energy in 2006, water used for U.S. coal mining ranges from 270 MLD to 980 MLD (million liters per day), or 70 MGD to 260 MGD (million gallons per day), which includes the water used for cooling the drilling equipment and for coal washing (USDOE 2006).

Sources of Mine Water

Regulations at the national, state, or local level often drive the water options available for mine uses. Mining requires a significant volume of water relative to the amount of ore to be extracted. Water for mining and mineral processing can be obtained from a variety of sources, and the water source may dictate the need for treatment:

- Oceans or seas—saline water
- Lakes or rivers—typically freshwater, but may be brackish
- Groundwater—may be freshwater, brackish, or saline
- Wetlands—may be freshwater, brackish, or saline

Each of these water sources has a unique set of potential associated issues. The only source of water for which supply is not limited is oceans and seas. However, very few processes can use water with the salinity levels found in seawater, and desalination costs are very high. In addition, seawater is very corrosive, resulting in higher maintenance costs.

Fresh surface water sources, such as lakes, rivers, and wetlands, are ideal for use in a mining operation. However, competition for use of this water can be high when there are other industries or communities in the immediate vicinity. Additionally, appropriating water from these sources, wetlands in particular, may result in the draining of unique habitats, causing other environmental impacts.

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Groundwater can be a convenient water source for mines operating below the water table; however, it can also be a major source of excess water that can affect the mining operation. Dewatering via extraction wells or sumps can generate significant quantities of water that need to be managed. The use of groundwater can have some of the same issues as seawater when the water is very saline, resulting in the potential need for expensive desalination treatment. Groundwater can also be very corrosive, depending on its quality, potentially causing scaling and maintenance issues. Groundwater may be the only option in arid regions. However, competition for this source of water is often very high in dry areas, creating tension with other necessary uses such as drinking water, agriculture, and other industries.

Mine Water Treatment

Two factors drive the need for water treatment at mining operations. First, water treatment may be necessary to obtain the quality needed for mining or mineral processing operations. This might involve treatment of either water with naturally high salinity levels or recycled water in which solutes have been concentrated by mining processes. Second, water treatment may be required to meet objectives for water effluent to be released into the environment. Mining operations in temperate and wet regions may accumulate excess water and need to discharge to a local water body. Discharges are typically subject to local or national water quality regulations, so water treatment may be necessary to meet the required concentration limits set by those regulations.

Most mining operations that treat their source or recycled water do so with active treatment, but passive biological or chemical treatment can also be effective under certain circumstances, especially after mine closure. Common treatment methods used in mining applications include

- Reverse osmosis/ultrafiltration or nanofiltration,
- Ion exchange,
- Evaporation,
- Active or passive biological treatment, and
- Active or passive chemical treatment.

Acid rock drainage (ARD) and heavy metal concentrations are the primary concerns associated with mine-impacted water from metal and coal mines that need to be managed. These concerns are the main drivers for water treatment in these types of mining, because ARD and heavy metal leaching can lead to long-term problems in downstream resources and very costly remediation.

Sulfate is a primary constituent associated with ARD that needs to be managed. Most metal-bearing ore bodies are found within sulfide-based minerals that oxidize into sulfate through the metal extraction processes or exposure to the natural elements and can lead to ARD. The management of sulfate has come under greater scrutiny around the world since the early 2000s, with regulations changing

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Table 15.1 International sulfate regulations

Region	Regulation	Sulfate Concentration, mg/L
Australia	ANZECC 2000	1,000
Brazil	CONAMA Resolution 357	250 (Class 1)
Chile	DS90 (Surface Water Discharge)	1,000–2,000
	DS46 (Groundwater Discharge)	250–500
	NCh 1333 (Irrigation)	250
United States	40 CFR 143.3 (Secondary Drinking Water)*	250*
Minnesota–Wild Rice	Minnesota Rules 7050.0224, subpart 2	10

Source: Adapted from West et al. 2011.
*The Secondary Drinking Water regulation is a guideline issued by the U.S. Environmental Protection Agency for states and public water systems regarding contaminants that may cause water to appear cloudy or colored, or to taste bad. It is not a federally enforceable standard, although some states have adopted it in their regulations. Therefore, the 250-mg/L concentration for sulfate is not a regulated limit across the United States.

from being completely unregulated to being subject to discharge limits as low as 10 mg/L in some circumstances, as listed in Table 15.1. Similar to sulfate, selenium is also a primary constituent of concern in coal mining and some hard-rock mining, which has also come under increased scrutiny in the last decade.

Increased regulatory restrictions on specific constituents such as sulfate and selenium are leading more mining companies to evaluate treatment options. The use of treatment within a mining operation can initiate evaluation of additional responsible mine water management options after assessing the comprehensive mine water and mass balance.

MINE WATER AND MASS BALANCE MODELS

"Rarely is there just the right amount of water, rather there is either too little or too much" (InfoMine, Inc. 2013). To effectively manage site-specific water challenges, mine operators need a comprehensive, calibrated, and continually updated water and mass balance model. This model accounts for all of the water and solutes entering and exiting a defined location. Water and mass balances are essential for understanding the quantity and quality regarding water needs and water availability for the facility, and the environmental consequences of mine water use.

Today's mines typically have complex water management strategies as water is reused and recycled in an attempt to minimize environmental impacts. Water from one mine feature is often collected and pumped to another mine feature for reuse, resulting in a highly connected system. A water and mass balance should integrate all of the mine features and other processes that can affect the quantity or quality of water moving through the system. Without a comprehensive water balance,

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changes in the design or operation of one mine feature may result in unexpected and unwanted changes to water quantity or quality elsewhere in the system. A water and mass balance for the entire mine, not just the processing plant, is vital to the appropriate sizing of mine water infrastructure, the design of improvements to plant water systems, and the implementation of environmental controls.

Water balances can also assist in facility risk assessments where upset conditions, such as extreme weather events or plant shutdowns, can be evaluated and preparations made accordingly (Spitz and Trudinger 2009). A large rainstorm, a long drought, or other extreme weather events can be evaluated within a water balance, allowing for a better understanding of the impact the upset condition can have on the mine water systems, resulting in better preparedness for a real event.

A water and mass balance model is a decision support tool designed to assist mine operations with mine site water management and to help regulators assess potential environmental impacts on water resources. It can also be a tool to communicate the impacts of potential changes to internal stakeholders (e.g., mine management) and external stakeholders (e.g., agencies, communities) that may have differing perspectives on the issues that surround water management at the mine. This full range of stakeholder perspectives should guide the many choices that must be made when creating a water and mass balance model. The team setting up the model must consider the following factors:

- Model complexity
- Model inputs and data sources
- Model outputs required
- Modeling to manage uncertainty
- Modeling programs

Model Complexity

The complexity of the water and mass balance is driven by the questions being asked of the model. A water balance can be as simple or complex as needed for the application. Model complexity relates to the geographic area to be covered (model boundaries), level of detail necessary, time periods to be considered, and frequency at which model predictions are needed (time-step). Complexity also depends on whether a deterministic or stochastic model is used, as discussed later in this chapter. A simple water balance might be centered around a solitary water body at a single point in time, while a complex water balance could include multiple water bodies and mine features as well as the water demand of the individual processes within the plant, evaluated continuously through time with a weekly time-step.

Water and mass balance models are not static and should be updated throughout the mine life cycle. The process of creating a water balance model should begin in the early planning phases of the mine, if possible, and the model should be continually updated and refined through construction, operations, and closure.

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Over time, a mine water and mass balance generally grows in complexity and accuracy as the mine develops and data are continually collected and used in the model (McPhail 2005). This is driven by more detailed questions being asked of the mine water and mass balance. For instance, in the planning stage of the mine, the first question is typically "is there enough water?" with a general water balance with a long time-step (e.g., yearly). During operations, the question may change to "how can water be used more efficiently?" (McPhail 2005). As a project becomes more defined, the water balance can become more refined with shorter time-steps (e.g., daily or monthly), more inputs, including water quality information, and potentially fewer unknown parameters.

The model boundary for mining operations is most commonly the property boundary, but water and mass balances can be scaled to answer site-specific questions. For example, if there is a concern only with the water quantities within a certain area of the mine, such as in a single mine pit, then a water balance can be built around that specific feature. If, however, there are concerns about water quality beyond the mine property, about water availability for other stakeholders, or about water supply to culturally or environmentally important locations, then the boundaries should be expanded to answer these questions. For example, at Rio Tinto's Australian iron ore operations, the mine water management strategy accounts for water supply and demand at regional, local, and mine-site scales, and evaluates the potential impact mining operations can have on each of these scales (Rio Tinto 2013b). As a water balance is being created, it may become apparent that it is necessary to expand the area to comprise other water impacts that were not initially included or, conversely, to add detail within a smaller area to better represent a specific process relative to the question at hand.

Depending on the complexity of the model, it may become necessary to use separate specialty models to develop the inputs necessary for the water balance. Detailed models are available that can evaluate individual aspects of a comprehensive water balance, such as groundwater flows, water quality predictions, or geochemical interactions. These separate specialty models may be necessary to expand the detail of the water and mass balance model, and the results can be used as inputs to an overall comprehensive water and mass balance.

Model Inputs and Data Sources

At its most basic, a mine water balance model consists of the known inflows, outflows, and associated production values that affect water usage, and solves for the unknown water flows. When combined with a mass balance model, the chemistry of the different water flows is included as well as processes, such as chemical weathering of waste rock, that can affect water quality. The Minerals Council of Australia Water Accounting Framework outlines the types of inputs needed as part of a mine water balance (MCA 2012). Model inputs can generally be grouped into five categories (Golder Associates 2011):

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1. Mine process and dewatering inputs, such as production rates, mine plan, and dewatering rates
2. Physical inputs, such as topography, land-use characteristics, and associated runoff coefficients
3. Climate inputs, such as precipitation, runoff, and evaporation
4. Hydrologic and hydrogeologic inputs, such as stream or groundwater inflows or losses
5. Geochemistry and water quality inputs, such as chemical weathering of waste rock or wall rock

Water and mass balance models rely on many data sources, including data that are measured, simulated, and estimated. The accuracy of model results depends on how many of the inputs must be estimated rather than measured. Accuracy generally improves over time, because as the mine develops, more actual data can be measured and applied.

Some of the data necessary for the development of a water and mass balance may be readily available. For example, water flows appropriated for use or discharged from the mine may have been measured and reported to regulatory agencies, which can then be incorporated into the model. The data collection process typically includes reviewing engineering drawings and flow sheets of processing facilities, measuring water levels or flows, conducting a bathymetric survey of water bodies to evaluate storage, collecting water quality samples, delineating watersheds, and discussing operational practices and strategies with the people that control the water use at the mine. Some internal flows that are not known may be estimated based on pipe sizes and pump curves. Existing and former personnel can often be an invaluable source for data not otherwise documented based on their personal experiences in the operation.

An essential step in gathering data for the water balance model is to evaluate the accuracy and relevance of the information for the model that is being created. Data must fit the location and system being modeled. This may require adjusting conventional techniques to better suit local conditions. For example, in the Andean High Cordillera region, where evapotranspiration plays a critical role in the groundwater recharge, mine operators realized that conventional methods for calculating potential evapotranspiration were not sufficiently accurate. A new method was created that calibrated the calculated values to observed data from the region, allowing the system to be more accurately represented (Clark and Guimerà 2013).

After available data have been gathered, data gaps should be identified and analyzed to determine their impact on the water balance (Blair 2007). Missing data can be measured, approximated, assumed, or solved in the model. The method of addressing data gaps is based on engineering judgment and needs to consider the significance of the missing data. Solving for the unknowns within the water balance is the final option for working with unknown data. There is typically a final unknown, typically an unmeasureable loss, which is determined by closing the water balance (McPhail 2005).

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As with any model, the quality of the input data directly impacts the quality of the results. Deciding how to work with the accuracy, uncertainty, and variability in the inputs of the water and mass balance model can be a driving factor in determining whether to create a deterministic or a stochastic model, as discussed later in this chapter.

Model Outputs Required

When developing a mine water and mass balance model, it is important to understand what output from the model will be needed, which is driven by the questions that are being asked of the model. Model outputs typically include ranges in flows, water volumes, or water levels, and constituent concentrations at selected locations. In the case of water and mass balances, the outputs should provide the expected water quality in each location along the water balance, including at discharge points. Time series plots, tables, and charts are the common format for presenting and displaying model output.

Deterministic and Stochastic Modeling to Manage Uncertainty

In addition to answering the questions being asked of the model, a water and mass balance model should also provide an estimate on the range of potential answers, from average to extreme conditions, and identify the uncertainty around the results. This can take the shape of several different deterministic model runs or stochastic modeling, depending on the needs of the model. Deterministic models have single-value inputs creating single-value results, whereas stochastic models have probability distributions for the inputs producing probability distributions for the results. Depending on the type of water balance model and desired results, either type of model may work for a given situation. The model can transition from deterministic to stochastic as dictated by the project, similar to how the model complexity can increase as the model is updated.

Deterministic models essentially simplify the real world by using an average value or a worst-case value as the input. This produces a single-value result that is easy to use and apply. Deterministic models are best suited for well-defined data, such as historic records, and are often used with less-detailed models. Big picture models are generally looking at an overview of a system, and a deterministic model can provide a usable result that, although not fully encompassing all of the unknowns of the system, will work for the situation. When a deterministic model is used with data that are not well defined, a single input value must be selected to represent the range of data. The range of uncertainty can be addressed by running a deterministic model with average conditions, and then again to assess the model request with extreme conditions to evaluate a change in climatic variables, production rates, or other model inputs. However, selecting conservative values for multiple inputs of a model can produce a result that is too conservative, without providing an understanding of the range of uncertainty around the result. This

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will often lead to several different models to be managed to understand the range of potential outcomes with changed conditions.

Stochastic modeling uses the uncertainty and variability of each input to quantify the resulting uncertainty of the model outputs. This approach adds value to a detailed model and is best suited to parameters that can be affected by many variables, such as modeling a new design in a natural system. Stochastic modeling reflects the reality that all natural systems exhibit uncertainty and variability. Some common mine water balance inputs for which there can be significant uncertainty include rainfall runoff coefficients, seepage, water trapped in the voids of tailings, and evaporation rates from wet beaches associated with tailings disposal (McPhail 2005). By using a stochastic water balance model, the uncertainty in inputs can be represented as uncertainty in the results, evaluating a wide range of variables within the same model.

Using probabilistic data in a stochastic water and mass balance model can be complex, but it allows a mining company to manage risk and make informed decisions on strategic mine water management questions. For example, a mining company in Australia, where seasonal climatic conditions can be extreme, coupled probabilistic climate analysis with stochastic mine water balance modeling. This allowed the company to predict the range of storage capacity needed during the wet season and to better integrate mine water management across multiple sites (Buckley 2012).

Water and Mass Balance Modeling Programs

A variety of modeling programs are available that can be used to build a customized mine water and mass balance. The selection of an appropriate modeling program must consider the complexity of the system, the ease of model modification, the need for stochastic modeling capabilities, and the flexibility with dynamic modeling (i.e., modeling dependent on time).

Spreadsheets are a common tool for creating high-level or simplified water and mass balance models; however, spreadsheet models have serious limitations for all but the most simple water and mass balances. Spreadsheet models lack transparency, and can be difficult to update and refine over time as the water and mass balance becomes more complex. Creating a stochastic water and mass balance model in a spreadsheet can be done by using a spreadsheet add-in package (McPhail 2005); however, there are specialized programs that are a better match for stochastic modeling. Spreadsheet models are best suited for simple deterministic models.

As the model becomes more detailed or when using stochastic modeling, it is best to use a more specialized modeling program such as GoldSim, MATLAB Simulink, or Stella (Golder Associates 2011), each of which provide a good platform for evaluating and managing the data associated with a comprehensive water and mass balance. The capabilities of the modeling programs vary, so it is important to understand the needs for the model first and then select the program that will fit

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those needs. Specialized models may include adjustable run time and time-steps, unit awareness, sensitivity analysis, and model calibration. Some also include a framework to make stochastic modeling more user-friendly. The modeling programs that are designed with this functionality allow inputs to be entered as a probability distribution, use statistical sampling to create multiple simulations of the model in a single run, and report results as probability distributions. Additionally, many of the modeling programs include a graphical user interface that makes the model simpler to set up and easier for nonspecialists to understand.

Mine Water and Mass Balance Summary

The mine water and mass balance model is a representation of the mine water management developed to answer specific questions. The mine water balance model should be developed early in the mine planning phase and be continually updated and refined throughout the development, operation, and closure of the mine. At each stage of mine development, different questions may be asked regarding the management of water at the mine; these questions drive the level of modeling complexity needed. Once developed, the mine water and mass balance model can be an invaluable tool to facilitate water conservation, use of new and innovative techniques, and positive environmental outcomes.

CREATIVE MINE WATER MANAGEMENT SOLUTIONS

Case studies illustrate how a comprehensive water balance can help mine operators make appropriate mine water management decisions and develop innovative solutions for responsible mine water management. This section includes a case study on water balance development and management in northern Minnesota. It also provides a small cross section of creative mine water solutions as documented by the ICMM in a new conference series, Mine Water Solutions in Extreme Environments. These case studies show how mining companies are being more responsible with their water use or using more efficient processes to make their long-term water use more responsible and sustainable.

Zero Surface Water Discharge Strategy in Northern Minnesota

Minnesota Steel and Essar Steel Minnesota, LLC (Essar Steel), used a comprehensive mine water and mass balance model to develop a zero surface water discharge strategy for a taconite mine in northern Minnesota. The zero discharge strategy overcame regulatory hurdles and led to successful commencement of a project that combines taconite ore processing, direct-reduced iron (DRI) production, and steelmaking in an integrated facility to provide slab steel for domestic and world markets. The facility is the first mine permitted in Minnesota without a surface water discharge permit.

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The mine is located on Minnesota's Mesabi Iron Range, which has a long history of hard-rock mining. Mining began at the site in 1903 and ceased in 1985. Minnesota Steel had developed plans to reactivate the former mine and tailings basin to process taconite ore and produce DRI pellets for steelmaking. The Final Environmental Impact Statement (EIS) for Minnesota Steel's project was approved by the Minnesota Department of Natural Resources (MN DNR) and U.S. Army Corps of Engineers (USACE) in August 2007, just months before the mine was acquired by Essar Steel in October 2007.

At the time the Minnesota Steel project was proposed, legal challenges to other National Pollutant Discharge Elimination System permits in the state had resulted in a moratorium on the issuance of new surface water discharge permits in Minnesota. There was a great deal of uncertainty around when the moratorium would be lifted. Rather than delay the project until the legal process was completed, Minnesota Steel opted to proceed with environmental review and permitting based on a zero surface water discharge strategy achieved by recycling and reusing process water. Development of this zero discharge strategy required Minnesota Steel to take a very close and comprehensive look at its water and mass balance.

Climatic conditions at the mine make zero surface water discharge challenging. The project site has an average precipitation of approximately 732 mm (28.8 in.) per year with a positive precipitation minus evaporation of approximately 216 mm (8.5 in.) per year, so excess water storage and management is very important. The winter is harsh, with average high temperatures below freezing for at least 3 months per year, so systems must account for significant ice formation.

The mine is an open pit mining operation. Minnesota Steel planned to reopen and expand one mine pit, open a second mine pit, and use a number of abandoned pits as reservoirs. Other site features that are incorporated in the overall water management strategy are the ore processing facility, the concentrator, and the tailings basin.

While collection and recycle of site stormwater and process water allows for a zero surface water discharge, it results in a significant reduction of watershed flows to downstream water bodies. Minnesota environmental regulations require that mine operators mitigate effects of decreased water flows to surface water bodies (MN DNR and USACE 2007). Therefore, the overall water management strategy also included plans to augment flows to downstream lakes and creeks from abandoned pits in the vicinity of the project.

Figure 15.1 shows the schematic of the Minnesota Steel zero discharge water management strategy as presented in the Minnesota Steel project Final EIS. The previous mining operation at the site had closed approximately 20 years prior, but some limited data from the earlier operation were available for use in the development of the water balance.

The zero discharge strategy developed for the Minnesota Steel EIS was based on a simple deterministic water balance using an annual time-step to show that stormwater and process water could be managed onsite without a surface water

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discharge while still having adequate clean water available for stream augmentation. It included a separate groundwater model (MODFLOW) and stormwater model (WATBUD), with these results used in the overall spreadsheet water balance model to show average conditions. Very little groundwater data were available for use in the modeling, resulting in a high level of uncertainty around the model results. Therefore, a sensitivity analysis was developed around the groundwater modeling, resulting in three cases for normal conditions to show the range of potential groundwater flows under average climatic conditions. Separate spreadsheet models were also developed for expected dry weather conditions and wet weather conditions, resulting in nine spreadsheet models to show the potential results under this range of expected conditions.

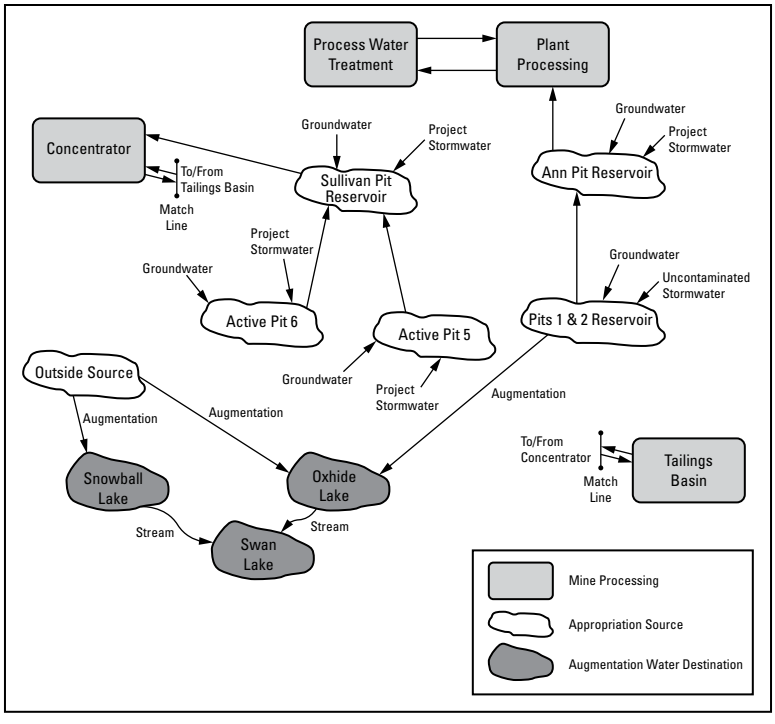
The Minnesota Steel EIS also included a water mass (chemical) balance. The water mass balance used data from the water balance as well as chemical data from a pilot plant study of the project's concentrator process and published information on sulfate release rates from a neighboring mine. Because of the zero surface water discharge strategy, this water mass balance was only developed to determine the expected water chemistry in the tailings basin pond to verify its suitability for reuse as process water and to estimate potential impacts to downstream water bodies due to deep seepage losses to groundwater from the tailings basin. This water mass balance was developed using the deterministic results of the average conditions from the water balance. The report concluded that the resulting water quality would be adequate for use in the process and would be below groundwater standards for seepage losses from the tailings basin (MN DNR and USACE 2007).

Shortly after Minnesota Steel's EIS and permits were approved, the project was acquired by Essar Steel. Before initiating construction, Essar Steel reevaluated the project and decided to make several changes. The following changes required a supplemental EIS process (MN DNR 2011a, 2011b):

- Taconite pellet production increased from 3.8 Mt/yr (million metric tons per annum) of low-flux pellets to 6.5 Mt/yr of high-flux or 7.0 Mt/yr of low-flux taconite pellets.
- The mine operation period decreased from 20 to 15 years to mine the same geologic ore body at a faster rate.
- Modifications were made in the air pollution control system, including installation of low-NO_x (oxides of nitrogen) LE burners and replacement of wet scrubber equipment to a semi-dry air pollution control system.

For the supplemental EIS, Essar Steel modified the water and mass balance to account for the new air pollution control system and the new mine plan, which included minor changes to area watersheds, process water needs, and pit sizes and depths. The company also refined the understanding of the water balance for the tailings basin by collecting supplementary data and conducting additional modeling. Although the Minnesota Steel project water balance used a simplified

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Figure 15.1 Minnesota Steel water supply, use, and recycling

seepage calculation with an assumed permeability for the base of the tailings basin, a refined water balance was developed for the Essar Steel project using a SEEP/W model, based on additional geotechnical data collected around the existing tailings basin. This change was primarily related to sampling that was conducted to define the actual hydraulic conductivity of the underlying glacial till. The SEEP/W model, which incorporated the collected field and laboratory data, indicated that the expected seepage losses from the tailings basin were less than 760 L/min (200 gpm), a substantial decrease from the approximately 2,900 L/min (760 gpm) projected by the Minnesota Steel project water balance (MN DNR 2011a, 2011b).

The change in the air pollution control system resulted in an additional reduction in the water demand, but more importantly, with the elimination of wet scrubbers, it allows Essar Steel to recycle water from the pellet plant back to the concentrator, reduces the need for an expensive water treatment system, and provides more flexibility with the recycled water. This change decreased capital costs and decreased long-term operational and maintenance costs. The increased flexibility in allowing for recycle of this water within the system will lead to significant savings over the original Minnesota Steel project.

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The refined tailings basin water and mass balance, as well as minor adjustments to other parameters based on changes to the project, were incorporated into a refined overall project water and mass balance. Several iterations were created to show the water and chemical balance for a variety of conditions:

- Normal conditions with a range of groundwater flows
- Dry weather conditions with a range of groundwater flows
- Wet weather contingency with a range of groundwater flows

A comparison of the water and mass balance results for the modified project to the results for Minnesota Steel's approved project was made. This comparison showed regulators and the public how the project water and mass balance had changed. It demonstrated that although the project would need additional water because of the increased production rates, adequate water would be available to supply the mining operation and to augment downstream water bodies (MN DNR 2011a, 2011b). The refined water and mass balance also showed that with the significant reduction in expected deep seepage from the tailings basin, the load expected to downstream water bodies would be significantly less than what was originally approved for the Minnesota Steel project (MN DNR 2011a).

The supplemental EIS was approved in December 2011. With the supplemental environmental review process completed and permit modifications in hand, construction is currently underway at the Essar Steel project site. The water and mass balance developed for environmental review and permitting has been used to answer construction and operational questions, such as the following:

- What month during construction will the DRI and steelmaking infrastructure need to be started for adequate water management?
- When will the existing pit be adequately dewatered to start mining?

Essar Steel continues to refine the water and mass balance. Water flow data are being collected as pits are dewatered and stormwater storage ponds are constructed. Water quality data are being collected onsite and in downstream water bodies. These and other data inputs will be used to continue refinement of the water and mass balance as a tool to help Essar Steel successfully execute its strategy for zero surface water discharge.

International Council on Mining and Metals

In 2012, the ICMM compiled 10 case studies gathered from its members that illustrate creative solutions to responsible mine water management (ICMM 2012). Three of these case studies, summarized in the following sections, describe examples where mining operations in the developed world have used responsible mine water management solutions to make positive contributions to neighboring communities. See Chapter 1 of this book for background information on the ICMM.

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Conservation and Protection of Water Resources in South Australia

Olympic Dam is a copper, gold, silver, and uranium mine operated by BHP Billiton and is Australia's largest underground mine. It is located in an arid region in northern South Australia. Mining has been ongoing since 1988, and the operation includes an underground mine and milling, flotation, leaching, smelting, electrorefining, and solvent extraction processes.

Olympic Dam obtains water from the Great Artesian Basin (GAB), one of the largest groundwater aquifers in the world, which underlies approximately 23% of the Australian continent. BHP Billiton has worked with the Australian government, Australian industries, and other water consumers to reduce water use and increase protection of the GAB. BHP Billiton has contributed to conservation and protection of the GAB in three ways. First, it contributed A$2.2 million to the Great Artesian Basin Sustainability Initiative, which works with landholders to rehabilitate open-flowing boreholes and replace open bore drains with piped delivery networks. Second, it purchased properties and restored well-field borings to protect the aquifer. Third, it completed a water savings project to reduce the amount of water used at the Olympic Dam mine site (ICMM 2012).

BHP Billiton started working on its Olympic Dam water savings project in 2004. Water reduction measures have resulted in a savings of 0.24 kiloliters per metric ton of material milled from 2004 through 2011. These measures have included increasing its water efficiency through increased water conservation and recycling activities, including

- Replacing high-quality water with hypersaline groundwater for dust control and mine vehicle wheel wash;
- Implementing a lockout system for water valves to ensure that water is recycled from storage ponds;
- Implementing advanced process controls to reduce water losses to tailings dams;
- Covering open water ponds to eliminate evaporation;
- Increasing the volume of wastewater reused in the metallurgical plant; and
- Monitoring and preserving natural spring flows along the margin of the GAB with unique ecological communities.

Olympic Dam posts its daily water demand on the mine's key performance indicator board near the site entrance as a way to show accountability to the community. BHP Billiton also produces articles for local newspapers to inform the community about the GAB and the use of water at Olympic Dam.

Reducing Water Use from Sources of Environmental Significance

Rio Tinto owns the Argyle diamond mine in northwest Australia. The Argyle mine is the world's largest single producer of diamonds, producing approximately 30

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million carats each year, one-fifth of the world's natural diamond yield. Production began in 1985 and is expected to continue through 2019.

Water is in limited supply in the region, where temperatures reach 40°C (104°F) in the wet season with an annual rainfall of 750 mm (29.5 in.). Water is a sensitive issue because of the impact the operation could have on local groundwater. Water is sourced from several reservoirs created by dams, including Lake Argyle. Lake Argyle is designated by Australia as a protected wetland site under the Ramsar Convention. Lake Argyle's wetlands serve as a dry-season refuge for waterfowl, and the ecosystem supports populations of plant and animal species important for maintaining the biological diversity of the region.

To reduce and eventually eliminate its use of water from Lake Argyle, Rio Tinto instituted a water recycling program at the mine. In 2005, the mine used more than 3,500 ML (925 million gal) from Lake Argyle. The biggest water usage at the site is in the processing plant, where water is needed to wash and separate the diamonds. Before 2005, all of this water was discharged. In 2005, Rio Tinto began capturing and recycling this water back through the process, achieving a recycling rate of close to 40%. Rio Tinto also captures and recycles seepage from tailings and water from pit dewatering for operational use.

By introducing these changes to water usage at the mine, the Argyle diamond mine has achieved a 95% decrease in water taken from Lake Argyle since 2005. In addition, the Argyle mine has been working closely with local and governmental stakeholders to ensure compliance with regulations and licenses and in the protection of sites of cultural significance (ICMM 2012).

Mine Reclamation Focused on Water Management and Cleanup

The Homestake gold mine is located in a semi-arid region near the western border of South Dakota in the United States. Mining at the site started in 1876 and ended in 2001 after Barrick Gold Corporation, which acquired the mine in 2001, closed the site the same year citing low ore grades, low gold prices, and high development costs (Homestake Mining Company 2000).

Homestake produced close to 1,250 metric tons of gold in its 125 years of operation and was the largest gold mine in the Western Hemisphere (SD DENR 2002). When the mine shut down in 2001, the mine site consisted of "between 300 and 400 miles [480–640 km] of underground workings, an open pit, three waste rock facilities, a tailings disposal facility, a mill site, a gold refinery and numerous other facilities and historical structures" (ICMM 2012). Over the 125 years of operation, methods of mining and processing varied and included processes such as gravity concentration, amalgamation, and cyanidation, some of which have resulted in impacts to local waterways (ICMM 2012). Reclamation activities are extensive and complex because of the impacts to water resources and because the mine's surface features covered such a large area.

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The mine is located in a hydrologically unique area with natural springs that supply water to surrounding communities and cold-water streams supporting abundant fisheries. Because of these unique water characteristics, Barrick has focused much of the reclamation on protection and cleanup of water resources with four key water management goals:

1. Rehabilitation of waste rock and ancillary mine facilities to improve water management
2. Collection of impacted water while routing clean stormwater to area streams
3. Onsite treatment of impacted water
4. Maintenance of the area's natural spring freshwater collection systems that supply process and potable water to surrounding communities

These goals have included the following activities:

- Construction of two water treatment plants to treat impacted water
- Construction of collection systems across the site to collect water that has surface drainage or seepage through mine-site facilities to be conveyed to the mine's water treatment plants
- Diversion of clean stormwater into area streams, preventing it from contacting mine-site facilities
- Removal of waste materials and structures, grading of the site to restore drainage, and revegetation to protect water quality in site runoff. More than 500 m (1,600 ft) of streambeds have been restored that had been diverted as a result of mining activities (ICMM 2012).

Water quality monitoring of area cold-water streams and other surrounding streams indicates that the reclamation mine water management strategy is appropriately protecting these receiving waters (ICMM 2012). In addition, the freshwater collection system that Homestake developed to collect water from a number of the area's natural springs now supplies water to surrounding communities for long-term economic development (ICMM 2012).

Mine Water Solutions Conference

A new conference series, Mine Water Solutions in Extreme Environments, was held in Lima, Peru, in April 2013. This conference was the first in a series of conferences to be held to examine responsible mining practices that can be undertaken to minimize water uses and preserve water resources in challenging environments such as extremely wet and dry settings, extreme cold, complex hydrogeological conditions, and challenging geochemistry. This conference was considered a success with 353 delegates from 25 countries in attendance. Topics examined included hydrology, hydrogeology, diversion, containment, conservation of water, minimization of water quality impacts, seepage interception, and treatment. Selected case studies from this conference are described in the following sections.

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Obtaining Precipitation Data by Unique Methods

The Pebble Project, which is the largest known undeveloped copper ore body in the world, is located in the Bristol Bay region of southwest Alaska in the United States. This project, which has been in the exploration/pre-permitting phase since 2004, is being led by Pebble Limited Partnership, co-owned by Anglo American and Northern Dynasty Minerals (AK DNR 2013). Climatic conditions are unique in this maritime continental climate, where average annual precipitation is estimated to be close to 1 m (40 in.), average annual temperatures of –1°C (30°F), and winds averaging 7.5 m/s (16 mph) on a year-round basis with gusts exceeding 54 m/s (120 mph; Cathcart and Smith 2013). Although there are six climate stations across the study area, these extreme temperatures and high winds have made it difficult to collect site-specific precipitation data; precipitation gauge capture is estimated to be less than 65% during winter months and 80% during summer months (Cathcart and Smith 2013).

To obtain accurate precipitation data, Cathcart and Smith used the 26 continuous streamflow gauges located across the site to interpolate precipitation. A site-wide watershed model was developed as part of a study area water balance, using the streamflow data set as the calibration instrument, and the precipitation data were extracted for the study area. The results show that the actual average annual rainfall ranges from 1 to 2 m (40 to 80 in.), depending on the location in the study area.

Providing General Guidance for Wet and Dry Conditions

Two papers developed for the Mine Water Solutions in Extreme Environments Conference by Hutchison et al. (2013) and Poinapen (2013) provide general guidance on wet and dry climate solutions. This guidance is presented in Tables 15.2 through 15.4 and summarized in the text that follows.

Potential wet climate issues range from acid-generating rocks or tailings, impacted contact water, precipitation accumulation, groundwater inflows, closure pit lake outflows, runoff, groundwater seepage, erosion and sedimentation, stormwater events, pregnant solution dilution, poor quality interstitial and contact water, and difficult cover placement, as shown in Table 15.2 (Hutchison et al. 2013). Potential solutions vary by facility, ranging from providing additional storage, separating drainage and collection systems from clean areas, groundwater extraction, makeup water, dust control, spray evaporation or enhanced evaporation, accelerated pit filling or pit backfill with in-situ treatment, treatment and discharge, biochemical reactors, carbonate material backfill, mine plugging, underdrains, and cover systems, also shown in Table 15.2. Poinapen (2013) lists wet climate water management solutions by onsite storage, treatment, evaporation, aquifer recharge, rapid release/pumps and piping systems, a combination of treatments, and direct discharge, with a comparison of these solutions by advantages, disadvantages, capital costs, operating costs, and other general comments, as shown in Table 15.3.

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Potential dry climate issues include makeup water shortages and the high cost of makeup water (Hutchison et al. 2013). Potential solutions involve various ways to minimize evaporation: grading to maximize runoff collection, building gravel haul roads to reduce the need for dust control, collecting groundwater to minimize re-infiltration, collecting and reusing drill water, minimizing the disturbed or actively worked areas, capturing and reusing stormwater, depositing thickened or paste tailings, dry-stacking tailings, cycloning tailings to maximize water recovery from coarse fraction, using long-distance pipelines, operating aquifer recharge facilities, providing onsite treatment and recycling systems, and using offsite waste waters as well as seawater or brackish aquifers.

CONCLUSIONS

Responsible mine water management strategies must be fit to the unique circumstances of each mine using all of the information available. This site-specific optimization approach can be led by some basic principles:

- Meet with all stakeholders, internal and external to the company, to understand the regional water management picture on a social, economic, and environmentally responsible level.
- Develop a comprehensive water and mass balance as a planning tool to understand water demand, water supply, potential water losses, water quality needs, and potential water quality impacts. Refine the water and mass balance as more information becomes available, and tailor it as needed to answer specific questions.
- Monitor water quantity and quality for continuous confirmation and refinement of the water and mass balance. Long-term monitoring data and a comprehensive water balance are critical to development of comprehensive, adaptable solutions.
- Link highest-quality water to highest use to optimize recycling capabilities.
- Optimize the treatment process, if needed, by potentially adding low-cost pretreatment systems, passive systems, or systems that can be used by numerous stakeholders.
- Look for ways to work with other stakeholders to create sustainable systems that benefit all parties in the area.
- Assess how climate change (more extreme droughts and storms) will affect the current water management strategies. Test extreme events in the water and mass balance to develop adaptive water management strategies on how these events will be handled if they occur.
- Prioritize water use through a reduction in water needs, reuse of water affected by mining processes, and recycling of water that has been contaminated either through treatment or further use in downstream systems.

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Table 15.2 Wet climate water issues and solutions

Facility	Issues	Solutions	
Open pits	• Acid-generating rocks • Impacted contact water • Precipitation accumulation • Groundwater inflows • Closure pit lake outflows	• Separate drainage and collection systems for "clean" rock faces • Seasonal in-pit storage • Groundwater extraction outside pit • Makeup water • Dust control	• Spray evaporation • Accelerated pit filling • Treatment and discharge • Pit backfill with in-situ treatment • Biochemical reactors (BCRs)
Underground mines	• Acid-generating rocks • Impacted contact water • Groundwater inflows	• Separate "clean" water drainage • Makeup water • Dust control treatment and discharge • Carbonate material backfill	• Surface water diversions to reduce infiltration • Mine plugging • BCRs for mine outflows
Waste-rock piles	• Acid-generating rocks • Runoff • Groundwater seepage • Erosion and sedimentation	• Underdrains to separate groundwater • Encapsulation of acidic materials • Separate "clean" from "impacted" makeup water • Dust control	• Treatment and discharge • BCRs for leachate • Evapotranspiration covers • Reclamation during operation
Heap leach pads	• Storm events • Rainfall runoff • Pregnant solution dilution • Pile erosion	• Larger "event" ponds • Treatment and discharge • "Lateral" heap phasing • Rainfall covers	• Impermeable closure covers • Combination covers
Tailings impoundments	• Acid-generating tailings • Poor-quality interstitial and contact water • Rainfall accumulation • Groundwater inflows • Seepage • Difficult cover placement	• Selection of smaller, higher impoundment sites • Diversion ditches • Makeup water	• Enhance evaporation; spray systems • Underdrain system • Water treatment and discharge

Source: Hutchison et al. 2013. Courtesy of InfoMine Inc.

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Table 15.3 Wet climate water management solutions

Type	Onsite Storage	Treatment	Evaporation	Aquifer Recharge	Rapid Release / Pumps and Piping*	Combination	Direct Discarge
Description	Transfer of surplus raw water from active and inactive pits and storage dams to new dams dedicated to the holding and storage of untreated groundwater	Treatment of raw water using a combination of technologies identified to achieve the treated water quality	Evaporation of untreated raw water using fan evaporators	Transfer of surplus raw water from active and inactive pits and storage dams to new aquifers (injection wells) dedicated to the holding and storage of untreated groundwater.	Quick transferral of large volumes of surplus water via pumping to existing or dedicated storage before accumulation in mine pits—used to ensure that a rapid water management response is available	Operation sites may choose to establish a combination of the above technologies that would suit their project goals and objectives	"Do nothing" approach—direct discharge of untreated raw water to nearby water courses in accordance with their authority obligations
Advantages	• Simple technology • Relatively straightforward to implement • Minimal ongoing operating costs and maintenance requirements • Zero discharge (maintains compliance with regulations and minimal risk of harm to nearby receiving water courses) • Can accommodate large volumes of water • Land availability should not be an issue	• Known technologies • Can be used as an ongoing treatment strategy for site water • Environmentally sustainable through compliance with the likely regulation discharge constraints • The treated water and side-stream products can be beneficially reused, offering an additional revenue stream and reducing the water volume discharged • This approach will actually reduce the surplus water volumes across operations	• Relatively low overall capital expenditures (CAPEX) for removal of large volumes of water • Relatively straightforward to implement • Can use existing storage dams as the receiving and feed storage facilities (reduced CAPEX) • Removes surplus water • Can be standardized and implemented across all mine sites	• Simple technology • Relatively easy to implement • Minimal ongoing operating costs and maintenance requirements • Can accommodate large volumes of water • Provides storage of water that can be accessed in the future if required (i.e., during drought conditions)	• Simple technology and easily implemented while accommodating a large quantity of water • Drainage flows from rainfall can be captured and stored for later use • Approach can be standardized and it is assumed that it can be easily "rolled out" across many mining operation sites	• Ability to meet both short- and long-term water management objectives • Offers a more sustainable approach for water management and disposal to ensure there is minimal impact on the receiving environment • Offers a more systematic and economical approach for water management during different seasonal conditions • Offers "redundancy" and therefore flexibility in regard to water management	

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Table 15.3 Wet climate water management solutions (continued)

Type	Onsite Storage	Treatment	Evaporation	Aquifer Recharge	Rapid Release / Pumps and Piping*	Combination	Direct Discarge
Disadvantages	• Requires large area of land • Must consider accumulation of salt within the storage dams and future removal requirements • High CAPEX • Additional storage dams may be required to accommodate additional flows	• Must consider treatment and discharge of brine concentrate streams • High level of operation and maintenance requirements	• New technology that has not been proven through all seasons or climatic conditions • Biggest installation in Australia claimed by vendor is 11 ML/d • Regulator acceptance of the system for water disposal at such large scales is unlikely • Transport of saline water over nearby agricultural/ grazing applications • Highly variable efficiency, depending on climatic conditions	• Potential health risks associated with the reuse of managed aquifer recharge water • Requires a process of acceptance from local communities, government, and environmental bodies that can be lengthy and costly • Potentially high-cost option if significant levels of treatment are required before injection or if the water needs to be pumped long distances prior to injection • Environmental risks including groundwater degradation and damage to ecosystems	• Additional storage may be required to accommodate additional flows during rain events • This water management approach does not remove the surplus water from the operation site		• Potential financial and nonfinancial implications • Little benefit for a long-term sustainable approach to water management
Capital Expenditures†	$28.87 M/GL	45 ML/d ~A$5.33 M/GL 90 ML/d ~A$4.78 M/GL	45 ML/d ~A$1.34 M/GL 90 ML/d ~A$1.25 M/GL	16.25 GL/yr ~A$3.76 M/GL 32.5 GL/yr ~A$3.76 M/GL	Can range in capital costs from A$1.8 M/km to A$2.7 M/km, based on pipe diameter ranging from 400 mm to 1,000 mm		

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Table 15.3 Wet climate water management solutions (continued)

Type	Onsite Storage	Treatment	Evaporation	Aquifer Recharge	Rapid Release / Pumps and Piping*	Combination	Direct Discarge
Operating Expenditures†	Assume nil. There will be an OPEX associated with overland pumping from the storage pits/ dams to the new dams	45 ML/d ~A$0.64 M/GL 90 ML/d ~A$0.59 M/GL	45 ML/d ~A$0.35 M/GL 90 ML/d ~A$0.35 M/GL	16.25 GL/yr ~A$0.15 M/GL 32.5 GL/yr ~A$0.15 M/GL			
	Regulatory negotiations would be required to establish if this method of disposal is acceptable. If operations cannot release the required volume of water to nearby water courses because of regulatory constraints, this option becomes quite feasible	Onsite plant trials are recommended if this water management strategy is considered for mine operations	Should yield consistent performance in evaporation of water; however, the key limitation is dependence on climatic conditions to effect evaporation. Trialing of this technology onsite across a range of flows and seasonal/ climatic conditions is recommended to determine design/ efficiency constraints of this technology as a water management approach	A number of additional items must be considered with the implementation of aquifer recharge, including identification of pretreatment requirements prior to injection into wells and environmental studies			

Source: Poinapen 2013. Courtesy of InfoMine Inc.

*Pumps and pipework—Regardless of which technology is adopted for water management at a mine site, overland pumping will be required to transfer the stored water. The costing provided in the above section under rapid release can be used as indicative prices for pumps and pipework.

†Economics are based on disposal (or treatment) of a surplus water volume of 16.4 GL/yr (45 ML/d) and 32.9 GL/yr (90 ML/d).

All dollars are Australian (A$). Units provided are in megaliters per day (ML/d) or gigaliters per year (GL/yr).

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Table 15.4 Dry climate water issues and solutions

Facility	Issues	Solutions
Open pits	• Makeup water shortage • High cost of makeup water	• Dewatering sumps to minimize evaporation • Grading to maximize runoff collection • Gravel haul roads to reduce need for dust-control water
Underground mines	• Makeup water shortage • High cost of makeup water	• Groundwater collection using piping and lined ditches to minimize re-infiltration • Collection and recycling of drill water
Waste-rock piles	• Makeup water shortage • High cost of makeup water	• Minimize active disposal area • Gravel haul roads to reduce need for dust-control water
Heap leach pads	• Makeup water shortage • High cost of makeup water	• Optimize emitter systems to minimize evaporation • Capture and reuse storm-event water
Tailings impoundments	• Makeup water shortage • High cost of makeup water	• Selection of smaller and higher sites • Thickened or paste deposition • Dry-stacking • Cycloning to maximize water recovery from coarse fraction • Maintain small water-collection pond
Process plant makeup	• Makeup water shortage • High cost of makeup water	• Long-distance pipelines • Conjunction use of groundwater and surface water • Aquifer recharge facilities (runoff infiltration pond) • Onsite water treatment and recycle • Use of offsite commercial and industrial wastewaters • Seawater or brackish aquifer usage (with or without treatment)

Source: Hutchison et al. 2013. Courtesy of InfoMine Inc.

By using these site-specific optimization methods, mining companies can manage risk and make informed decisions about strategic mine water management and develop creative mine water management solutions that are sustainable, responsible, and adaptive to the changing environment of mining.

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CHAPTER 16

Mine Water Treatment Techniques and the Application of Vacuum Membrane Distillation

Mohammad Ramezanianpour and Muttucumaru Sivakumar

INTRODUCTION

Population growth, industrial and agricultural activities, urbanization and affluence, together with climate change, create considerable stress on freshwater supplies. The role of water reuse is now widely accepted as a sustainable response to the increasing demand for potable water. On-site treatment and reuse of water not only prevents serious damage to the environment but also reduces consumption of fresh water as well as the cost of the treatment process in large-scale plants. Ample opportunities arise in the mining industry to reuse treated mine water on-site.

The diversity of mine water quality is due to many factors: excavation type (surface and subsurface mining), mine location, mining process, and the water source. Four major sources of poor water quality at the discharge point of a mine site are acid mine drainage (AMD), mine dewatering, processed water, and mineral processing water. Mine water discharge, especially AMD, is recognized as one of the more serious environmental problems because of its typically low pH and high concentrations of metals. Sulfidic metal and coal mines produce AMD when waste materials from the mining operation are subjected to the influence of air and water. Among the variety of sulfide minerals, the predominant AMD producers are iron sulfides, pyrite, and marcasite (Demetriou et al. 2010). The effluent water pH level may be neutralized using alkaline, such as calcite; otherwise, acidic discharge with a high concentration of metal ions is generated. The dominant ions observed in mine water are Fe, Ca, Mg, Mn, Al, and sulfate (SO_4^{2-}), occurring because of

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operational processes as well as during the production of AMD. Nitrate and ammonia are generated from the explosion of the eruptive compounds for ore extraction. For this reason, mine dewatering management is essential for the effluent, which contains ammonia, nitrate, and suspended solids. Chemicals such as sulfuric and hydrochloric acid, used to improve metal recovery, may also be present in process waters, often resulting in low-pH water effluent. Finally, various types of salts are generated using an alkaline environment for sulfide ores in the grinding and flotation processes, resulting in low mill-effluent pH levels and increased dissolved solids concentration (Kuyucak 1998).

Large amounts of water need to be pumped from aquifers or reservoirs for use in various mining processes. The quantity of water greatly depends on the mining processes. However, mine water quality varies widely from mine to mine depending on local conditions, and it will contain elevated levels of heavy metals, suspended solids, organic materials, dissolved solids, and/or conductivity due to the effect of processes such as milling, flotation, and refining (Rieger et al. 2009). Every mine is unique in terms of its potential for producing sulfate, chloride, and heavy metals, so the nature and size of the treatment alternatives will vary from site to site. Apart from AMD, a typical range of mine water characteristics has been identified in the early literature from Australian mining operation (Sivakumar et al. 1994):

- High total dissolved solids (TDS) (500–2,000 mg/L)
- High hardness (500–2,000 mg/L as calcium carbonate [$CaCO_3$])
- Low suspended solids (10–100 mg/L)
- Low biochemical oxygen demand (BOD) (<5 mg/L)
- Low chemical oxygen demand (COD) (10–100 mg/L)
- Near neutral pH (7.0–9.5)
- High conductivity (600–10,000 μS/cm)
- High apparent color (30–600 TCU [true color units])
- Moderate concentrations of other minerals (Na, Mg, Ca, carbonate [CO_3^-], chloride [Cl^-], SO_4^{2-}, and trace elements such as, Al, Fe, etc.)

These data indicate the necessity of a suitable treatment process before disposal or reuse. It is important to recognize the potential problems associated with each mine to preserve the surrounding environment and minimize the impacts. A brief review of mine water quality for coal and metal mines for surface and underground operations was conducted by the authors, and results are summarized in Table 16.1. The ranges of pH values as well as the concentration of dominant ions for mine water are compared to desirable values for drinking water, irrigation, and industrial use in Table 16.1. The range of data shows its dependency to many parameters. However, in all cases, mine water has to be treated to a highest level of quality for the reuse purpose as a target. The water quality guidelines, especially for mining discharge, vary from country to country. Sulfate in water can affect the taste and can have laxative effects at concentrations greater than 600 mg/L. Therefore, the

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Table 16.1 Summary of selected mine water quality parameters

Parameter, mg/L	Surface Mine*		Underground Mine*		Desirable Value for Drinking Water†	Desirable Value for Irrigation†	Desirable Range for Industrial Use†
	Coal Mine	Metal Mine	Coal Mine	Metal Mine			
pH	1.8–9.63	2.7–8.4	2.1–8.4	2.8–8.9	6–8.5	6–8.4	6.5–8
SO_4^{2-}	0.03–21,115	740–14,000	15–4,096	65–3,350	200	10–20	0–80
Ca^{2+}	9.6–88.2	106–490	9.9–516	25.89–376	75	800	N/A‡
Mg^{2+}	0.44–28	20–530	5–180.91	16.82–153	30	120	N/A
Na^{+}	1.59–45.2	10.1–70	12.34–996	42–1,400	50	920	N/A
Mn^{2+}	0.16–980	11–321	0.02–74	0.6–87	0.5	0.2	0–0.1
Cl^{-}	1.34–102	106–430	16–1,066	1.18–1,750	250	142	0–40
Al^{3+}	2.73–2,240	1.7–10	0.01–108	1–220	0.1	N/A	N/A
K^{+}	1.2–28	0.8–29	1.44–8	2.2–8.2	100	2	N/A
Fe^{2+}	0.01–2,640	0.1–4,900	0.04–787	1–69	0.3	5	0–0.2
TDS	29–8,790	2,000–10,000	65.54–4,780	3,200–4,860	500	N/A	0–200

*Bosman et al. 1990; Du Plessis and Swartz 1992; ADTI 2000; Maree et al. 2001; Murarka et al. 2002; Geldenhuys et al. 2003; Perry et al. 2005; Cox et al. 2006; USEPA 2008; Gammons et al. 2009; Nganje et al. 2010; Navarro Torres et al. 2011; Caruso et al. 2012.
†Zakir et al. 2013.
‡NA = Not available.

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level of sulfate is set by environmental agencies in many countries ranging from 250 to 500 mg/L for mine effluent (Silva et al. 2012). When sulfate concentration exceeds 500 mg/L, the taste becomes noticeable. Although the World Health Organization does not recommend a health-based standard for sulfate in water supplies (WHO 1993), the U.S. Environmental Protection Agency (USEPA) has introduced a concentration of 250 mg/L for sulfate in potable water along with TDS of 500 mg/L. The allowable concentration of dissolved inorganic substances is set at 1,000 mg/L for irrigation and stock watering as well as aquaculture. However, the state of Minnesota has shown that high sulfate concentration can affect wild rice production (Walker and Swain 2013). Therefore, a low limiting value of 10 mg/L sulfate has been adopted for the state of Minnesota to grow rice. The Ministry of Environment of the Province of British Columbia has established a maximum for sulfate of 100 mg/L as a guideline for the protection of freshwater aquatic life (Meays and Nordin 2013). Australian and New Zealand guidelines for fresh and marine water quality established the maximum concentrations of 15 mg/L, 40 mg/L, 10 mg/L, 3,000 mg/L, and 40 mg/L for BOD, COD, carbon dioxide, TDS, and total suspended solids, respectively, for the protection of aquaculture species (ANZECC 2000). The color may not exceed 15 color units for drinking water, but this is not applicable to agricultural or industrial water supplies. Levels of pH between 6.0 and 8.5 are acceptable for drinking water, and a range of 5.0 to 9.0 is allowed for other purposes. In the state of Nevada, a standard for mine effluent discharge presents the following acceptable concentrations (Billin 2013):

- Al: 0.2 mg/L
- Cd: 0.005 mg/L
- Mn: 0.1 mg/L
- Ni: 0.1 mg/L
- Zn: 5.0 mg/L
- SO_4^{2-}: 500 mg/L
- TDS: 1,000 mg/L

Nevada also allows a satisfactory pH range of 6.5 to 8.5 for groundwater recharge (Billin 2013). Accordingly, maximum levels are set and the water must meet certain water quality parameters and must not be toxic to aquatic life. A suitable treatment system is required to fulfill the guidelines.

Physical, chemical, and biological processes may be required to treat mine water depending on the characteristics of the water source and the operational processes. The physical and chemical parameters of mine water vary widely. However, biological contamination is usually low. The major problems are high levels of dissolved matter and other undesirable compounds. Treatment objectives are usually set based on reduction of the impurities to acceptable levels to meet water standard regulations, influencing the selection and design of an appropriate treatment process for each mine. A suitable system is chosen to comply with water quality and

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quantity requirements for its on-site reuse for the processing of ores, recovery of metals, flotation process, irrigation, dust suppression, or aquifer reinjection.

Various methods and processes available for mine water treatment are presented in this chapter, along with an example for using a membrane separation process for mine water treatment. Next, vacuum membrane distillation (VMD) as a thermally driven separation process for separation of a gaseous phase from the entry liquid is described. Treatment of mine water and effluent water using a VMD technology is also evaluated, and effluent water quality is presented. Finally, a sustainability assessment of the proposed treatment technology and its associated technical issues are assessed.

MINE WATER TREATMENT AND REUSE

Although contaminant removal and impurities minimization are the concerns of mine water management strategies, appropriate treatment technologies need to be reviewed and investigated. Treatment technologies for mine water discharge or reuse employ physical, chemical, and biological processes to ameliorate associated environmental impacts. A broad range of treatment processes are available for dealing with mine water. The major processes are categorized into physical (sedimentation, aeration, dilution, membrane separation), chemical (oxidation, coagulation, absorption, hydrolysis, precipitation) and biological (biosorption, biomineralization, alkalinity generation). These technologies can be placed under different categories such as neutralization of acid, removal of metals, desalination, and removal of specific target compounds (Thiruvenkatachari et al. 2011). Ammonia, sodium-based, and lime/limestone processes as well as biological sulfate reduction and wetlands are major neutralization methods. Metals can be removed by a precipitation process and/or an oxidation pond. Membrane-based technologies, ion-exchange, and electrochemical processes come under the desalination category. Specific pollutant removal includes cyanide, arsenic, and radioactive nuclides. Regardless of categorization, in most treatment systems a combination of these processes are used. A representative selection of these processes is described in this section.

Physical Processes

The main challenge of mine wastewater treatment is the high level of TDS. In recent years, there has been mounting attention to the integration of membrane technologies for mine effluent water treatment and reuse. The application of an integrated membrane system and membrane distillation (MD) is a physical process. An overview of the performance of reverse osmosis (RO), integrated ultrafiltration (UF) and RO, and VMD are discussed in the following paragraphs.

In the RO process, the pressure applied and the type of membrane depend on the chemical composition of the feedwater. In one study, mine water with pH 8.4,

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TDS concentration of 4 g/L, and sulfate concentration of 2.2 g/L was treated by a pretreatment unit for suspended solids removal followed by RO (Du Plessis and Swartz 1992). The pH of the pretreated water was adjusted using sulfuric acid to between pH 5.5 and 6.5. The pressure was controlled to be continuous at around 30–40 bar. High-quality permeate was achieved by the following reductions in concentration:

- Chloride: from 220 mg/L to 26 mg/L
- Sulfate: from 2,200 mg/L to 14 mg/L
- Na: from 917 mg/L to 26 mg/L
- Ca: from 176 mg/L to 2 mg/L
- Mg: from 80 mg/L to 0.0 mg/L
- Fe: from 0.3 mg/L to 0.1 mg/L
- COD: from 70 mg/L to <2 mg/L

The RO process produces high-quality water; however, operating costs vary considerably depending on the quality of the feed solution. Fouling, mechanical failure of the membrane, and brine disposal are some of the major disadvantages of this method.

The efficiency and performance of the integrated UF and RO membrane system in mine water treatment have been investigated for use at copper and coal mines (Shao et al. 2009). The integrated system for this application was a combination of outside-in pressurized hollow-fiber UF followed by spiral-wound RO membranes. The main advantages of the UF membrane as pretreatment of RO are low turbidity of the permeate, reliable removal of bacteria and viruses, and the highly automated nature of backwash and chemical cleaning. During the performance of the integrated membrane system, the concentration of TDS was reduced from 8,458 mg/L and 10,000 mg/L to 335 mg/L and 536 mg/L for coal and copper mines, respectively.

One study examined the effluent discharge from a local coal mine containing 2,332 mg/L TDS, 14.4 mg/L Ca, 2.72 mg/L Mg, 1.92 mg/L Fe, and 3.38 mg/L Al, which was treated by a VMD process (Sivakumar et al. 2013). This technology removed particles and dissolved impurities by evaporation and condensation. It employed a hollow-fiber membrane that enables the removal of 99.9% of TDS from mine water.

Membrane separation technologies effectively remove suspended solids, bacteria, and dissolved solids from mine water. The stable operation of the membrane separation system relies on suitable pretreatment of raw water. However, UF membranes eliminate only small amounts of oil or dissolved organic compounds and the hardness of water that pose threats to RO membrane fouling. MD methods, especially VMD, can allow either the efficient and cost-effective reuse of mine water on-site or its discharge into the environment.

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Chemical and Ion Exchange Processes

Most mine water treatment systems use aggregate carbonate to neutralize the pH and encourage sedimentation of metals as hydroxides or sulfide minerals. Alkalinity is provided mostly by organic matter in passive treatment systems and can also reduce the precipitation of metal sulfides. Membranes can fail when they come in direct contact with AMD containing low levels of pH. For this reason, a passive water pretreatment system prior to the filtration techniques is required.

The treatment of AMD by lime and limestone is the most commonly used commercial process. Lime and limestone neutralize AMD through precipitation of gypsum, which results in sulfate removal. The sulfate ion concentration determines the solubility of the gypsum at this level. Moreover, lime addition increases the pH, which results in the precipitation of most toxic metals. Aeration of the feed tank can also assist in the oxidization of Fe and Mn. This process is inexpensive during the construction stage. However, the lime and limestone process is less efficient in terms of permeate quality and reaction time. Two types of limestone neutralization methods are available: open and anoxic. Open channels containing coarse limestone aggregate make no attempt to cut off oxygen, so a larger mass of limestone is required compared to anoxic neutralization. Open systems are designed to increase the pH of water from about 2 to 6–8. Field results from a number of mines prove that open systems are capable of removing approximately 70% Fe, 40%–50% Al, and 10%–20% Mn from mine water (Skouse 1997). The anoxic limestone method consists of layers of coarse limestone aggregate buried in carefully constructed drainage lines to maintain low oxygen conditions to keep dissolved iron in its reduced state. The major function of the anoxic system is to raise the pH from about 2 to 6–8.

Another alternative neutralizer is magnesium hydroxide, which can produce more metal hydroxide sludge with lower volume compared to limestone and sulfides. This is because the solubility of metal sulfides is usually less than metal hydroxides. However, sodium hydroxide is an expensive compound (Kuyucak 2000).

More recently, a limestone process was developed that is capable of reducing the Mn, Cu, Mg, Fe, and SO_4^{2-} concentration in AMD by an average of 59.9%, 94.3%, 28.2%, 69.1%, and 67.7%, respectively (Silva et al. 2012). This approach performed acceptable sulfate reduction for moderate anion concentrations using limestone to increase the calcium concentration. Complete sulfate removal was performed with a COD/SO_4^{2-} ratio of higher than 0.67. The pH was increased to 8.1 in permeate. Although the process was cost-effective, the poor quality of the permeate water was a disadvantage. Nevertheless, it can be used as an appropriate pretreatment for membrane technologies and electrodialysis to prevent fouling and microbial growth.

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Very acidic mine water effluent at the Navigation coal mine near Witbank in South Africa was neutralized by adding limestone and then reclaimed because of the addition of lime to remove the sulfate (Geldenhuys et al. 2003). Finally, the pH was adjusted using carbon dioxide in the gas phase, which was recovered from the first stage of the treatment process. For a 10-m^3/d plant capacity, a hydraulic retention time of 1 h, a gypsum crystallization time of 2.7 h, and 0.5 h in the calcite precipitation stage were determined. The concentrations of SO_4^{2-}, Mg, Mn, and Cl were decreased from 3,000 mg/L to 1,219 mg/L, 160 mg/L to 3.03 mg/L, 17 mg/L to 0.01 mg/L, and 16 mg/L to 0.0 mg/L , respectively. In addition, Ca and Na concentrations were increased from 420 mg/L and 41 mg/L to 542 mg/L and 46.8 mg/L, respectively. Precipitation of dissolved Mg after lime treatment at pH 12.3 enhanced sulfate removal. The sludge of gypsum and magnesium hydroxide is produced as waste in this treatment process. The removal of sulfate to below the saturation level of the gypsum and the neutralization of acidic mine water are the two main advantages. Major disadvantages are the production of a mixed sludge and limits in some cation removal.

A calcium silicate feedstock, dunite, and barium salt can also be used to remove dissolved sulfate from mine water. Calcium silicate is capable of neutralizing acid solutions in the same way as limestone, but in the presence of heavy metals, silicic acid species are absorbed into the metal surface and lead to the formation of colloidal complexes. In this manner, negatively charged colloids stabilize the metals (Ziemkiewicz and Skousen 1998). The effectiveness of acid mine drainage treatment by dunite was investigated using the addition of 1, 10, 100, 250, and 500 g dunite to 1 L AMD (pH 2.8), which increased the pH of the AMD solution to pH 2.9, 4.1, 5.7, 6.7, and 7.8, respectively (Demetriou et al. 2010). Significant precipitation of Cr, Co, Ni, and Pb is derived in permeate; however, the concentration of Mn, Fe, Cu, and Zn remained 79.8 mg/L, 156.8 mg/L, 39.8 mg/L, and 141.6 mg/L, respectively, for one of the samples using 10 g/L of dunite solution. The application of dunite in AMD treatment is cost-effective where it is naturally available.

Among the barium salts, barium sulfide (BaS) was highly insoluble and outstanding for sulfate removal over the entire pH range (Bosman et al. 1990). The procedure is very similar to the lime and limestone treatment process along with sulfate removal gas elimination and a water softening stage. In one study, BaS reduced the sulfate concentration of 17,500 mg/L and 2,060 mg/L of two very acidic samples (pH 1.4 and 2.7) to 175 mg/L and 190 mg/L, respectively. The only advantage of the barium sulfide process is a shorter retention time compared to limestone.

The ion exchange process can remove potentially toxic metals, chlorides, and sulfate complexes from mine water. The feed solution is first passed through the cation loading stage using strong acid cation resin to remove cations such as Ca. Carbonate is then eliminated in a degassing tower, and finally the anion loading stage removes sulfate. The technical feasibility of a developed laboratory plant

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ion exchange using lime and sulfuric acid was evaluated for treatment of AMD (Schoeman and Steyn 2001). Precipitation of lime and gypsum raised the pH from 2.7 to 8.5, whereas the sulfate concentration was decreased from 8,000 mg/L to 1,980 mg/L. The following concentrations were also reduced:

- Ca: from 490 mg/L to 50 mg/L
- Mg: from 420 mg/L to 20 mg/L
- Na: from 70 mg/L to 50 mg/L
- Fe: from 100 mg/L to <0.1 mg/L
- Mn: from 182 mg/L to <0.1 mg/L
- Cu: from 186 mg/L to <0.1 mg/L
- Zn: from 550 mg/L to <0.1 mg/L

The disadvantage of this method includes its high-cost dependency on feed quality as well as gypsum sludge output in the regeneration of the ion-exchange resins.

Biological and Passive Processes

The most common biological and passive treatment systems based on sulfate-reducing bacteria are natural and constructed anaerobic and aerobic wetlands, bioreactors, and biosorption (Kuyucak 1998). The efficiency of biological and passive processes depends on the quality and quantity of the raw mine water. Sulfate-reducing bacteria can convert sulfate to sulfide in anaerobic conditions in the presence of organic carbon nutrient. Organic materials are added into the system to provide a slow release of nutrients to bacteria while limestone and soil also improve the nutrient mixture to increase alkalinity. In wetlands, mine water drains by gravity, subsequently exerting metal removal and neutralization via a range of physical, chemical, and microbial processes. Aerobic wetlands reduce suspended solids and increase water retention times, while precipitates are retained on plant surfaces. The wetlands must receive water with pH >6 and which has reached a dissolved oxygen concentration at saturation level, usually from a pretreatment system. Aerobic wetlands are effective in many situations for the removal of Fe by 60%–95%, but low precipitation of <10% of Mn is obtained. Anaerobic wetlands pass AMD through organic-rich material to remove oxygen from water. Anaerobic wetlands are effective in the treatment of AMD with pH >2.5 and ambient oxygen concentration at the surface. Long-term maintenance can be minimized by vegetation.

Bioreactor systems, an engineered process to neutralize AMD and precipitate metals, consist of a sulfate reduction bioreactor and metal sulfide precipitator. These systems are suited for the treatment of AMD with pH 3.0–5.5 and a saturated level of oxygen. Biological materials are used in biosorption systems to remove metal ions by adsorption/absorption performance. Bacteria, algae, and fungi accumulate heavy metals from mine water. They are successful in the removal of Mn concentrations from 30–100 mg/L to <5 mg/L (Duggan et al. 1992). In a bioreactor, a COD/sulfate ratio of >0.67 possesses sufficient organic matter for complete reduction of

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the available sulfate. In one study, an anaerobic bioreactor with a cone for sludge separation was used to reduce sulfate from a calcium carbonate treatment stage of AMD (Maree et al. 2001). Feed solution was pumped to the bioreactor at a rate of 8 to 16 m^3/h while ammonium sulfate and phosphoric acid were added to maintain a COD:N:P ratio of 1,000:7:2. The results demonstrate that the dissolved sulfate concentration was reduced from 8,342 mg/L to 198 mg/L. A pH of 7.7 was also achieved in permeate. In this integrated process, the remaining dissolved sulfate from the calcium carbonate treatment stage is efficiently removed by biological sulfate reduction; however, the production of various types of sludge is the only disadvantage.

Wetlands are usually known as a cost-effective passive treatment technology. Metal precipitation as carbonates or sulfides occurs from their oxidation at suitable pH values. In one study, a wetland consisting of three cells was used for the precipitation of metal sulfides (Machemer et al. 1993). Both an upflow and a downflow water stream, a substrate of fresh mushroom compost, and limited vegetation were employed in the cells. The results showed that pH was increased from 3.01 to 6.17 while levels of sulfate were decreased slightly by limestone from 1,700 mg/L to 1,560 mg/L. In addition, this process was successful in reducing Al, Fe, Zn, Cu, Ni, Cd, and Pb by 98.3%, 83.7%, 99.5%, 93.7%, 88.9%, 68.8%, and 79.9%, respectively. The concentrations of Na, Ca, Mg, and Cl were increased from 44.3 mg/L to 54.4 mg/L, 376 mg/L to 452 mg/L, 140 mg/L to 161 mg/L, and 6.29 mg/L to 19.8 mg/L, respectively. Consequently, the process is effective in reduction of heavy metals; however, sulfate concentration was not greatly reduced.

Mine Water Treatment and Reuse Summary

The treatment processes reviewed are summarized in Table 16.2 in terms of permeate water quality. A suitable treatment technology for a specific site can be selected based on the quality and quantity of mine water, the regulation of treated water quality, and the capital and operational costs. The availability of space and access to equipment are also important. Selection of a treatment process depends on the variation of mine water quality parameters. RO and ion-exchange processes are distinguished by the production of high-quality water. RO requires pretreatment stages such as lime addition, aeration, pH adjustment, and sand filtration to improve the performance and reduce the fouling; however, this pretreatment is not necessary for ion exchange. Evaporation ponds or thermal evaporation is essential for both treatment processes in the brine disposal stage. For this reason, the operation and maintenance (O&M) costs are the main disadvantage. On the other hand, water management in mining advocates the approach of using nonoptimal water instead of freshwater sources to ensure the sustainability of the water supply for any mining operation. Sometimes a combination of proposed technologies is required to improve the permeate quality, such as a chemical pretreatment stage followed by the RO process.

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Table 16.2 Summary of mine water effluent quality parameters from various water treatment processes

	Techniques															
	Pretreatment/ RO (Du Plessis and Swartz 1992)		Limestone (Silva et al. 2012)		Limestone/ Lime/CO_2 (Schoeman and Steyn 2001)		Dunite (Demetriou et al. 2010)		BaS (Bosman et al. 1990)		Ion Exchange (Schoeman and Steyn 2001)		Bioreactor (Maree et al. 2001)		Wetland (Machemer et al. 1993)	
Parameter (mg/L) except pH	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent	Influent	Effluent
pH	8.4	5.5–6.5	6.9	8.1	2.7	8.5	2.8	7.8	1.4	7.1	2.7	8.5	1.8	7.7	3.01	6.17
SO_4^{2-}	2,200	14	935.3	302.1	8,000	1,219	—	—	17,500	182.5	8,000	1,980	8,342	198	1,700	1,560
Ca^{2+}	176	2	135.3	142.8	490	542	—	—	—	—	490	50	—	—	376	452
Mg^{2+}	80	0.0	50.6	36.3	420	3.03	—	—	485	7	420	20	—	—	140	161
Na^{+}	917	26	—	—	70	46.8	—	—	—	—	70	50	—	—	44.5	54.4
Mn^{2+}	—	—	28.2	11.3	182	0.01	111.2	78.4	—	—	100	<0.1	—	—	31.3	29
Cl^{-}	220	26	—	—	—	—	—	—	—	—	—	—	27	30	6.29	19.8
Al^{3+}	—	—	—	—	—	—	—	—	—	—	—	—	—	—	3.68	<0.06
Fe^{2+}	0.3	0.1	2.36	<0.73	100	<0.1	306.7	85.5	—	—	182	<0.1	2,500	<56	43.1	7

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FUNDAMENTALS OF VACUUM MEMBRANE DISTILLATION

Membrane separation technologies provide the ability to produce fresh water from contaminated water sources. Competing interests such as social acceptance and community perception, health hazards, cost of production, population growth forecasts, and economic development must be considered. The transmembrane hydrostatic pressure, concentrations, and electrical or chemical potentials are known as driving forces in isothermal membrane processes such as microfiltration, UF, nanofiltration and RO (Khayet 2011). MD as a thermally driven physical separation process is now widely accepted as a purification technique. Hydrophobic porous membranes are employed in MD as a thermally driven separation process to isolate the entry liquid from a gaseous phase on the permeate side. The feedwater solution to be treated by MD is passed on one side of the membrane, and the hydrophobic nature of the membrane surface prevents liquid from penetrating the dry pores (Qtaishat et al. 2008). A negative pressure on the permeate side implies physical separation in all four configurations of MD: direct contact MD, sweeping gas MD, VMD, and air gap MD (Khayet 2011).

Desalination by VMD has grown steadily over the past years. In fact, VMD is progressively becoming recognized and accepted as an economically competitive and energy-efficient alternative to conventional membrane separation processes such as regular distillation and RO. The VMD process rejects all nonvolatile constituents such as ions, dissolved nonvolatile organics, colloids, and pathogenic microorganisms, and produces ultra-pure water. The VMD system has many advantages, including the production of pure distilled water at lower operating temperatures, resulting in lower operating costs (Safavi and Mohammadi 2009). Vacuum pressure on the permeate side of the membrane reduces the pressure below the saturation pressure of the feed solution in the convective transport process that occurs in VMD. A liquid–vapor boundary layer is created on the surface of a hydrophobic membrane because of the surface tension forces that prevent the liquid solution from entering its pores. It is, therefore, necessary to carefully select the physicochemical properties of the membrane to ensure the best performance. Wetting can happen only if the hydrostatic pressure exceeds the liquid entry pressure (LEP) of the water. During VMD, a liquid–vapor interface minimizes heat transfer losses within the system and reduces the potential for membrane fouling. Therefore, similar flux rates are achievable with lower energy inputs compared to other MD and pressure-driven desalination processes (Mericqa et al. 2011).

The available literature on the theory behind mass transfer in VMD (Lawson and Lloyd 1996; Alklaibi and Lior 2005; Al-Obaidani et al. 2008; Safavi and Mohammadi 2009) and small-scale experimental system design, construction, and installation (Criscuoli et al. 2008; Xu et al. 2008) have been studied. In addition, energy and cost-effectiveness studies of large-scale VMD systems have illustrated theoretically that VMD is competitive with other distillation methods (Wu et

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al. 2006). The kinetic theory of gases through porous media is proposed by the Knudsen flow model, the viscous flow model, the molecular diffusion model, and any combination of these models for mass transfer in MD systems. Theoretically, both molecule–molecule and molecule–pore-wall interaction occurs in a VMD process.

Flux represented as the rate of flow of a property per unit area depends on experimental conditions. Monitoring the performance of VMD, and investigation of the flux sensitivity to feed flow rates, temperatures, and vacuum pressures, will help to identify specific correlations that these parameters have with flux. *Flow rate* refers to the rate of fluid injection into the membrane. The effectiveness of VMD to treat specific water sources and the effects of their properties on the flux and fouling of membranes should be investigated to improve the design and implementation of an efficient desalination method.

Membranes and Modules

The characteristics of the membrane play an important role in flux determination, liquid–vapor interface establishment, and separation efficiency in a VMD process. Pore size, membrane thickness, hydrophobicity, chemical resistance, porosity, material composition, and heat conductivity determine the permeability and stability of the membrane. The hydrophobic nature of the membrane depends on pore size, membrane materials, and liquid characteristics. It is possible for water to intrude into the pores as a result of the application of higher pressure than LEP, membrane fouling, or scaling, due to salt deposits at the pore entrance. In this situation, feed solution will be passed directly through the membrane. Salt deposition at the pore opening can provide a hydraulic pathway through the membrane as moisture condenses on the salt and can cause contamination of the permeate (Li and Sirkar 2005). Flat-sheet and hollow-fiber membranes also make up the laboratory-scale MD modules. The benefit of moving from flat-sheet to hollow-fiber membranes is the higher membrane-surface-area-to-module-volume ratio (Khayet 2008).

Membranes considered in VMD must be significantly more hydrophobic than with other MD processes due to the existence of vacuum pressure in the VMD process, which favors wetting of the membrane pores and liquid penetration. Increased hydrophobicity has been achieved in many studies using special materials. Coating is an effective alternative for reducing the wetting of the pores because it keeps the feed solution at a very small distance from the membrane surface. Since there is no positive pressure on the feed side of the membrane, there is no driving force to pass water through the hydrophobic coating. Obviously, higher porosities, larger pore diameters, and a more open coating lead to a higher flux rate, but larger pore sizes reduce the critical entry pressure required for feedwater to penetrate the membrane pores. Therefore, following membrane characteristics are essential for effective VMD:

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- Hydrophobicity
- High porosity (70%–90%)
- Large surface area that results in higher flux and lower conductive heat loss (Khayet 2011)
- Thermal stability and low thermal conductivity of 0.04–0.06 W/m·K (Khayet and Matsuura 2011)
- Chemical resistance to feed solutions
- High LEP between 100 and 200 kPa (Khayet and Matsuura 2011)
- Large contact angle >100°
- Small thickness
- Narrow pore size distribution

Pressure difference across the membrane (ΔP) depends directly on pores size, surface tension, and the cosine of the contact angle. It decreases with the increase in maximum pore size and the decline of the surface tension of the feed solution, as illustrated in Equation 16.1. On the other hand, the pore size must be large enough to facilitate high mass transfer but small enough to prevent the penetration of the liquid feed. Therefore, determination of an ideal pore size depends heavily on the membrane material and the characteristic of feed solution.

$$\Delta P = \frac{2\gamma \cos\phi}{r} \qquad \text{(EQ 16.1)}$$

Subsequently, measuring a solid–liquid contact angle is necessary to determine the relative wettability of the membrane module. A Ramè-Hart goniometer was used to measure the mean contact angle of mine water effluent on three commercially available membrane surfaces, as shown in Figure 16.1. The contact angles of mine water samples were 125°, 112°, and 108° for polytetrafluoroethylene (PTFE), polyvinylidene difluoride (PVDF), and polypropylene (PP) flat-sheet membrane samples, respectively. A Microdyn PP hollow-fiber membrane was employed as well as an Emflon PTFE module because of its effective pore size and higher LEP than the PVDF type.

Mass Transfer in VMD

In the VMD process, only water molecules in the gaseous vapor state are transported through the microporous and hydrophobic membrane. The mine water effluent to be treated by a thermally driven separation process is passed on one side of the membrane. Mass transfer in the VMD process is derived by applying vacuum on the permeate side of the membrane. The concept of vapor flux through a hydrophobic membrane along with heat transfer in the VMD process is shown in Figure 16.2. T_{fm} and T_{pm} indicate temperature at the feed side and the permeate side of the membrane surface, respectively. The feed solution is inserted at T_f temperature, whereas the permeate vapor is extracted at T_p temperature.

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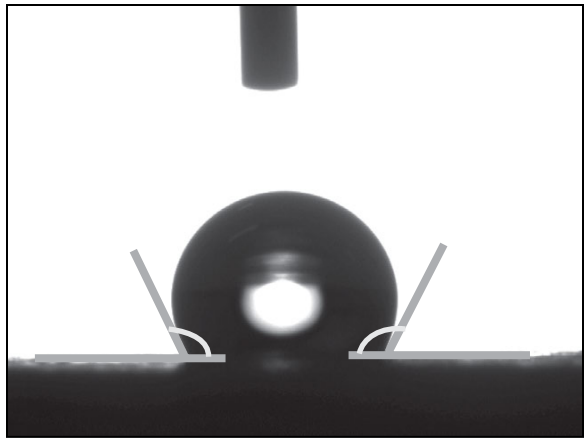


Figure 16.1 Water droplet on the surface of a membrane

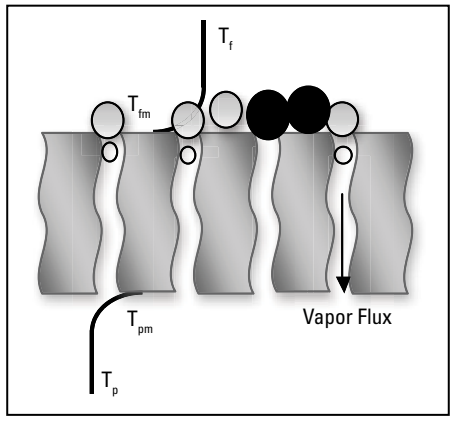


Figure 16.2 Concept of mass transfer and heat transfer in VMD

The mass transfer in the VMD processes is explained through the Knudsen flow model, the viscous flow model, the ordinary molecular diffusion model, or a combination of these models (Lawson and Lloyd 1997). The Knudsen number ($K_n = \lambda/d$), which is defined as the ratio of mean free path, λ, of the transported molecules to the diameter of the membrane pores, d, provides a guideline to determine the accurate mechanism.

In the transition region ($0.01 < K_n < 1$), molecule–molecule and molecule–pore-wall collisions have to be considered in the VMD process presented. Moreover, the low partial pressure of air within the membrane pores makes the molecular diffusion model inadequate for estimating flux performance. The kinetic theory of gases describes the heat and mass transfer mechanism in VMD. VMD performance is modeled through the implementation of the Knudsen diffusion equation, which can be adapted for most MD configurations. The Knudsen diffusion model expressed in Equation 16.2 assumes a Knudsen flow regime for vapor passing

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through small holes in a thin wall (Lawson and Lloyd 1997). The number of molecules that pass through a hole is proportional to the driving pressure of the gas and inversely proportional to its molecular weight.

$$N_w = \frac{K\Delta P}{RT_{fm}\delta}\sqrt{\frac{8RT_{fm}}{\pi M_w}} \quad \text{(EQ 16.2)}$$

where N_w is the molar flux (mol/m^2·s), K is the Knudsen diffusion constant (m), ΔP (Pa) is the pressure difference between the partial pressure of the solution and the absolute vacuum pressure, R is the gas constant (8.31 J/mol-K), δ is the membrane thickness (m), and M_w is the molecular weight of water (18.01528 g/mol).

The Dusty-gas model is also used in the transition region to describe VMD performance (Khayet and Matsuura 2004). Equation 16.3 is based on the assumption of both molecule–pore-wall and molecule–molecule interactions:

$$J_w = \frac{\Delta P}{RT_{fm}}\left[K\upsilon_m + B\frac{P_{av}}{\mu}\right]\frac{1}{R_{out}\ln\left(\frac{R_{out}}{R_{in}}\right)} \quad \text{(EQ 16.3)}$$

where J_W is gas flux (kg/m^2·s); υ_m is the mean molar gas velocity (m/s), B is the viscous flow morphology parameter (m^2), P_{av} is the average partial pressure (Pa), μ is the dynamic viscosity of the feed solution (Pa-s), and R_{out} and R_{in} are the outer and inner radius of hollow fiber (m), respectively.

Models based on the Knudsen type of diffusion have been widely investigated, and the appropriate one for describing mass transfer through a porous membrane in the VMD process is nominated. For both molecule–molecule and molecule–pore-wall collisions in the transition region, Equation 16.4 is used to determine the gas flux:

$$J_w = \frac{\Delta P}{RT\delta}\left[K\left(\frac{8RT}{\pi M_w}\right)^{\frac{1}{2}} + B\frac{P_{av}}{\mu}\right] \quad \text{(EQ 16.4)}$$

where T is the average of membrane surface temperatures (K).

The proposed flux model predicts flux response to changes in temperature, pressure, flow rate, and feed solution characteristics for a specific membrane. As previously mentioned, PTFE and PP membrane modules are employed to monitor the trend of flux during mine water effluent treatment. Mine water quality before and after treatment is determined, as well as the experimental conditions using appropriate probes and sensors. The experiments are monitored, and important

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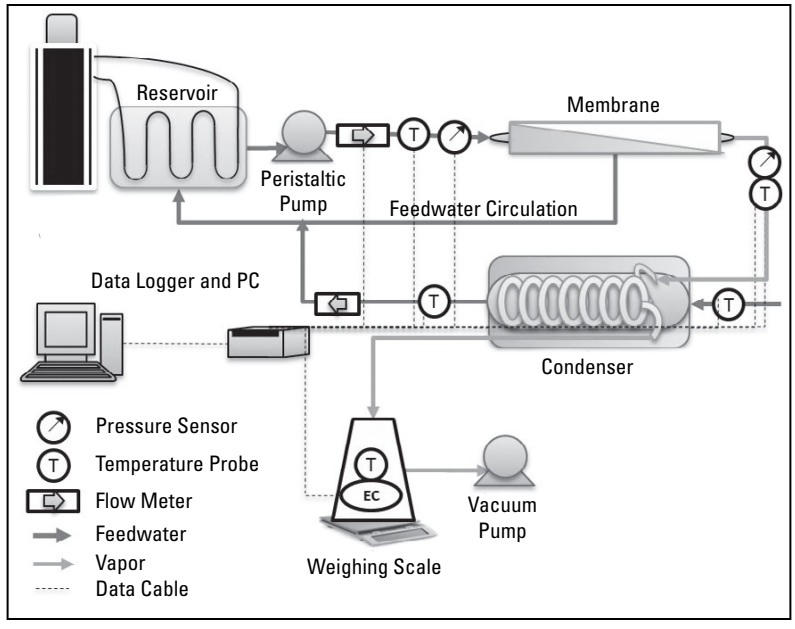


Figure 16.3 VMD experimental arrangement

factors such as temperature, pressure, and flow rate are measured to plot the relevant graphs.

VMD Set-up and Operation

It is important to monitor the effects of various operating parameters on the permeate flux and to investigate how the system reacts when treating mine water from various sources to analyze and refine the system. Feedwater is warmed up and circulated in a closed system. Once the temperature reaches the desired point, vacuum pressure on the permeate side of the membrane is performed. The amount of air inside the permeate trap and hoses is evacuated. Subsequently, the system balances the permeate side of the membrane to evaporate feedwater. Cold feedwater is passed through the condenser, and permeate water is then collected in a trap. The VMD process is shown schematically in Figure 16.3.

Feedwater temperatures from 45 to 65°C are exerted using a water bath circulator to provide and maintain heat to the feedwater bulk supply. Feedwater is pumped directly from the reservoir, heated by the coil in the water bath, and recirculated back to the bulk supply. It is important to ensure that the recirculation hose remains above the membrane level so that the membrane module remains full at all times. The desired feedwater temperature is adjusted on the water bath circulator, and the feedwater temperature is read from a temperature probe at the membrane inlet. Temperatures above this range are considered to consume too much energy and

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are also not applicable for certain membranes. On the other hand, high vacuum pressure is required to evaporate feedwater in low temperatures, which results in more energy consumption.

The feedwater flow rate is analyzed during experiments. Feedwater flow rate is a sensitive parameter in that excessive feed pressures generated by high flow will exceed the pressure difference from inside to the permeate side of the membrane.

Vacuum pressure plays an important role in flux variation. It is therefore important to vary the vacuum pressure to thoroughly investigate the mechanisms behind the VMD process. The pressure difference across the membrane induces the feedwater to vaporize, thereby creating transport of water vapor molecules across the membrane. Precise vacuum pressure is measured through vacuum sensor gauges.

VMD Performance and Membrane Fouling

Experiments were carried out using Milli-Q water, saline solutions, swimming pool salt water, and mine effluent. The saline solutions were made by combining sodium chloride (NaCl) with distilled water. First, the variations of permeate flux with temperature, flow rate, vacuum pressure, and the salinity of the feedwater for a given set of experimental conditions were investigated. The contribution of each parameter to the flux rate increment was determined. Second, long-term experiments were conducted to investigate the rate of flux decline due to the fouling phenomenon. Finally, the optimum conditions for the VMD process were determined using the energy consumption of each test. These investigations were performed using the PP membrane module.

The effect of feedwater temperature was examined by varying the temperature between 45 and 65°C. Feedwater temperature has a large effect on vapor permeation flux. Figure 16.4 illustrates the relationship between feedwater temperature and the flux permeation rate for a given set of experimental conditions. The rate of permeate flux rises significantly as feedwater temperature increases. This is due to an increase in temperature that drastically increases the water vapor pressure, which is the driving force for water vaporization. Another reason is that temperature increases the Reynolds number, which in turn raises the heat transfer coefficient, eventually increasing the flux. A significantly higher vapor flux in the VMD process is achievable through optimization of feedwater temperature in accordance with other parameters. Figure 16.4 shows that the VMD experimental data fits well with the iterative permeate flux model.

The absolute pressure on the permeate side is decreased from 20 to 7 kPa to investigate the flux variation. The system was operated at various vacuum pressures within this range while all other parameters, such as temperature and flow rate, remained constant at the set levels. Flux decline is observed by pressure increments in Figure 16.5. It can be seen that a decline in absolute pressure on the permeate side of the membrane results in a rapid increase in the permeate flux rate because of a significant rise in the driving force for flux.

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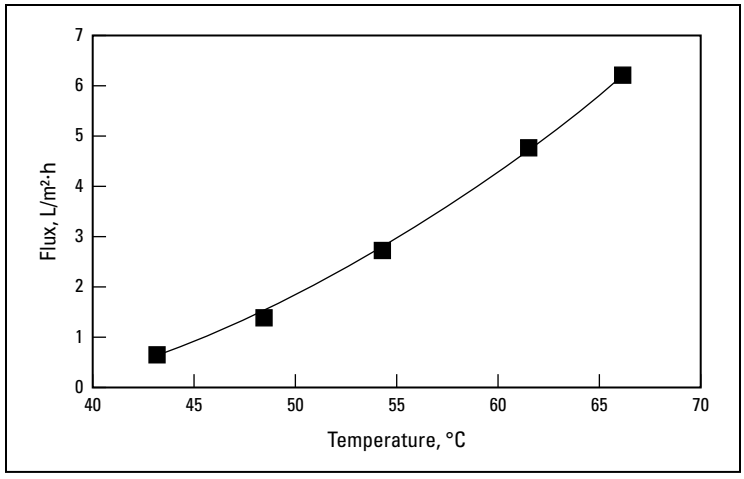


Figure 16.4 Effects of feedwater temperature on flux: (—) modeled flux, (■) experimental flux; flow rate = 1 L/min, vacuum pressure (abs) = 5 kPa, electrical conductivity = 7,250 µS/cm

The resulting flux rates obtained by varying flow rates between 0.5 and 3.75 L/min are illustrated in Figure 16.6. The feedwater temperature and vacuum pressure was set to 65°C and 7 kPa absolute, respectively. An increase of 1 L/min in the flow rate raised the flux rate by 4.46% because of the increase in the Reynolds number followed by the Nusselt number, heat transfer coefficient, vapor temperature and finally the saturation pressure of the feed solution. Hence, the effect of feedwater flow rate on permeate flux is small compared to the role of temperature and pressure.

The feed solution salt concentrations of 0, 7, 16, and 21 g/L were prepared, and the effect of salinity concentration on flux was evaluated. Figure 16.7 illustrates that salinity concentration has a negligible effect on the rate of permeate flux. This is a significant advantage of using the VMD process for desalination purposes. A slight decline in the rate of permeate flux is the result of a decrease in vapor pressure due to the salt concentration. The salinity concentration increment also influences the temperature and concentration polarization, resulting in a slight decline in flux rate.

The contribution of the assessed parameters on the increasing rate of flux is presented in Figure 16.8. Vacuum pressure is the dominant factor having the most significant effect on the flux rate, followed by temperature, flow rate, and salinity concentration.

The removal of suspended and dissolved substances from mine effluent water is accomplished by the VMD process. During the process, deposition of dissolved or colloidal organic matter on the membrane surface occurs. Vapor is formed at the boundary of the open pore area on the feed side of the membrane. The open pore area is reduced by precipitation of the substances on the surface of the membrane because of the crystallization of salts. The settlement of solutes prevents

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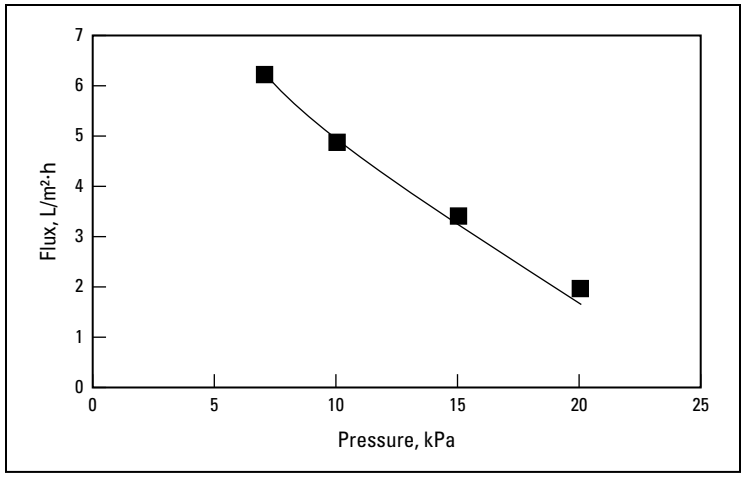


Figure 16.5 Effects of pressure on flux: (—) modeled flux, (■) experimental flux; flow rate = 1 L/min, temperature = 65°C, electrical conductivity = 7,250 µS/cm

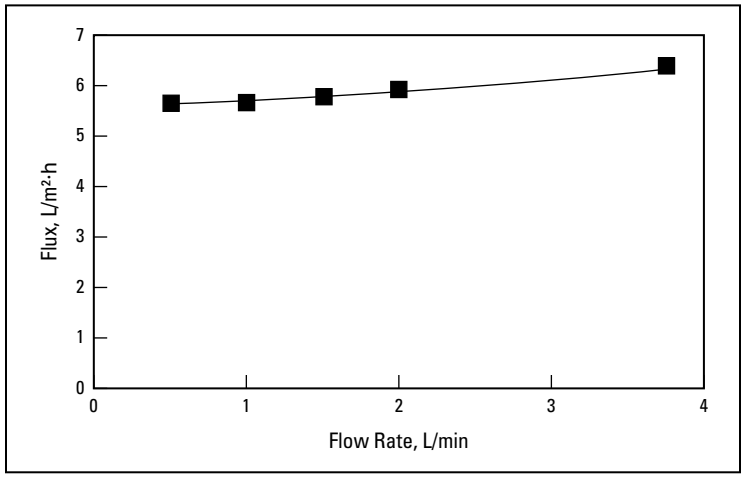


Figure 16.6 Effects of feedwater flow rate on modeled flux (—) and experimental flux (■); temperature = 65°C, pressure on the permeate side = 7 kPa (abs), electrical conductivity = 7,250 µS/cm

vapor passing through the membrane pores. Permeate flux decreases initially as an immediate effect of fouling; however, the long-term effect may cause the reduction of membrane lifetime because of irreversible biological fouling. Investigation of the fouling phenomena, which is a key factor affecting the economic and technical feasibility of full-scale installation of VMD, is therefore required. Fouling phenomena are observed by treatment of a swimming pool salt water sample. A VMD process was carried out with the same temperature of 65°C and a flow rate of 1 L/min. Several permeate-side pressures of 7, 10, 15, and 20 kPa for the duration

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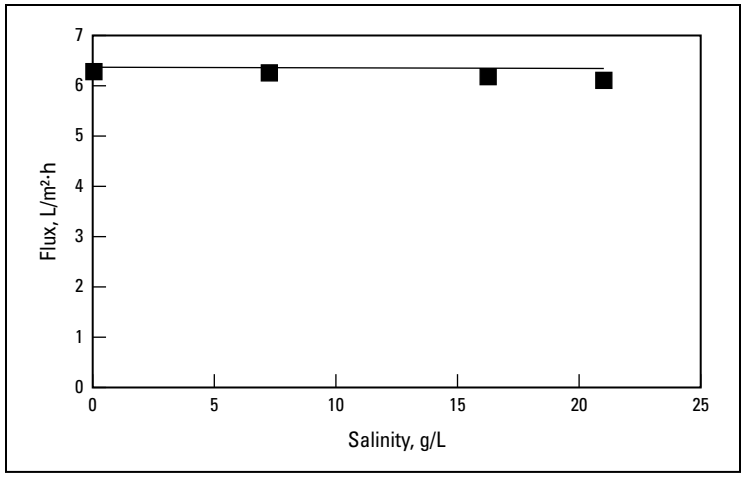


Figure 16.7 Effects of feedwater salinity on flux rate: (—) modeled flux rate, (■) experimental flux rate; temperature = 65°C, vacuum pressure = 5 kPa, flow rate =1 L/min

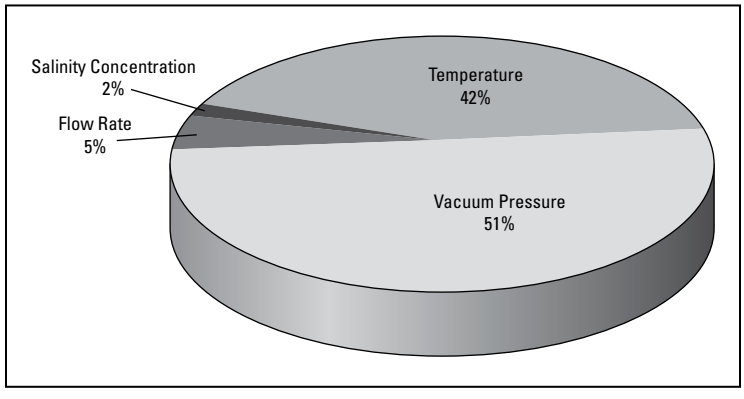


Figure 16.8 The contribution of four parameters on flux rate

of 1 hour were applied, and the flux was measured at various time intervals, as shown in Figure 16.9. A flux rate decline of 2.45%, 4.48%, 21.11%, and 14.78% was observed for 7, 10, 15, and 20 kPa absolute pressure on the permeate side of the membrane, respectively. Deposition of NaCl precipitate was seen as the major obstacle.

A power meter measured the energy consumption of each test to evaluate the efficiency of the VMD process in terms of energy. Temperature and pressure were defined as the two dominant factors in flux variation. For this reason, a constant flow rate of 1 L/min along with temperature and pressure variables were considered in the energy tests. The specific energy consumption, with and without considering heating energy, is illustrated in Figure 16.10. Vacuum and circulating pumps consume less energy to produce a certain volume of permeate water when the flux rate

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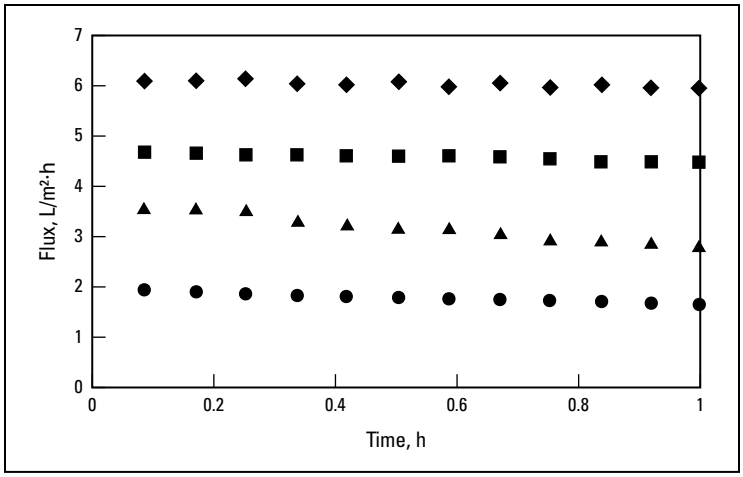


Figure 16.9 Flux rate decline during salt water treatment: pressure = 7 kPa (♦), 10 kPa (■), 15 kPa (▲), and 20 kPa (●); temperature = 65°C, flow rate = 1 L/min

is high. Therefore, it is advisable to operate the VMD process using solar energy for warming up the feed solution at a pressure of 7 kPa. On the other hand, including heat energy shows that the optimum configuration of the VMD process is at a temperature of 55°C and pressure of 7 kPa while the flow rate is constant at 1 L/min.

VMD PROCESS FOR MINE WATER TREATMENT

Microdyn PP and Emflon PTFE modules were used separately in the VMD process. The success of the VMD process in the treatment of mine water was assessed. Mine water samples were collected from two coal mine sites. The first mine water effluent sample was prepared from the BHP Billiton Westcliff mine site located in Appin, New South Wales. A sample was collected from the USEPA monitoring point, LDP10, which discharges recirculated mine water from Brennans Creek Dam into Brennans Creek, which flows into the Georges River. The second and third samples were collected from NRE No. 1 Colliery coal mine. The NRE No. 1 Colliery mine site is located in Russell Vale, New South Wales. The water quality characteristics of the prepared samples were recorded.

Table 16.3 shows the average results from water quality analysis of mine water samples before and after treatment by VMD process. The VMD process successfully removed TDS with an average efficiency of more than 99% for all mine water samples. The prepared samples contained less concentration of sulfate, because the pH level in most cases dropped from the feedwater to the permeate. The reason for the decline in pH level is because alkalinity as $CaCO_3$ is reduced in the condensed water vapor and carbon dioxide is absorbed by the permeate water. The removal efficiency of major ions was also investigated by measuring the concentration of

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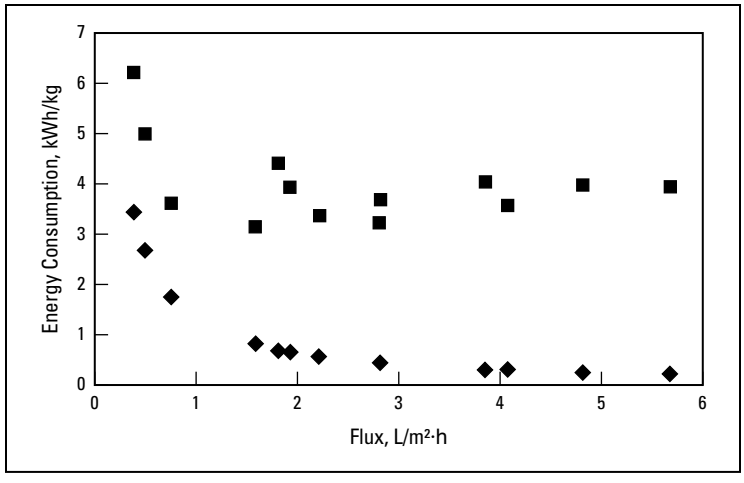


Figure 16.10 Energy consumption including heat (■) and excluding heat (◆)

Table 16.3 Quality analysis of mine water

Parameter, mg/L except pH	PTFE Membrane			PP Membrane			PP Membrane		
	Feed	Permeate	% Removal	Feed	Permeate	% Removal	Feed	Permeate	% Removal
TDS	2,332	2.66	99.9	1,350	2.41	99.8	1,520	3.05	99.8
pH	7.68	6.32	N/A*	8.05	6.42	N/A	8.14	6.38	N/A
Calcium	14.4	0.74	94.9	21.2	0.09	99.6	34.1	0.15	99.6
Magnesium	2.72	0.03	98.9	3.45	0.01	99.7	4.02	0.01	99.7
Iron	1.92	0.04	97.9	8.24	0.02	99.8	5.92	0.03	99.5
Aluminum	3.38	0.00	100	2.32	0.01	99.7	2.68	0.00	100

*N/A = not applicable.

Ca, Mg, Fe, and Al in feed solution and permeate samples. Generally, the removal efficiency was very high and the permeate quality was close to distilled water.

Average removal efficiencies of 94.9%, 98.9%, 97.9%, and 100% were achieved for calcium, magnesium, iron, and aluminum, respectively, in the VMD treatment process using the PTFE membrane module. The PP membrane module also removed 99.6%, 99.7%, 99.5–99.8%, and 99.7%–100% of calcium, magnesium, iron, and aluminum, respectively, from mine water effluent.

Finally, the reduction of flux during mine water treatment by VMD process was investigated. As shown in Figure 16.11, the test was carried out using a large permeate trap. A small reduction of 3.31% was observed over 130 hours. The rate of decline was increased to 5.30% by the end of the experiment. The test showed a small reduction in the rate of flux during mine water treatment. This proves

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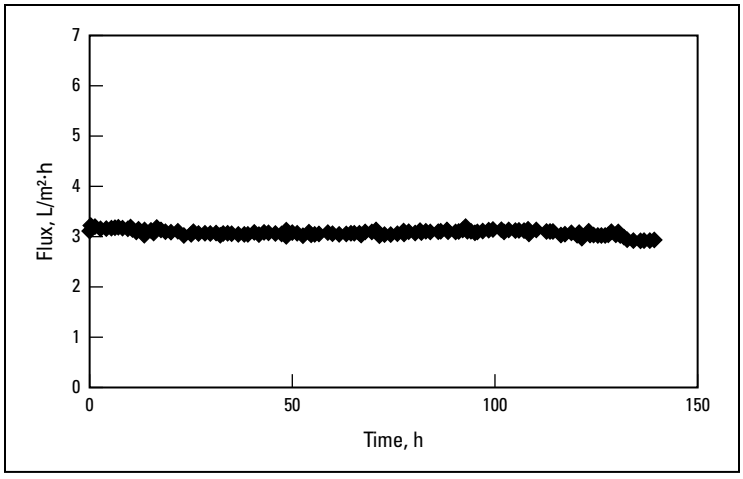


Figure 16.11 Flux decline during mine water treatment: pressure = 7 kPa, temperature = 65°C, flow rate = 1 L/min

the superiority of this treatment process over high-pressure membrane filtration methods such as RO.

SUSTAINABILITY ASSESSMENT OF VMD

Technologies are evaluated according to environmental, economic, and social criteria to assess their comparative sustainability. Relevant indicators in the three sustainability pillars must be selected. The water quality of the permeate from a treatment system is an important environmental factor. The membrane filtration process is subjected to fouling phenomena and cleaning methods, which make the level of fouling and the cleaning required a key factor. The extra pretreatment and posttreatment stages are also a significant factor. In addition, the disposal of the waste produced within the whole treatment process should be considered. The proposed indicators of the environmental criterion are a combination of quantitative and qualitative parameters. The economic evaluation is performed using the cost of the treatment process in the construction and operation phases. Capital and O&M costs are estimated based on the available information. The application of renewable energy can also affect operating costs. Social indicators are mostly qualitative and require decision makers' judgments to be explained. A company's acceptance of using recycled mine discharge, as well as the complexity of the project, availability of equipment and technology, and the level of risk are the main indicators.

The significant advantage of VMD reported in this research describes how efficiently it reduces concentrations of TDS, Ca, Mg, Fe, and Al. A screening pretreatment stage is required to reduce the concentration of total suspended solids in effluent. Fouling and the accumulation of particles on the membrane surface will

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be reduced, and this will increase the life of the membrane. Chemicals are only used in the membrane cleaning process. The experimental results also show a small reduction in the flux rate, which demonstrates a low level and slow accumulation of particles on the membrane surface.

Ongoing O&M costs are expected for membrane cleaning and replacement, waste collection and disposal, and overall repair for the life of the project. Compared with conventional separation techniques, VMD has advantages such as the ability to operate with low energy consumption (1.2 kWh/m^3), whereas RO requires 2.4 kWh/m^3 to achieve the same rate of flux (Cabassud and Wirth 2003). The main advantage of VMD is employing solar energy for heating in remote and isolated areas, and producing a high-quality permeate water even where groundwater is not available. The VMD process requires only a moderate level of membrane cleaning, whereas the common cleaning method requires using chemicals. A screening unit as a pretreatment can be used to increase the efficiency of the VMD process. There is little or no health and safety risk because the temperature of the feed solution will not exceed 60°C. Acceptance of the technology is expected to be high because of its small size and the high quality of the resultant permeate water that is suitable for reuse.

SUMMARY

Following a brief review of selected mine water treatment processes, an innovative mine water treatment method was proposed in this chapter. Based on experimental studies, VMD successfully treated mine water effluent using PTFE and PP membrane modules. Satisfactory contact angles between the selected membranes and mine water samples were achieved. The effect of various operating parameters on flux rate was investigated using swimming pool salt water. VMD is capable of effectively desalinating and bringing water to acceptable standards with TDS removal up to 99.9%. Removal of 99.9%, 99.6%, 99.7%, 99.8%, and 100% for TDS, Ca, Mg, Fe, and Al, respectively, was achieved using the VMD process. The efficiency of the VMD process in mine water treatment demonstrates that although remineralization might be required before consumption, the quality of the permeate water was of acceptable standards for potable water. With a possible energy consumption of less than 1 kWh/kg, VMD may work well with solar energy sources for remote applications.

Sensitivity analysis was performed on VMD to investigate the effect of various operating parameters on flux rate. Variation of parameters such as feedwater temperature, salinity, flow rate, and vacuum pressure were applied independently to record the corresponding flux rates. It was shown that vacuum pressure was the most influential parameter, followed by feedwater temperature, feedwater flow rate, and finally salinity. The selected mass transfer model provides a precise description of flux behavior in a VMD process.

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CHAPTER 17

Integrating Pit Lakes into Water Basin Planning: The Meirama Brown Coal Mine

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INTRODUCTION

Water management, in terms of quality and availability, represents a core issue for mine operators at the time of ore recovery, site cleanup, and reclamation when water is either abundant or scarce. Modern mine operations rely on comprehensive mine water management plans, which are consubstantial elements of the mine projects themselves.

Natural water quality can be deleteriously affected by mine operations, although the severity of the impact ranges widely from a simple increase in the solid load to more conspicuous problems derived from acid rock drainage (ARD). It is generally accepted that reducing water use by optimizing processes and facilities, using closed-loop recycling of mine-affected waters, and avoiding unnecessary impacts on water quality provide a solid foundation on which the application of best available techniques (e.g., EC 2009) ensures achievement of the increasingly stringent goals established by the environmental legal framework worldwide (WMWG 2008). The start of enforcement of the European Union (EU) Directive 2004/35/EC on Environmental Liability (ELD) in 2007 is a representative example of this legal framework (EC 2004). This directive, which was extended to cover extractive waste from mines and quarries by Directive 2006/21/EC on the Management of Waste from Extractive Industries (MWD), establishes a legal framework based on the "polluter-pays" principle to prevent and remedy environmental damage (EC 2006). The polluter-pays principle, which is set forth in the Treaty on the Functioning of the European Union, article 191-2 (EC 2008a), is the commonly accepted practice

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in which any polluter should bear the cost of measures to reduce pollution according to the extent of either the damage done to society or the exceedance of an acceptable standard of pollution (UN 1997). The ELD was enacted to address "pure ecological damage" as distinct from "traditional damage," which results from personal injuries, damage to property, and economic losses (Scannell 2012). The concept of environmental damage (and its economic dimension through mandatory financial guarantees) encompasses not only the impacts on protected species, natural habitats, and lands but also surface water and groundwater. Therefore, legal constraints create an additional stimulus to follow good mining and water management practices while fostering the leadership of operators in their search for responsible, sustainable, and environmentally safe projects.

Open pit mines change the landscape by creating large voids and hills (overburden piles) and modifying the natural course of streams and rivers. These features become permanent following mine closure because backfilling is not technically or economically feasible in many instances (Zhao et al. 2010). For those resources developed below the water table, the end of extractive operations results in spontaneous flooding associated with the rebound of groundwater triggered by the halting of dewatering systems (Eary 1999; Gammons et al. 2009). Because of the nature of many of the exploited commodities and the enhanced weatherability of pit slopes and overburden stockpiles (often containing pyrite or related sulfide minerals) when exposed to oxic and humid conditions, ARD and metal leaching become issues of concern when considering the safe closure and reclamation of the area.

The life cycle of a mine extends far beyond the extractive operations. The life cycle includes the postmining stage, which is when sustainable engineering practices rehabilitate the mine-affected areas. With respect to water, the flooding of underground works or surface voids entails significant environmental challenges (Doupé and Lymbery 2005; Wolkersdorfer 2008; Gammons et al. 2009; McCullough and van Etten 2011). The typical sources for infilling underground works or open pits include piezometric-surface rebound, groundwater seepage, surface runoff, direct precipitation, diverted river/stream courses (except sea water; Fisher 2002) and process-affected waters.

Although there are many additional contributing factors, the following aspects are most relevant to determining the physicochemical characteristics of these new water bodies (Castro and Moore 2000; Werner et al. 2001; Boland and Padovan 2002; Denimal et al. 2005; Castendyk and Webster-Brown 2007; Castendyk and Eary 2009):

- Type of commodity exploited (aggregates, coal, base metals, oil sands, diamonds, etc.)
- Neutralizing or acid-producing capacity of the host rock
- Climate conditions

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- Availability or scarcity of water
- Morphometry of the pit and the relative depth of the water table
- Rate of flooding
- Sources of water associated with the flooding process

The vast majority of pit lakes that exist worldwide have resulted from unplanned management. This means that most of the pit lakes have naturally evolved toward their present-day conditions without ex ante proviso of specific environmental goals (cf. Kalin et al. 2001; Ramstedt et al. 2003; Pellicori et al. 2005; Blodau 2006; Sánchez-España et al. 2008; Zhao et al. 2010; Schultze 2012; Gammons et al. 2013). Consequently, the direct comparison of their present-day water quality with the corresponding regulatory standards, an assessment of their impact over the surrounding environment, or their ecological performance reveals striking contrasts. Recent research provides outstanding summaries of the processes affecting the final quality of pit lakes and mine-affected surface waters as well as a wide database of case studies (cf. Miller et al. 1996; Shevenell et al. 1999; Castro and Moore 2000; EPLWG 2004; Gammons et al. 2009; Castendyk and Eary 2009; Nordstrom 2011; Geller et al. 2013; and references therein). Growing societal and corporate awareness regarding the environmental impacts of mining and its aftereffects has transformed previous perceptions and attitudes to the point that unplanned water management is currently an unacceptable option.

Pit lakes belong to the realm of river basins, and their final water quality has the potential to adversely affect the surface waters and groundwaters located downstream as well as the connected aquatic and land ecosystems. Likewise, pit lakes also have a significant potential for beneficial uses from environmental and economic standpoints. Although efforts have been dedicated to assessing pit lakes for their inclusion in integrated river basin management plans (RBMPs), these efforts are far from this target. For example, pit lakes are not even considered in either the report on integrated sustainable lake/watershed management of the International Lake Environment Committee Foundation (ILEFC 2005) or the World Lake Basin Initiative (World Bank 2005). A similar situation can be found when international regulations concerning mining, water management, and environmental protection are analyzed.

The regulatory context surrounding mine waters in Europe are presented in this chapter. Also provided is a case study of the brown-coal Meirama mine in Spain, where a large pit lake (~146 hm^3) is in the process of forming from the forced flooding of the mine void with primarily surface waters. One of the singularities of this reclamation project is that the mine is located in a relatively small catchment (~100 km^2) that is a major tributary of a reservoir (Abegondo-Cecebre, ~23 hm^3). This reservoir supplies water to the city of A Coruña and its metropolitan area (~400,000 inhabitants).

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PIT LAKES AND THE EUROPEAN LEGAL FRAMEWORK

The EU is a supranational organization of 28 member states, and each has its own legal framework. Each of the states shares responsibility with the EU for ensuring that EU laws are effectively and properly executed (Scannell 2012). The EU has the power to enact legislation that is binding on all member states. There is supremacy of EU law over national law, which is subject to exclusive review by the EU's Court of Justice (Kroll et al. 2002). A directive must be implemented in the national legal orders of the member states in a way that guarantees that the objectives prescribed in the directive are attained. The authorities that, in practice, are responsible for implementing a directive are called "competent authorities."

Mining is one of the oldest industrial sectors in Europe. However, for historic and economic reasons, mining has been specifically excluded from European environmental policy (Kroll et al. 2002). Consequently, there is no "Mining Directive" in the EU, although the different aspects of mining are covered by broad-range directives. Scannell (2012) provides a wide and up-to-date summary describing the interplay among the directives from the mining industry's point of view.

The 2006/21/EC MWD was published in the *Official Journal of the European Union* on April 11, 2006. The major goal of this directive is to provide a legal framework that can prevent or reduce mining-related adverse effects on the environment (water, air, soil, fauna, flora, and landscape) and any resultant risk to human health from the management of the corresponding mine waste. Before the adoption of the MWD, there was no specific legislation in the EU addressing mine waste.

In the absence of specific legislation, the EU authorizes member states to use their own legislation, provided the legislation gives an adequate level of protection and does not contradict other EU regulations. This framework is the case for mine permits. In Spain, the basic mine legislation is the 22/1973 Law of Mines, which has been in force nationally for the past 40 years. More recently, the Royal Decree 975/2009 transposed the MWD and includes issues related to the rehabilitation of areas affected by extractive mining and other requirements derived from the ELD. Spain has a federal structure based on 17 autonomous communities, and some of these communities have approved their own subsidiary regulations. This arrangement is in use in Galicia, where the 3/2008 Law for the Arrangement of Mining was enacted in 2008.

Since 1982, Spain's mining legislation has required mine developers to complete restoration activities and to commit a readily available bond, financial guarantee, or insurance policy to ensure that the approved reclamation project is fully developed and that the expected goals are achieved within a prescribed warranty and monitoring period. Because of this legislation, Spain has experienced successful mine reclamation projects, although the number of large-scale open pit flooding projects is limited. Examples of this success include the groundwater infilling of the carbonate-enclosed Reocín zinc mine in Cantabria (Fernández-González et al.

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2009) and the forced flooding with river water of the As Pontes (Fleischhammel and Menéndez-Lolo 2010) and Meirama coal mines, both located in A Coruña.

The EU-funded Environmental Regulation of Mine Water in the European Union (ERMITE) project (Younger and Wolkersdorfer 2004) defines *mine water* as "water which is in mined ground (including waste rock/tailings depositories) and/or which is now flowing from mined ground into adjoining water bodies (such as streams, wetlands, lakes, aquifers, and oceans)" (Kroll et al. 2002). It is implicit in this definition that pit lakes, as long as they are located within mined or mine-affected ground, are mine waters; no specific rule or principle is provided with respect to how to manage these human-made water bodies. Although the MWD does not include mine water as an explicit waste category, article 13.1 of the MWD acknowledges the necessity of specific treatment of leachates prior to its discharge toward the receiving media. In this respect, water covers are effective oxygen transport barriers that reduce the weathering of reactive tailings and reduce the generation of leachates. Although this is a valid context for a pit lake from the point of view of the MWD (i.e., a capping layer), it is clearly unsatisfactory when considering the wider scope of the hydrological cycle and self-sustainable integration at the river basin scale.

Although the ERMITE guidelines provide general recommendations concerning the integrated management of mine water within the context of river basins (Younger and Wolkersdorfer 2004), there is no obvious legal link between the Water Framework Directive, or WFD (EC 2000) and mine operations other than that provided by the MWD. The cause of this missing link is that the MWD addresses the impact of mine wastes over the receiving media (surface, ground, transition of coastal waters, and their corresponding ecosystems), whereas the WFD takes account of the amelioration, when possible, of the ecological status of continental waters, irrespective of the sources of contamination.

The WFD (EC 2000) constitutes a significant advance toward the effective implementation, on a continental scale, of integrated and sustainable RBMPs focused on comprehensive protection of the aquatic environment. That protection applies to inland surface waters, transitional waters, coastal waters, groundwaters, and their ecosystems. The WFD also places public participation at center stage of the decision-making process by seeking the active involvement of stakeholders and individuals, and opening the entire process to public consults.

The WFD defines, as a general objective, what is termed "good status." This status is assessed in a tiered approach by considering different ecological and chemical indicators, which are compared with representative reference conditions. The WFD outlines that, by 2015, all EU surface and groundwaters should attain good status, provided that a comprehensive program of remediation and corrective measures is enforced. The WFD also grants justified exemptions (i.e., less stringent objectives or the extension of the deadline beyond 2015) in certain specific situations, such

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as when the general objective cannot be reasonably attained in the given time, when the cost of the measures for achievement is disproportionate, or in the case of artificial water bodies.

The core units for water management in the WFD scheme are river basin districts. Following the general schedule for the implementation of the WFD by 2009, each river basin district had to issue the first RBMP and its associated program of measures to meet the environmental objectives established in the plans. The RBMPs, which are revised on a 6-year basis, must be approved by the European Commission.

The application of the WFD is not mandatory within the granted right boundaries (concession) of a mine, even though it is binding outside these boundaries. However, at the permit-issuing stage, mine developers must demonstrate (through corresponding studies) that permanent or nontolerable adverse effects will not occur in the receiving media as a result of the mine operation. If there are effects on the quantity or quality of a water body located beyond the granted concession, the mine owners must conduct remediating measures or obtain permits from the river basin authorities to eliminate or mitigate any adverse effects on the receiving media. Although the WFD seeks to establish homogeneous environmental criteria throughout all of the European countries, this framework has not been the case for mining and, in particular, for mine water management.

According to the WFD water body classification scheme, pit lakes correspond to artificial surface water bodies that must be monitored (if >0.5 km^2) and managed to achieve or maintain good chemical quality and a given ecological status. Because of their origin, flooding history, relative youthfulness (compared to natural lakes), and other physicochemical, hydrological, and biological circumstances, the assessment of ecologically meaningful reference conditions in pit lakes is challenging. For artificial water bodies, the WFD suggests a methodology based on a comparison with a natural surface water body that closely resembles the artificial body in question. Through the selection of a set of key biological quality elements that are measurable and representative of the reference system (phytoplankton, macro- and microphytobenthos, macrozoobenthos, and fish communities), it is possible to trace a bundle of reference conditions aimed at identifying the "maximum ecological potential" that the artificial water body under scrutiny could attain. Setting aside the chemical quality issue (which, in any case, must satisfy the threshold values established by the WFD and Directive 2008/105/EC on Environmental Quality Standards [partly amended by Directive 2013/39/EU; EC 2008b, 2013] or case-specific threshold values given by the river basin authority), the ecological target for an artificial water body is to attain so-called "good ecological potential" (in contrast to the "good ecological status" expected for natural water bodies). A good ecological potential is one in which the biological indicators selected for the assessment show a close resemblance to those of the reference water mass.

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Nixdorf et al. (2005) discuss how to handle realistic ecological reference conditions in pit lakes within the WFD. They propose a preliminary classification scheme using acidity and phytoplankton assemblages as discriminating criteria. The authors recommend that extremely and very acidic lakes remain in an acidic state to protect these valuable ecosystems. In contrast, they recommend that moderately and weakly acidic lakes be managed by external flooding and chemical or engineering measures to achieve the optimum conditions necessary for recreation, fishery establishment, or other uses.

From a chemical quality perspective, the assessment of the chemical status of a water body also requires the identification of meaningful reference conditions. The establishment of these conditions entails documenting the characteristics corresponding to pristine or nearly pristine conditions (i.e., without or with only a very minor impact from human activities). However, because of human population growth, such circumstances have disappeared in many regions of the EU; therefore, the WFD also makes it possible to define reference conditions using additional criteria such as the use, when available, of time series and historical data, modeling, or expert judgment. The identification of hydrochemical reference conditions has proved to be complicated in many river basin districts. This difficulty arises because the majority of long-term monitoring programs have focused on large-scale river basins, where the human impact has been more pronounced. For a mining project developed under the rule of the WFD, the assessment of hydrochemical reference conditions is a necessity that arises at the time of the initial authorizations or when the postmining project is presented. The assessment is also a relevant document that is required by the river basin authority to assess past environmental impacts. It also constitutes an important safeguard for mine developers to prove that certain impacts are of natural origin or predate their activities.

According to the WFD, the hydromorphology of the system (i.e., the combination of hydrological and geomorphological processes, and attributes that determine the performance of the different ecosystems in a river basin) contributes to its ecological potential. When considering pit lakes, the identification of hydromorphological pressures is relevant for developing postmining projects because they affect the self-sustainability of the whole system. Therefore, corrective actions must be planned prior to flooding, but this process is not necessarily a requirement of mine laws or related regulations. It is the future release of the mine-affected land (which is subject to the permits of the mine authorities and positive reports from the environmental and river basin authorities) that requires a good fit with the environmental objectives of the corresponding RBMP.

Literature is scarce concerning the management of pit lakes within the context of the WFD and, more specifically, the RBMP. For example, Graupner et al. (2005) discuss how to develop a practical methodology for the assessment of the pollution potential of coal mine districts at the river basin scale. When considering

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the ecological goals of the WFD in the Lusatia mining region of eastern Germany, Graupner et al. (2008) conclude that it might be necessary to define less stringent environmental objectives. The authors suggest, as a realistic working approach, defining acceptable higher concentrations of certain constituents (in their case sulfate) due to mining. Fleischhammel and Menéndez-Lolo (2010) illustrate the case of two European postmining lakes (Lake Bärwalde in Lusatia, Germany, and Lake As Pontes in Galicia, Spain) whose flooding and intended discharges have been designed to meet the environmental objectives of their corresponding river basins. Koch et al. (2005) and Schoenheinz et al. (2011) present interesting case studies of regional-scale river basin management in areas affected by lignite mining (lower Lusatia) and assess different scenarios in which active mining and postmining pit flooding affect the water resources balance.

The final use of pit lakes is an issue of great interest because of its link to river basin water management. Several researchers have explored a variety of options, including pit lakes' potential for flood regulation, aquaculture, waste storage, recreation (bathing and fishing), or consumptive purposes (irrigation, livestock watering, or human water supply; Gibb and Evans 1978; Castro and Moore 2000; Hrdinka 2005; Nixdorf et al. 2005; Gammons et al. 2009; Schultze et al. 2011a). The success of the intended use depends on many factors. The most relevant reasons include the final quality of the raw lake water, the renewal rate of the water, the sustainability and cost of the amelioration measures, and the proactive engineering actions envisaged in advance of lake formation.

Various experiences have demonstrated that the flooding and flushing of pit lakes with clean, diluted river water (especially in situations where final conditions of mild acidity are expected) offer a potentially effective and economically efficient approach to obtaining a water body of acceptable-to-good quality for many purposes (Schultze et al. 2002, 2011b; Gammons et al. 2009; Schultze 2012). The flushing of pit lakes is a general approach followed in many countries where water scarcity does not hinder its implementation. Under the WFD in the EU, the abstraction of continental waters for any purpose requires the approval of a detailed project by the river basin authorities. However, the approval of a mine reclamation project is legally governed by the competent national or regional mining administration service, which, while investigating the different aspects involved in the project, must request any complementary report considered necessary for the final decision. If the plan is to flood an open pit, then the permit for water abstraction from the river basin authority constitutes a key element of the administrative record.

The WFD fails to account for a dynamic scenario in which natural changes tend to modify the ecological status and availability of continental waters. In recent years, a new paradigm has been arising in which other considerations apart from water quality, ecosystem preservation, and cost recovery drive water policy.

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Accounting for the tendency of southern EU countries to suffer more frequent episodes of water scarcity and drought, a new priority in the EU water policy is to ensure access to water in sufficient quantities for all legitimate uses (see http://ec.europa.eu/environment/water/blueprint/index_en.htm). On a different scale, the reclamation of a mine space illustrates transient, evolving systems where ecological succession (i.e., the more-or-less predictable and ordered changes in the composition or structure of an ecological community; Grant 2006) must be considered as a reality of the restoration project. Similar changes happen in lakes (Campbell and Lind 1969) and are more pronounced in pit lakes (Brinker et al. 2011; Delgado et al. 2013). Acknowledging these complexities, it is important to reflect on the long-term applicability of immutable reference conditions provided by the WFD.

CASE STUDY—THE MEIRAMA BROWN COAL MINE

The Meirama mine (Figure 17.1) is an open pit located in the province of A Coruña in northwestern Spain, approximately 20 km south of the city of A Coruña (43° 12'N, 8° 26'W). The extraction of lignite began in 1980 under the management of Limeisa. The lignite was burned in the nearby 550-MW thermal power station that the Gas Natural-Fenosa utility owns. Because of the exhaustion of technically and economically recoverable resources, the extraction of lignite stopped by December 2007. Over the course of nearly 30 years, approximately 81 hm^3 of clay, 50 hm^3 of granite, 44 hm^3 of schist, and 93 hm^3 of lignite were mined. The volume of material moved or used for profit amounts to a total of 268 hm^3, although part of the leftover material has been returned to the pit, reducing the final excavation volume.

The overall budget of the mine restoration project is 60 million euros (~$82 million in U.S. dollars). The major components of the restoration project include forced flooding of the mine pit with stream water and reforestation of the mine-affected lands and slag heaps. Limeisa managers expect that the reclamation project will allow an exemplary integration of the mine space into the local environment while providing a boost for economic and tourism development in the area.

As early as the mid-1980s, Limeisa planned the reclamation of the mine pit by proposing to flood it with water and defining a number of postmining alternatives aimed at integration of the degraded mine landscape while following general guidelines for sustainability, land management, and regional development (*Berlin II Guidelines*; UN 2002). Considering that a spontaneous flooding with runoff/groundwater would lead to an acidic, metal-loaded water mass, it was concluded that a fast, forced flooding using external river water was the best option to compensate for diffuse acidic seepages (either by dilution and/or neutralization), to minimize the weathering of rocks exposed in the pit slopes (capping effect), and to avoid the access of low-quality waters by occupying the pit basin with good-quality waters (Schultze et al. 2011a). The rapid rise of the water level was also an important consideration when assessing pit bank stabilization needs. The success of external

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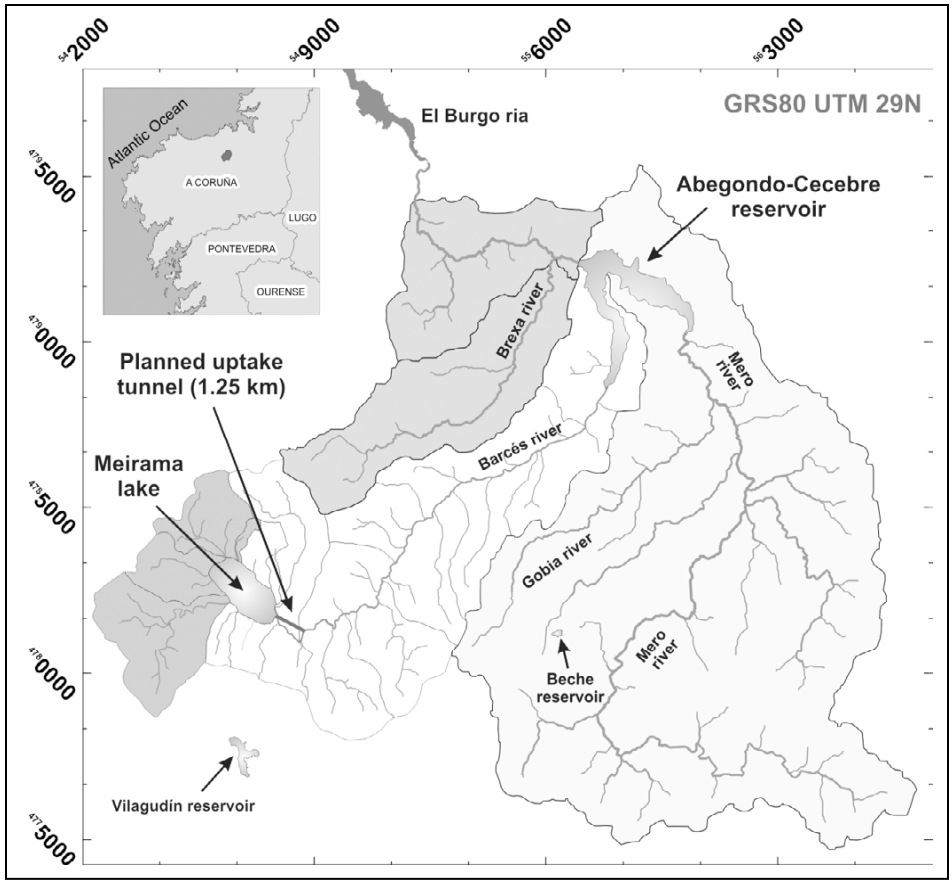


Figure 17.1 Location of Meirama Lake within the Barcés River (middle area) and Mero River (right-most area) watersheds. The shaded area to the left of the lake identifies catchments contributing waters to the flooding of the pit. The locations of the Abegondo-Cecebre Reservoir and the planned uptake tunnel are also shown.

flooding depends on groundwater flows, the location of overburden piles, the initial water level when the flooding begins, and the alkalinity/acidity balance of the infilling waters. Because the alkalinity of the locally available stream waters was low and the acidity of the combined pit-runoff overburden/groundwater seepage was significantly higher, it was decided that the external flooding should begin as early as possible. A graphical summary of the flooding project is presented in Figure 17.2.

The mine is located in the headwaters of the Barcés River. The catchments draining toward the mine void have a total area of ~30 km^2, which is approximately one third of the total area of the Barcés River watershed (~100 km^2). The Barcés River and Mero River watersheds (~250 km^2 in conjunct) feed the Abegondo-Cecebre Reservoir. The reservoir was commissioned in 1976 and has a nominal

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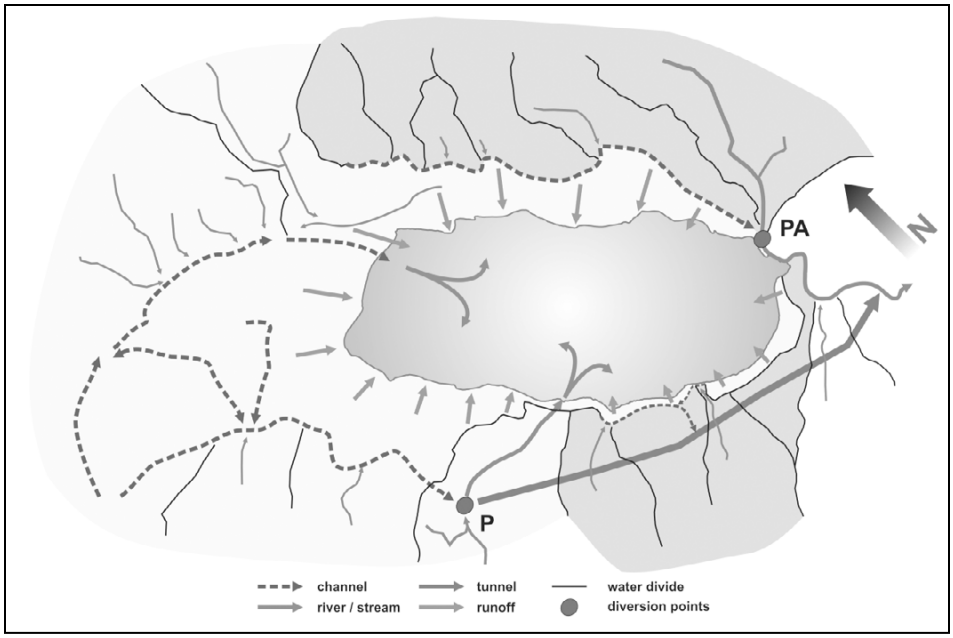


Figure 17.2 Contributing areas (lightly shaded area) and main water sources available during flooding of the Meirama pit. Different hydraulic structures (runoff, stream-collecting channels, and tunnel) are also shown. The two diversion points correspond to the location of the gate systems, allowing mine managers to decide whether the Pereira (P), the Porta Antiga (PA), or both rivers flow toward the lake.

capacity of ~23 hm^3 and an actual regulation capacity of 20.6 hm^3 (12.9 hm^3 in rainy periods, when flood control is necessary). This reservoir constitutes the only source of drinking water for the city of A Coruña and its metropolitan area. For nearly 30 years, treated water has been discharged from the mine area toward the Abegondo-Cecebre Reservoir through the Barcés River with no observed problems affecting water quality. This is especially relevant when considering that current discharge limits are more stringent than the limits granted for the mine discharges during its lifetime. However, the prospect of the flooding project also triggered some environmental concerns from interested parties who, based on noncomparable situations, presented the future lake as a potentially contaminated, acidic, and heavy-metal-loaded water mass that would threaten the existing human water supply system. These preconceptions have not been validated by the observations available from the comprehensive monitoring survey that is described later in this chapter.

The Mero and Barcés rivers, the Abegondo-Cecebre Reservoir, and Meirama Lake are located within the so-called Galician-Coast River Basin district (16,372 km^2). The increasing demand for water for human and industrial purposes challenges the capacity of the Abegondo-Cecebre Reservoir supply system. This challenge is

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especially acute when, in hydric-stress situations, the availability of water becomes reduced and the water quality is adversely affected by a number of hypolimnetic processes or by episodic algal blooms. For many years, the river basin authority has considered the construction of a new dam to support the Abegondo-Cecebre system. However, even setting aside the ecological and societal burdens associated with this hypothetical project, the storage capacity of the draining watersheds only makes the construction of a relatively small reservoir (8 to 16 hm^3) possible in the Mero River. The economic crisis affecting Spain, and the concomitant low availability of financing, have stalled this project until at least 2017, and no budgetary provision was made in the recently approved Galicia-Costa RBMP. In this context, Meirama Lake constitutes a water mass that, provided it fulfills the environmental quality objectives established by the river basin authority (Table 17.1), is crucial to use in the face of the aforementioned problems. In August 2012, the regional government and the river basin authority presented a project that will allow draining of the lake by gravity using an uptake tunnel (1.25 km in length; 2.7 m in diameter; 0.5% constant slope) that connects it to a point located 15 m below the natural spillway height (156.25 m ASL, or above sea level) and the Barcés River. The lake volume, regulated in such a way, will be ~24 hm^3, effectively doubling the current storage capacity of the water supply reservoir.

Pit Lake Description

The open pit is funnel shaped, and at the overflowing height of 171.25 m ASL, it spreads over a surface of 1,886 km^2. The most important characteristics of the lake include its storage volume (146 hm^3), maximum length (2,290 m), maximum width (994 m), maximum depth (205 m, which is attained at –33.75 m ASL), mean depth (78.6 m), and shoreline length (7.5 km). Further details about the lake are provided in Delgado et al. (2011b, 2013).

The hillsides at the pit have a generally moderate slope (6% to 25%) with locally steeper areas (up to 55%). The geology of the mine pit is dominated by the presence of igneous and metamorphic rocks (Órdenes Schist Formation and Monte Xalo granite), with generally low and fracture-controlled permeability. The mine soils are mainly umbrisols (humic, endoleptic), with local developments of cambisols and anthropic regosols. On average, infiltration dominates from November to April, but potential evapotranspiration is higher between May and October. The climate is typical of the Atlantic zone. Rainfall is high all year round (~1,500 L/m^2; minimum values occur in the summer and maximum values in the winter) and, on a yearly basis, exceeds potential evapotranspiration (~750 L/m^2). Since 1976, Limeisa has recorded the monthly rainfall around the mine. The rainiest year recorded in the past 30 years was the year 2000, with 2,069.6 L/m^2. By contrast, the driest year occurred in 1988 (1,037.6 L/m^2). Temperatures are mild near the mine, with a markedly limited thermal range (7 to 17°C). A few months after the start of the flooding, a complete weather station was installed on a floating deck anchored to

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Table 17.1 Yearly median values of parameters (March 2009 to August 2013) whose concentration is prescribed in the discharge permit issued by the river basin authority

	pH	κ_{25} µS/cm	SO_4 mg/L	N_{tot} mg/L	DBO_5 mg/L	P_{tot} µg/L	NH_4 µg/L	Al µg/L	As µg/L	Cd µg/L	Cr µg/L	Fe_{dis} µg/L	Fe_{tot} µg/L	Hg µg/L	Mn µg/L	Ni µg/L	Pb µg/L	Se µg/L	Zn µg/L
2009	8.9	631	239				19	51	0.2	0.21	0.1	8		2.5	153	26	0.1	1.9	6
	P_{95}=4.7	P_{95}=839	P_{95}=276	na	na	na	P_{95}=63	P_{95}=148	P_{95}=0.5	P_{95}=0.8	P_{95}=0.2	P_{95}=205	na	P_{95}=3.7	P_{95}=1,387	P_{95}=147	P_{95}=0.44	P_{95}=2.1	P_{95}=307
	n=178	n=178	n=34				n=37	n=37	n=37	n=37	n=37	n=37		n=37	n=37	n=37	n=37	n=37	n=36
	nd=0	nd=0	nd=0				nd=0	nd=0	nd=0	nd=15	nd=26	nd=2		nd=34	nd=0	nd=0	nd=8	nd=35	nd=2
2010	7.2	527	169	1.7		10	18	27	0.3	0.3	0.2	7		0.1	338	63	0.1	<0.5	60
	P_{95}=6.6	P_{95}=590	P_{95}=231	P_{95}=1.7	na	P_{95}=194	P_{95}=—	P_{95}=76	P_{95}=0.5	P_{95}=0.5	P_{95}=0.3	P_{95}=22	na	P_{95}=0.1	P_{95}=830	P_{95}=113	P_{95}=0.51	P_{95}=—	P_{95}=183
	n=246	n=246	n=52	n=3		n=47	n=52	n=52	n=52	n=52	n=52	n=52		n=52	n=52	n=52	n=52	n=48	n=52
	nd=0	nd=0	nd=0	nd=0		nd=36	nd=31	nd=0	nd=6	nd=10	nd=41	nd=2		nd=50	nd=0	nd=0	nd=46	nd=48	nd=0
2011	6.8	459	164	1.9	0.8	12	42	13	0.5	0.3	<0.1	13	104	1.2	315	69	2.7	7.9	109
	P_{95}=6.21	P_{95}=484.0	P_{95}=176	P_{95}=1.7	P_{95}=3.0	P_{95}=49	P_{95}=94	P_{95}=70	P_{95}=0.6	P_{95}=3.9	P_{95}=—	P_{95}=60	P_{95}=212	P_{95}=6.4	P_{95}=365	P_{95}=80	P_{95}=2.69	P_{95}=1.0	P_{95}=157
	n=126	n=126	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=33	n=36
	nd=0	nd=0	nd=0	nd=0	nd=0	nd=33	nd=32	nd=0	nd=30	nd=18	nd=36	nd=0	nd=0	nd=22	nd=0	nd=0	nd=35	nd=30	nd=0
2012	6.5	431	150	1.4	0.6	21	27	22	0.3	0.3	0.6	11	106	0.4	250	62	4.8	<0.5	109
	P_{95}=6.1	P_{95}=469	P_{95}=179	P_{95}=1.5	P_{95}=1.8	P_{95}=65	P_{95}=27	P_{95}=51	P_{95}=0.5	P_{95}=3.6	P_{95}=1.7	P_{95}=35	P_{95}=193	P_{95}=2.8	P_{95}=354	P_{95}=82	P_{95}=8.6	P_{95}=—	P_{95}=163
	n=159	n=174	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36	n=36
	nd=0	nd=0	nd=0	nd=0	nd=4	nd=29	nd=39	nd=0	nd=6	nd=0	nd=34	nd=0	nd=0	nd=7	nd=0	nd=0	nd=34	nd=36	nd=0
2013	6.4	360	115	1.4	0.6	14	29	15	0.2	0.2	0.7	20	92	0.1	215	54	<0.5	<0.5	102
	P_{95}=6.1	P_{95}=410	P_{95}=137	P_{95}=1.6	P_{95}=1.8	P_{95}=51	P_{95}=32	P_{95}=36	P_{95}=0.4	P_{95}=0.3	P_{95}=1.1	P_{95}=138	P_{95}=151	P_{95}=1.3	P_{95}=242	P_{95}=62	P_{95}=—	P_{95}=—	P_{95}=117
	n=156	n=156	n=40	n=40	n=40	n=35	n=40	n=40	n=24	n=40	n=24	n=40	n=40	n=24	n=40	n=40	n=24	n=40	n=40
	nd=0	nd=0	nd=0	nd=0	nd=2	nd=15	nd=38	nd=0	nd=3	nd=0	nd=21	nd=0	nd=0	nd=5	nd=0	nd=0	nd=24	nd=40	nd=0
Legal limit	6–9	500	250	10	3	400	1,000	1,000	10	5	50	300	1,000	1	1,000	100	10	10	1,000

κ_{25}= specific conductance at 25°C; P_{95} = 95th percentile; n = number of measurements; nd = number of measurements below the detection limit; na = not analyzed;
Fe_{dis} = total ($\Sigma Fe^{+2} + \Sigma Fe^{+3}$) dissolved iron concentration after 0.45-µm filtering; Fe_{tot} = total unfiltered iron concentration.

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the deepest location of the lake. According to the collected data, rainfall during 2008, 2009, and 2010 (1,546.3, 1,492.5, and 1,451.0 L/m^2, respectively) was close to the mean value of the historic series. Although a significant drop in precipitation occurred in 2011 and 2012 (869.9 and 1,046.9 L/m^2, respectively), the trend in 2013 (~950 L/m^2 by mid-October) points toward a return to historic mean values.

Because of the proximity of the water table to the original pre-mine surface, Limeisa had to build an extensive dewatering system to prevent flooding of the pit during mining operations. The system included several kilometers of channels and tunnels (to divert surface waters), a network of perimetric pumping wells (to drain groundwater), and a mobile pumping system (to evacuate rain and runoff water flowing toward the pit bottom). The diversion tunnel and some of the channels remain operative (Figure 17.2). The collaborative peak pumping capacity of the groundwater wells was ~12,000 m^3/h. From 1982 to 2007, the average volume of water drained from the pit (rain + runoff + groundwater) was ~4.3 hm^3/year.

In addition to general decommissioning activities (dismantling of pipelines, conduits, electrical connections, transformers, conveyor belts, etc.), several preparatory tasks were conducted to prepare the pit for the reception of water and to minimize the impact of acid drainage. The bottom of the pit, where lignite was still exposed, was sealed with a thick cover of clay material taken from selected outcrops of the mine. This clay cover has a dual purpose. First, because the exploited lignite has an average S content of ~4.5% (mostly in the form of fine-grained iron sulfides), the clay lining should lessen the oxidation of sulfur and the appearance of supplementary acidity sources. Second, the lining serves as a buttress to increase the safety factor of the slopes, from 0.9 to 1.1 before the start of the flooding to more than 1.45 when the lake is full.

Several rock-lined ditches were constructed to redirect stream water from existing pipelines and concrete channels. These ditches were built during mine operations as part of the pit's dewatering network. No permit was required from the river basin authority because these restitution operations were performed within the scope of the mine reclamation project. A total of eight channels and other related streams have been instrumented with flumes and pressure or level gauges connected to data acquisition and telemetry systems. The two main rivers upstream of the mine (the Pereira and Porta Antiga Rivers) have also been equipped with mechanical gates so that it is possible to control whether their corresponding waters flow toward the void. Additional control equipment includes a laser tracking system (georobot) to monitor slope movements and two seismometers to record microseismic activity.

Permit Issuing

According to Spanish and EU legislation, several permits must be issued before authorizing the closure and abandonment of a mine. In Spain, the competent

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administrative authority in charge of the follow-up on a mine reclamation project is the Regional Mining Administration, which, in the case of the autonomous community of Galicia, is its regional government (Xunta de Galicia) through the Industry, Energy and Mining Directorate. However, when the reclamation project involves natural waters with any purpose, the corresponding river basin authority (Entidad Pública Augas de Galicia) assumes a principal role as an auditor and verifier of the achievement of the environmental objectives established in the corresponding River Basin Management Plan (Galician-Coast 2011) and by the WFD.

Prior to application for the corresponding flooding permits, Limeisa commissioned several technical studies investigating issues such as

- Reference chemical and ecological conditions for both surface and ground waters (Delgado et al. 2008a, 2011a),
- A numerical model concerning the infilling duration and its impact on ground and surface waters upstream and downstream of the mine (Juncosa et al. 2008; Hernández et al. 2012),
- A numerical model for assessing the future water quality of the lake (Delgado et al. 2008b),
- A numerical model based on the worst-case scenario (nonfulfillment of the water quality objectives) and its impact on the Abegondo-Cecebre supply system, and
- Slope stability assessments and modeling.

The flooding project was submitted for its environmental impact assessment (EIA), a condition that was not required when the restoration project was detailed, and the corresponding periods for public consultation and amendment. The environmental impact statement that was issued included general conditions concerning

- Water (to meet the requirements of the RBMP; to ensure the fulfillment of environmental quality standards and other restrictions related to fishing, bathing, and water supply; to guarantee water uptake rights already existing in the river basin; and to keep operative the mine's water treatment plant to correct the eventual noncompliance of some legally prescribed parameters),
- Ecosystems (attention to riparian vegetation, and reforestation and preservation of environmental flows),
- Waste management,
- Landscape integration, and
- Other cultural heritage issues.

In addition, Limeisa was asked to implement a monitoring and control plan, including the relevant aspects indicated in the EIA.

To flood the pit, the river basin authority granted Limeisa a monthly variable (0.17 and 0.5 m^3/s) water-abstraction permit that accounted for water availability and environmental flows; that is, the quality, quantity, and timing of water flows

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Table 17.2 Prescribed frequencies for sampling and monitoring of relevant parameters in surface water and groundwater related to the flooding of the Meirama pit

Surface Water							
Place/Phase		Physicochemical Parameters	No. of Control Points	Biological Parameters	Hydromorphological Parameters	Parameters Directive 2008/105/EC (EC 2008a)	No. of Control Points
Upstream	Pre-flooding	Quarterly	5	Semiannual	Annual	Annual	5
	Flooding	Quarterly	5	Semiannual	—	Annual	5
	Overflowing	—	—	—	—	—	—
Mine void	Pre-flooding	—	—	—	—	—	—
	Flooding	Monthly/Quarterly	3	—	—	Annual	3
	Overflowing	Quarterly	3	Quarterly	Triennial	Annual	3
Downstream	Pre-flooding	Quarterly	3	Semiannual	Annual	—	3
	Flooding	Quarterly	3	Semiannual	—	—	3
	Overflowing	Quarterly	3	Semiannual	Triennial	—	1
Groundwater							
Up- and Downstream	Pre-flooding	Semiannual	8	—	—	—	—
	Flooding	Semiannual	8	—	—	—	—
	Overflowing	Semiannual	8	—	—	—	—

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required to maintain the components, functions, processes, and resilience of aquatic ecosystems that provide goods and services to people (Hirji and Davis 2009). Target lake discharge values were prescribed by the river basin authority (Table 17.1). The river basin authority also prescribed the control of a wide number of indicator and control parameters as well as frequency and sampling locations (Table 17.2). The permit applications for river water uptake and discharge from the lake, as required by the WFD, were both submitted for public consultation.

Limeisa also submitted the corresponding closure and abandonment permit, which was granted provided that several requirements were fulfilled, to the mining authorities. In summary, these requirements included the control of slope movements, measurement of the recovery of groundwater heads, establishment of a water quality monitoring program (which is compatible with that of the river basin authority), and periodic assessment of the trophic state of the lake. As an additional condition, the mining authorities prescribed maintenance of the control and monitoring program for a period of 10 years after the overflowing condition in the lake is attained. Both the water and mining authorities asked Limeisa for proof of environmental financial support to guarantee the execution of all of the prescribed actions.

Throughout the permit-issuing process, the most typical concerns raised by stakeholders were always related to water quality and the eventual effects on the Abegondo-Cecebre Reservoir caused by acidic, metal-loaded discharges originating at Meirama Lake. Most of the questions raised were based on perceptions derived from negative examples developed elsewhere. Although the results from the available predictive models were optimistic with respect to the final quality of the pit lake, it is important to acknowledge that the nontechnical public relies more on measured evidence than on numerical models. Consequently, the mining and river basin authorities prescribed a list of parameters to be accounted for and monitored. A comprehensive sampling and monitoring survey was initiated at the beginning of the flooding. The survey included the installation of dedicated equipment (a complete weather station anchored to the deepest point of the lake, a thermistor chain, sediment traps, a multiparameter probe, etc.), an expanded number of sampling points (upstream water courses, pit slope runoff, bulk precipitation), and the measurement of complementary parameters (PAR radiation, stable isotopes, trace metals, organic contaminants, etc.). Using July 2013 as a reference, 51 continuous depth profiles have been executed to date. In addition, more than 1,500 water samples have been analyzed for more than 50 parameters (T, pH, O_2, EH, κ_{25}, turbidity, chlorophyll-a, phycocyanin, dissolved inorganic carbon, dissolved organic carbon, total suspended solids, alkalinity, acidity, Na, K, Mg, Ca, Mn, Fe, SiO_2, Fe^{+2}, Fe^{+3}, NH_4, F, Cl, Br, SO_4, NO_3, NO_2, PO_4, Ag, Al, As, B, Ba, Cd, Co, Cr, Cu, Hg, Li, Mo, Ni, Pb, Rb, Sb, Se, Sn, Sr, Ti, U, V, Zn, P_{tot}, N_{tot}, $\delta^{18}O_{V\text{-}SMOW}$, $\delta^{2}H_{V\text{-}SMOW}$, BOD_5 [biological oxygen demand], polychlorinated biphenyls, and volatile organic compounds). An additional ~1,000 samples have been

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used to analyze a portion of these constituents. This large database, coupled with its judicious interpretation, provides an unusual and lengthy record of the evolution of this pit lake. However, more important is that it represents, from a management perspective, the cornerstone for confidence building and credibility as well as a demonstration of restoration best practices to third parties. Without this data set and the corresponding analysis, it would be difficult to support the decision of the river basin authority to use the lake as an emergency source of water.

Pit Lake Flooding

The flooding of the lake began on March 18, 2008, when, upon approval from the mining authority, the dewatering system for the pit was powered down (Figure 17.3). The termination of pump operation was stepwise instead of sharp. The goal was to try to synchronize the rise of the lake level with the recovery of the groundwater level. However, because of a backlog affecting the river basin authority, the permit for river water uptake was delayed, and the lake was only fed with groundwater, rain, and pit-slope runoff water during the first ~7 months. In this period, an acidic water mass (pH ~3.2; acidity ~150 mg $CaCO_3$/L; κ_{25} ~2.4 mS/cm) of ~2 hm^3 developed. On October 3, 2008, the permit for river water uptake was issued, and several water courses located upstream of the mine (the Pereira River being the major one) were restored to a course similar to pre-mine conditions. Since the permit was issued, the lake has been receiving water from this source, except in certain periods (such as August to November 2011) when, because of the scarcity of precipitation and the need to maintain the ecological integrity of the streams, the delivery of surface water is halted. Upon completion of the flooding, upstream waters will naturally flow toward the lake, accomplishing full river–lake integration.

The pluviometry and the flooding record of the lake are illustrated in Figure 17.4. Figure 17.5 depicts the flows computed from the measured height of the free surface of the lake and a detailed digital elevation model of the pit. A marked dependence on precipitation of the available flow for infilling can be observed. On average, the groundwater flow is limited to ~0.12 m^3/s.

To reduce the acidity of the initial water body, Limeisa constructed a treatment system that delivers lime to one of the stream inlets. Because of the relatively low alkalinity of the Pereira River water, the decision was made to prolong the lime treatment. Between May 2008 (when the system was installed) and November 2010 (when liming was interrupted), 1,973 t (metric tons) of $Ca(OH)_2$ and 1,405 t of CaO (~5,600 $CaCO_3$ metric ton equivalents) were added to the lake. Liming was considered a necessary engineering measure at the early stages of lake development to correct acidity. However, it was soon acknowledged that the continuous treatment with lime was not sustainable and, given the evolution of the lake, most likely unnecessary.

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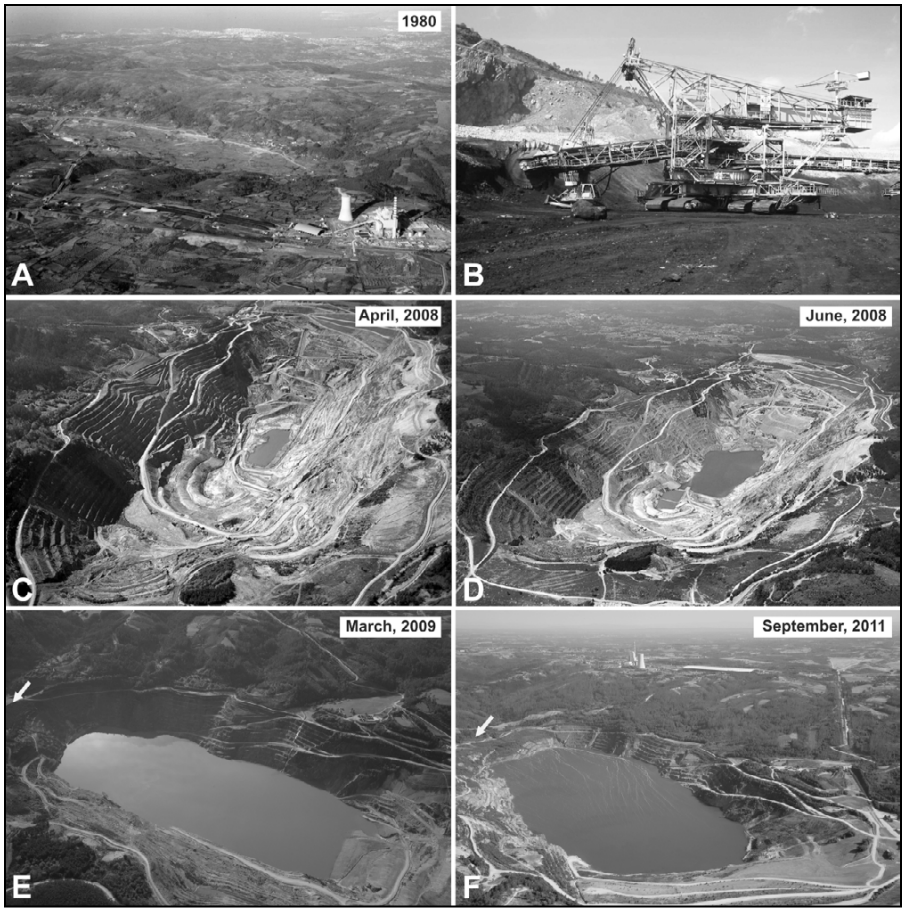


Figure 17.3 Sequence of photos showing different moments in the history of the Meirama mine: (a) The sedimentary basin at the beginning of extraction operations; (b) bucket-wheel excavator in the early stages of exploitation; (c, d, e, f) different moments during the pit hole flooding. The two small pools shown in photo d are ponds used to treat the initial acidic waters with lime. The arrows in e and f indicate the approximate location of the planned tunnel mouth.

From June 2013 to the present, the river basin authorities requested that Limeisa block the entrance of stream water to conduct some preliminary works on the lakeside of the uptake tunnel (tunnel portal and valves chamber). This action has not fully stopped infilling (due to the continuous seepage of groundwater, direct precipitation, and the ingress of a limited flow of nonderivable surface water) but has drastically reduced the rate of ascent of the free surface. By the end of October 2013, the lake held approximately 108.1 hm^3, which is slightly more than 73% of its final volume. By the same date, the free surface was located at 146.5 m ASL, which is 25 m below the overflow height. The corresponding chemical quality is reported in Table 17.2, and further details are provided in Delgado et al. (2013).

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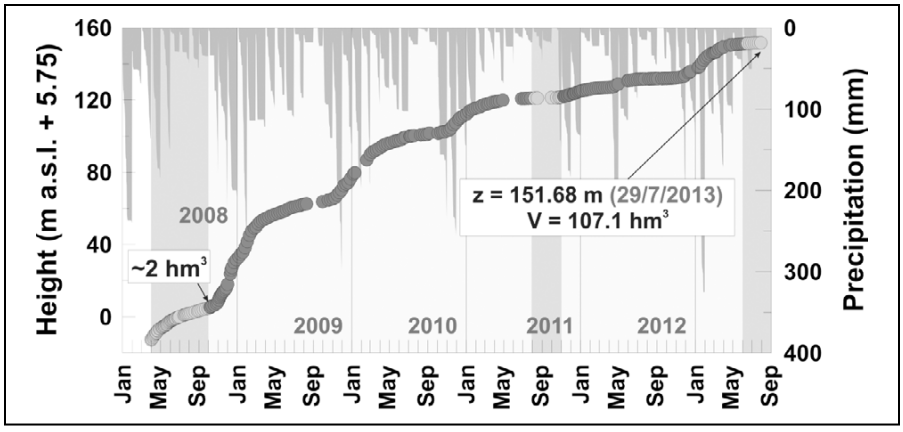


Figure 17.4 Flooding and precipitation records for Meirama Lake. As of July 2013, the lake had attained a maximum depth of ~152 m and stored ~107 hm³ of water. The vertical gray-shaded areas and light gray dots in the periods April to September 2008 and August to November 2011 highlight when only groundwater (plus direct rain and runoff) entered the lake. Thereafter, the most significant input for flooding has been river water. In June 2013, the water basin authority required mine managers to stop the direct river input as a precautionary measure before tunnel work began.

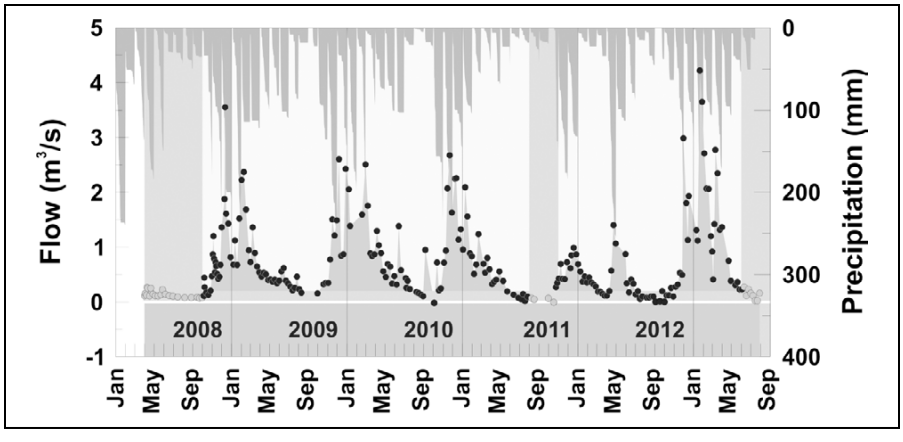


Figure 17.5 Time-distributed inflow (computed from the change in height of the free surface of the lake and a digital elevation model) and monthly cumulative rainfall. The vertical gray bands (and light gray dots) correspond to periods in which the lake was fed only with groundwater (plus direct rain and runoff).

Summary of Pit Lake Characteristics and Evolution

A detailed summary of the characteristics and evolution of Meirama Lake is presented in Delgado et al. (2011b, 2013). Therefore, only a brief summary of the main features are given here. By the end of July 2013, Meirama Lake was a steadily stratified meromictic (permanently stratified) system, with a deep portion

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(monimolimnion) isolated from the annual mixing dynamics (December/January) of the upper water body. The depth of mixing was restricted to a surficial water column 35 to 40 m thick. This mixing depth clearly exceeds the depth at which the uptake tunnel is planned to be located. Thus, the tunnel structure will be placed in the middle of a water body of good chemical quality (i.e., well oxygenated, circumneutral pH, low metal concentrations, etc.; Table 17.1, Figure 17.6).

The potential of pit lakes to become meromictic may be useful. Meromixis can be expected in the lower portion of deep lakes and also in shallow lakes with highly mineralized waters. The anoxic monimolimnion of these lakes provides a matter sink and space for reduction processes that can generate alkalinity while avoiding the back-release of nutrients to the waters above. The oxicmixolimnion provides a zone where light and the enhanced nutrient supply support the growth of biomass using photosynthesis to provide organic matter that stimulates the alkalinity-generating reduction processes below (Nixdorf et al. 2005).

By October 2013, all of the constituents and parameters with value limits in the discharge permit were in compliance with the prescribed environmental targets. In addition, most of the parameters showed a decreasing concentration trend, suggesting that this compliance is not circumstantial.

The chemical quality of the surface waters of Meirama Lake tends to be buffered by the chemistry of the Pereira River. There is a very limited impact from the acidic seepages on the general chemical quality of the lake, which is only evidenced by the slightly increased concentration of certain substances (Ca, Mg, F, SO_4, Co, Li, Ni, Sr, Zn, and κ_{25}). This low impact is maintained even in situations when, due to the scarcity of precipitation, flooding with surface water is arrested. Other constituents in the lake display lower concentrations than in the Pereira River (Fe, NH_4, NO_3, Cl, As, B, Mo, Sb, and V). This difference is likely due to dilution and other geochemical processes.

Even though the chemical composition of the Pereira River water has been nearly constant during the observation period, the concentration of many metals and the pH in the lake display a prominent peak-and-valley pattern. This pattern appears to be connected to the photosynthetic activity of phytoplankton during the growing periods: When primary production is at its minimum, the pH reaches its lowest values and metals reach their highest values; when the situation is reversed, the pH rises and the metal concentration drops. Available data suggest a progressive increase of the biomass in the lake.

The evolutionary trend observed in the surface water of the lake points toward the attainment of a nearly steady condition by which month-to-month changes are limited, although seasonal patterns may have a moderate importance for some constituents. Moreover, the planned uptake tunnel may serve as an additional aid to improve mixing with good-quality surface water in the upper portion of the lake. This relatively steady situation supports the feasibility of using the upper portion

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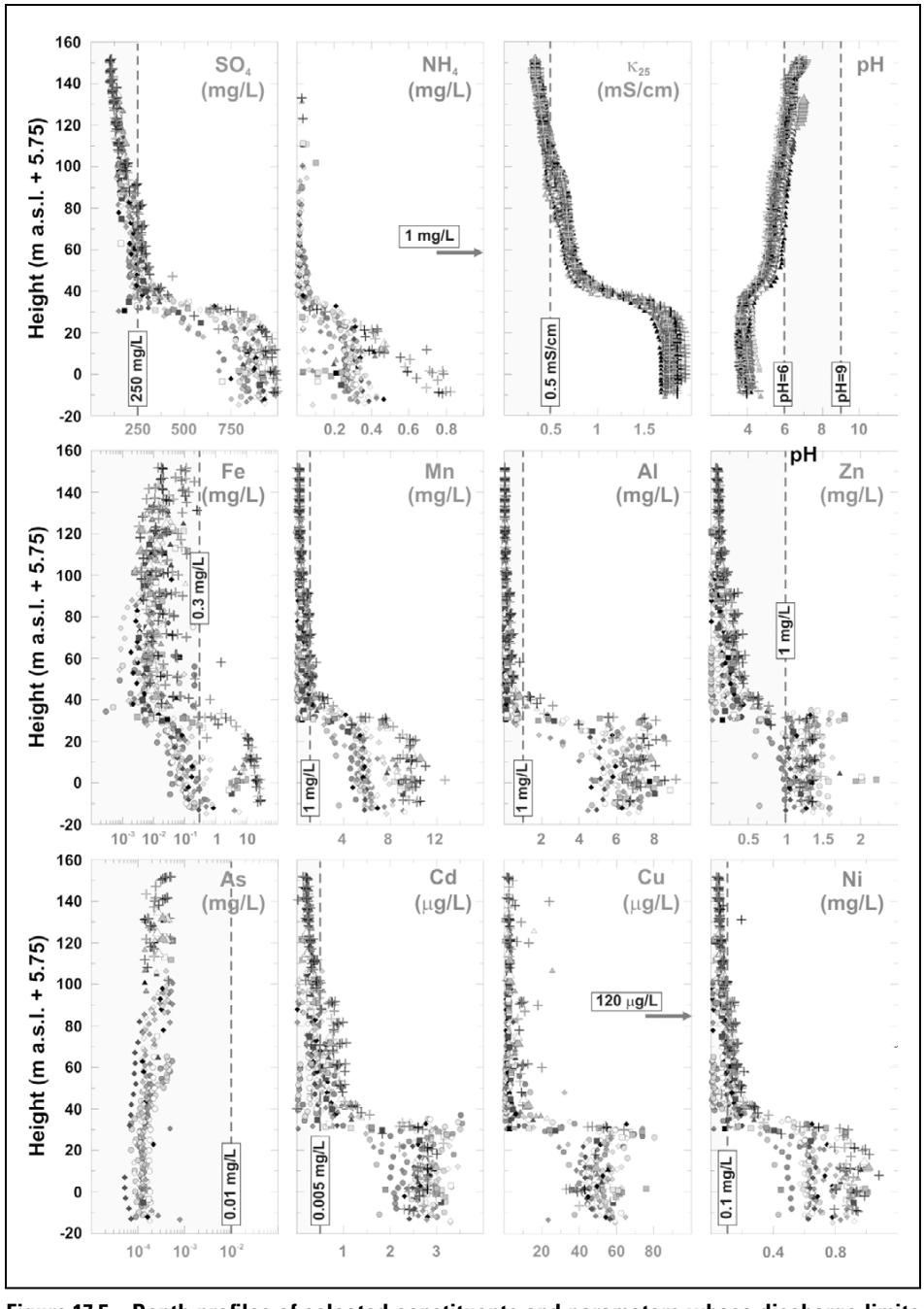


Figure 17.5 Depth profiles of selected constituents and parameters whose discharge limits (labels and dashed line) are prescribed. All data correspond to samples taken from February 2009 to October 2013, except for pH and κ_{25} (January 2012 to October 2013).

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of the lake as an emergency reservoir for water supply, even when considering that the lake itself will evolve over the coming decades.

Fit of the Flooding Project into the WFD

The Galician-Coast District RBMP was approved by the regional government in September 2011 and by the national authorities one year later (Royal Decree 1332/2012, September 14, 2012). The RBMP makes no mention of the Meirama pit lake, a tacit recognition that as long as the lake belongs to the mine concession, the river basin authorities have no other power than to supervise the effects of the infilling process on the surrounding media. However, because there are potential adverse effects on the receiving media while the flooding process proceeds and, upon completion, when overflowing starts, mine managers are subject to the permits outlined previously, which mainly relate to water uptake for the purpose of infilling and the downstream discharge from the lake. Obviously, the intended use of the lake determines the necessity of its integration into a future revision of the RBMP and the development of specific management criteria for the river–reservoir–lake hydraulic system.

In Spain, there is a legal term called the "hydraulic public domain" that encompasses renewable inland waters, both surface water and groundwater, regardless of the time of renewal; channels of natural streams, either continuous or discontinuous (i.e., the land covered by water under maximum normal rises); beds of lakes and lagoons, and surface impoundments of public waterways; aquifers; and water from the desalination of seawater. The "corresponding banks" are defined as the side strips of public waterways that are located above the low water level and the land margins that border the channels. The banks are subject, along the waterway's full length, to a bonded area of 5 m wide for public use and to a 100-m-wide surveillance area where land use is restricted to authorized activities. Under the Spanish Law of Mines, a mine concession can be envisaged as private property and thus persists until the competent authorities allow the closure and final abandonment of the mine. The incorporation by the state of new hydraulic public domain is not automatic because it may imply the acceptance of additional management burdens, especially when some of the precepts of the WFD are not fulfilled. Therefore, a negotiation process follows between mine managers and authorities. To conduct the mine restoration project to a fruitful end, it is necessary to have good coordination and complementary actions among the main permit-issuing entities (mine, water, and environmental administrations), stakeholders and mine managers.

CONCLUSIONS

The Meirama project is a good example of the growth of positive public awareness that started with a relatively negative perception that was based on widespread prejudices concerning mining, mine closure, restoration, and the risk associated with

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the eventual effects of mine waters on the water supply system. The chapter authors stress the importance of good planning when considering the development of pit lakes. Based on this experience, it is important to draw attention to monitoring programs. The strict observance of environmental best practices, transparency in communication, and constructive interaction between mine owners and mining and river basin authorities are enabling the integration of this new artificial water body into the management scheme of the river basin.

Managing a pit lake within the context of the WFD requires effective coordination, communication, and understanding among mining and water authorities, mining companies, and stakeholders. It is important that the role of the pit lake in the river basin be acknowledged at the very beginning of the mine planning process. There is limited experience in the management of pit lakes, which poses unique challenges in regard to diagnosing the ecological performance and evolution of lakes in the current working scheme of the WFD. Because of the uniqueness of each case, it is desirable to share experiences to define better integration within river basins.

Much can be done to improve the expectations for the chemical quality and ecological status of a pit lake, especially if these expectations result from a well-documented, scientifically and technically sound project. Future uses of pit lakes should be considered, when possible, from the early stages of mine planning because there are clearly positive factors that can be added in the early design stages that can be implemented later at zero or very low cost.

The rehabilitation of the Meirama mine and the intended use of the pit lake for water supply fit nicely into the concept of "green offsets" defined by the New South Wales Environmental Protection Authority (NSW-EPA 2002) as a net environmental improvement resulting from the development of the mine project. If any additional environmental impact that is generated by mining is offset by actions taken off-site, this approach can significantly reduce the environmental impact so that the net effect of development is positive. In this case, from the perspective of an integrated water basin management scheme, the use of Meirama Lake as a reservoir for emergency water supply makes the construction of a new reservoir in the basin (and its non-negligible environmental impacts) unnecessary, offers chances for new economic and leisure activities and provides opportunities for ecosystem development.

ACKNOWLEDGMENTS

Funds for this work were provided by the Spanish Ministry of Economy and Competitiveness (CGL2008-05940/BTE), the Xunta de Galicia (10MDS008CT), the European Regional Development Funds 2007/2013, and Limeisa. The views expressed in this paper are attributable solely to the authors and do not imply endorsement by the Xunta de Galicia, the Entidad Pública Augas de Galicia, or Gas Natural-Fenosa.

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PART VI

TAILINGS AND WASTE ROCK

Michelle E. Jarvie-Eggart

Tailings and waste rock are often the most visible aspect of mining. Management of these materials embodies the challenge of sustainability's triple bottom line: managing economic, environmental, and social risks. Tailings and waste rock impact local ecosystems and biodiversity through their physical placement on the landscape, and associated water quality impacts may exist, especially where native rock has acid-generating potential. These environmental impacts are often cited as reasons to oppose the development of new mines. Proponents of new mines must clearly demonstrate that contemporary mining practices can prevent the serious environmental impacts caused by tailings and waste rock at legacy mines. Regulations require modern mine operators to assess the potential environmental impacts from tailings and waste and to design systems for safe containment and the management of environmental impacts. The chapters in this section discuss the responsible management of tailings and waste rock, from the physical containment of tailings to engineered systems that prevent water impacts and treat water.

In Chapter 18, the authors discuss the practices involved in tailings disposal at taconite facilities in the northern United States, including dam construction, tailings transportation and deposition, basin operation, water management, emerging technologies, and proper reclamation methods. They describe the observational approach, whereby a tailings storage facility is designed using the most current data available, then modified as appropriate based on actual performance. Although the case study focuses on lessons learned at taconite mines in a cold climate, the observational approach can be adapted to improve outcomes at other types of mines in other regions.

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Chapter 19 addresses the responsible management of acid mine wastes. It reviews the origins of acidic and metalliferous drainage from mine wastes, waste rock, and process tailings. The chapter summarizes practices for reducing acid generation rates through neutralization and microbial actions. It includes case studies from the Savage River iron ore mine in northwestern Tasmania, Australia; the East Sullivan mine (copper, zinc, gold, and silver) in northwestern Québec, Canada; the Benambra underground copper-zinc mine in East Gippsland, Victoria, Australia; the Waite Amulet mine (copper-lead-zinc) in northwestern Québec, Canada; and Elliot Lake (uranium) at Copper Cliff (pyrrhotite), Ontario, Canada.

Together, these two chapters illustrate how tailings and waste management is central to overall responsible mining practices. Tailings storage facility design and operation dictate mine water demand, influence environmental outcomes, affect reclamation options, and shape long-term land use after closure. Proper treatment of waters that come in contact with tailings and waste prevents the potential environmental effects caused by acid and metalliferous drainage, protecting local waters for aquatic life, recreation, and drinking water use. The realm of tailings and waste management is much greater than the examples presented in this section, and entire SME texts have been dedicated to the subject. Underwater tailings placement is discussed in the 2002 SME book *Underwater Tailing Placement at Island Copper Mine* by George W. Poling. Derek V. Ellis, James W. Murray, Timothy R. Parsons, and Clem A. Pelletier. For further reading on fine coal refuse, see the 2012 SME text *Challenges in Fine Coal Processing, Dewatering, and Disposal*, edited by Mark S. Klima, Barbara J. Arnold, and Peter J. Bethell.

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CHAPTER 18

Responsible Tailings Disposal at Minnesota Taconite Mines

P.B. Solseng, T.W. Skoglund, and S.K. Dickinson Jr.

INTRODUCTION

This chapter describes the general properties of taconite tailings, tailings basin dam design and construction, tailings transportation and deposition, tailings basin operations and maintenance, water management, emerging tailings storage methods, and reclamation. Each of these topics is a specialized discipline, but they are highly interdependent. Knowledge, planning, and decision making must be tightly coordinated among these areas during design, construction, operation, and reclamation. Although the chapter is structured around these separate topics, the reader will notice many cross references, because responsible tailings management hinges on continuous communication among members of an interdisciplinary team.

BACKGROUND

Minnesota's Mesabi Iron Range was initially developed in the late 1800s for direct-ship high-grade iron ore. The iron formation is a narrow band, about 180 km (112 mi) long, averaging 2–5 km (1–3 mi) wide. Between 1900 and 1980, the Mesabi Range produced about 60% of total U.S. iron ore output. Production peaked during World War II, and the high-grade ore was nearing depletion by the 1960s. The immigrant communities that had grown up around the mines faced economic downturn. Fortunately, efforts to find a way to use the large quantities of remaining low-grade taconite iron ore were successful, and by the mid-1960s, shipments of taconite pellets outpaced shipments of natural ore (Lamppa 2004).

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Taconite processing plants finely grind the ore, which is only about 35% iron, and separate the magnetite to produce an iron concentrate. The concentrate is mixed with binders, shaped into 1-cm (0.4-in.) -diameter pellets, and fired at high temperature to produce durable pellets that contain about 65% iron. Taconite mining on the Mesabi Range presented new waste disposal challenges because processing the low-grade ore results in large volumes of tailings. Taconite operations store the tailings in large tailings basins, often with multiple cells, that are constructed using large dams. These structures are sometimes referred to as tailings storage facilities or tailings management areas, but on the Mesabi Iron Range they are known as tailings basins. Today on the Mesabi Iron Range, there are eight major taconite tailings basins, covering a total of approximately 153 km^2 (59 mi^2).

Local geography compounds the challenges for responsible management of large volumes of taconite tailings. Northeastern Minnesota is rugged land, unsuitable for farming, with a short growing season and severe winters. Before iron ore was discovered, it was a sparsely populated area, home to several Ojibwe tribes, with a modest economy built on fur trapping and logging.

The seemingly plentiful water resources of the Iron Range area present opportunities and challenges for tailings management. Relative to other parts of the United States, the area receives a moderate amount of precipitation, with annual precipitation exceeding evaporation by approximately 15 cm (6 in.). The Laurentian and St. Lawrence continental divides intersect on the Iron Range, so the area serves as a headwaters region for the Lake Superior, Hudson Bay, and Mississippi River watersheds. The water table is generally very shallow, and wetlands, lakes, and streams cover 40% of the land (Kloiber 2010).

Initial estimates predicted that taconite processing would require large quantities of water and that many lakes in the region would need to be converted to reservoirs to provide adequate supplies. Fortunately, engineers developed ways of building and operating taconite tailings basins that reduced seepage losses and increased water recycling. Actual water requirements were decreased to half or less of the original estimates. As a result, many of the lakes targeted as potential reservoirs were spared and now remain in their natural state.

Taconite industry development in Minnesota slightly preceded the promulgation of modern environmental regulations. The major taconite processing plants and their tailings basins were constructed from the 1950s to the 1970s. The National Environmental Policy Act was passed in 1970 and the Minnesota Environmental Policy Act in 1973, but regulations implementing these laws lagged by nearly a decade. Consequently, most of the existing taconite tailings basins in Minnesota were developed before environmental review practices came into effect. Furthermore, *mine tailings* and *waste* are specifically excluded from the legal definitions of *hazardous waste* under the Resource Conservation and Recovery Act of 1976. However, tailings basin expansions have triggered environmental review at

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several facilities, and permit renewal processes have required the existing taconite tailings basins to comply with a range of standards governing reclamation, water quality, air emissions, and dam safety.

The regulation of environmental risks and impacts associated with taconite tailings basins began with efforts to address the proper reclamation of mined lands. The Minnesota Mineland Reclamation Act was passed in 1969. Rules implementing this law were promulgated in 1980 "to control possible adverse environmental effects of mining, to preserve the natural resources, and to encourage the planning of future land utilization, while at the same time promoting the orderly development of mining, the encouragement of good mining practices, and the recognition and identification of the beneficial aspects of mining" (Minnesota Administrative Rules 2013a). These rules required operators to obtain a "Permit to Mine" and to have an approved, financially assured reclamation plan.

Today, many taconite tailings basins have a surface water discharge that is permitted under the National Pollutant Discharge Elimination System (NPDES), established in 1972. In Minnesota, seepage to groundwater is regulated under the State Disposal System (SDS). NPDES and SDS permits limit the quantity and quality of water discharge and seepage, and set monitoring and reporting requirements. Air emissions from taconite processing operations have also been regulated since the passage of the Clean Air Act in 1977. Air permits limit fugitive dust emissions from tailings basins and require fugitive dust control planning. Air and water permits give the public participatory processes to limit the environmental impacts associated with tailings basins.

Public safety risks are also regulated. Federal and state dam safety rules have been in place since the late 1970s. Taconite tailings basins must conduct regular dam safety inspections, develop an emergency action plan, and submit annual dam safety reports including monitoring data and conclusions.

Recently, the mining industry and regulators worldwide have accelerated efforts to improve tailings management. Guidelines and protocols for responsible tailings management have been developed in many countries, including Canada, Australia, and the European Union (MAC 2010; Australian Government DITR 2007; EC 2004). Taconite tailings disposal in Minnesota predates these efforts, although it was ahead of its time in some ways, incorporating tailings management practices that are now widely seen as key to responsible tailings management:

- Protection of health and safety for workers and the public
- Mitigation of negative environmental impacts
- Reclamation to facilitate acceptable postclosure use

The lessons learned from northern Minnesota, which represents one of the major low-grade iron ore deposits in the world, can be adapted to the site-specific challenges of tailings disposal in a wide variety of other settings.

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Table 18.1 General geotechnical properties of taconite tailings

Material	Particle Size, mm	Permeability, cm/s	Drained Strength, Mohr Coulomb ϕ'	Undrained Strength Ratio	
				Su(yield)/σ'vo	Su(liq)/σ'vo
Coarse tailings	>0.074	1×10^{-3} to 5×10^{-5}	Upper envelope 35°	—	—
Fine tailings	0.010 to 0.074	1×10^{-4} to 1×10^{-5}	Lower envelope 27°	0.25	0.13
Slimes	<0.010	1×10^{-5} to 3×10^{-7}	17°	0.25	0.105

CHARACTERISTICS OF TACONITE TAILINGS

Mesabi Range taconite comes from the Biwabik Iron Formation, a Precambrian-age ferruginous chert with 25% to 30% iron (Morey 1972). The primary minerals in the Biwabik Iron Formation are chert, magnetite, siderite, anchorite, and minnesotaite; sulfide minerals are present in minor amounts (Severson et al. 2010).

Taconite processing involves grinding the ore into progressively smaller particles and liberating the iron from the gangue with either magnetic or flotation techniques. Due to the mineralogy of the iron formation, the tailings particles are hard and angular. Generally, taconite processing produces approximately 40% coarse tailings (larger than 0.074 mm), 30% fine tailings (0.010 to 0.074 mm), and 30% slimes (smaller than 0.010 mm). Coarse tailings are usually separated at the plant for use in future dam construction. Fine tailings and slimes are piped as slurry to the basin and hydraulically deposited. Table 18.1 presents general geotechnical properties of taconite tailings, based on the authors' work at numerous taconite basins. See Das and Sobhan (2013) for more details on geotechnical properties of soils.

TAILINGS BASIN DAM DESIGN AND CONSTRUCTION

Taconite tailings basins are enclosed by large dams and natural topographic features (if they are available). Dam construction is typically ongoing over decades and is the major cost in tailings disposal. The tailings dams are designed and constructed to safely contain tailings and process water. Design also considers the features that will be needed in the future for successful reclamation. Tailings basin design involves identifying an appropriate site and understanding the nature and quantity of tailings that will be produced over the life of the mine. Some of the basic considerations for siting tailings basins are

- Proximity to the concentrator to minimize pumping distance;
- Availability of nearby topography to minimize dam construction;

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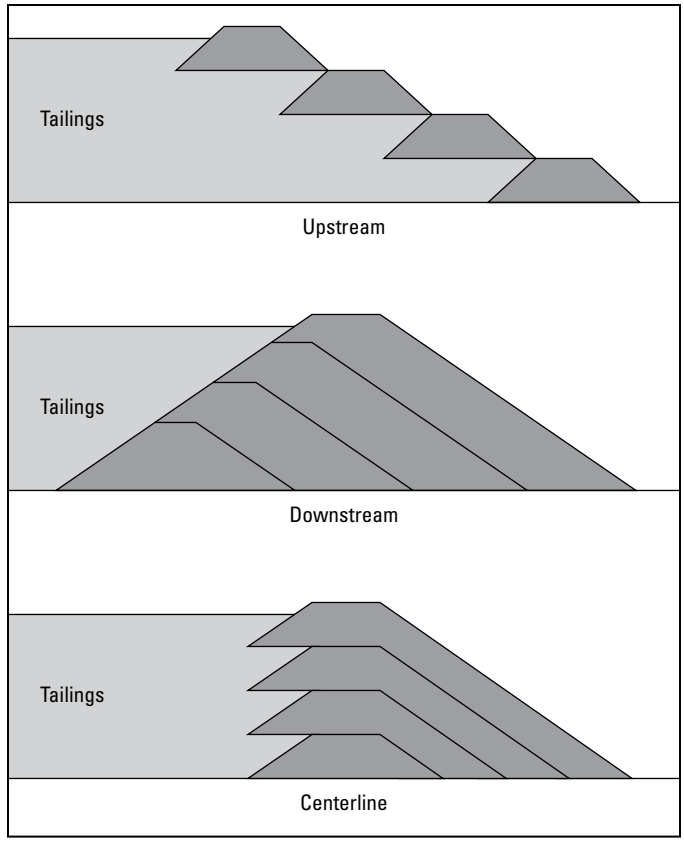


Figure 18.1 Tailings dam construction methods

- Minimization of impacts to wetlands, as defined by the Minnesota Department of Natural Resources (MDNR);
- Maximization of distance from major social/environmental features such as lakes, rivers, and public recreational areas;
- Adequate area for potential expansions of the tailings basin; and
- Layouts with multiple cells that can offer operational flexibility.

Once the location and layout for the tailings basin are determined, tailings dam construction generally begins with a starter dam to confine the initial tailings from start-up. Natural materials are typically used for the starter dams, but dam construction material transitions to coarse tailings as they become available. Use of coarse tailings for dam construction reduces environmental impacts by minimizing the need for borrow pits that disturb local ecosystems.

Tailings dams can be constructed by three general methods: downstream, centerline, or upstream, as simplistically illustrated in Figure 18.1. Upstream

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construction methods for taconite tailings basins are common in Minnesota. Upstream construction raises the dams in stages as the tailings volume and thickness increase. Each new dam is placed toward the interior of the basin, on top of a portion of the previously deposited tailings. Upstream construction is typically the lowest cost method of dam construction, mostly because it uses the least total volume of dam material, minimizing labor and material costs (Vick 1983). An environmental benefit of upstream construction is that it generally contains the tailings in a smaller area, minimizing ecosystem disturbance.

Although upstream construction is the most economical method of dam construction, it requires the most engineering effort to make it successful. Without proper engineering, upstream construction represents the most risky method of dam construction, because the hydraulically deposited fine tailings and slimes are used as the dam foundation. In fact, fine tailings and slimes may eventually be located below the crest of the dam at a significant depth below the surface. Dam safety could be compromised if the fine tailings and slimes are not allowed sufficient time for consolidation and pore pressure dissipation. For successful upstream construction, the performance of the dam and the characteristics of the tailings deposits must be carefully monitored, and the design adjusted according to the observed performance of the dams and the tailings within the foundation. This approach, of staged construction with performance monitoring before, during, and after the dam raises, is referred to as the *observational approach*.

The Observational Approach

The engineering, monitoring, and maintenance practices for safe upstream dam construction use what is known as the observational approach (Terzaghi and Peck 1967). The observational approach is a form of adaptive management that has been practiced and refined at taconite tailings basins in northern Minnesota for more than 50 years. In the observational approach, a design is developed using the most current data and then modified as appropriate, based on the actual performance of the dam and the tailings foundation.

Dams are raised using staged construction. With staged construction, a specific thickness, or lift, of dam construction material is placed over previously deposited tailings that have been allowed to drain, consolidate, and gain the appropriate strength. This sequence is repeated as the dams are incrementally raised to meet the storage requirements. Figure 18.2 shows a cross section of a typical taconite tailings basin dam constructed by staged upstream methods.

The harsh Minnesota climate can be used as an advantage for staged construction using upstream methods. If the previously deposited tailings that will be the foundation of the next stage are too soft to support heavy equipment, then the initial foundation lift can be placed during the winter, when the frozen ground allows

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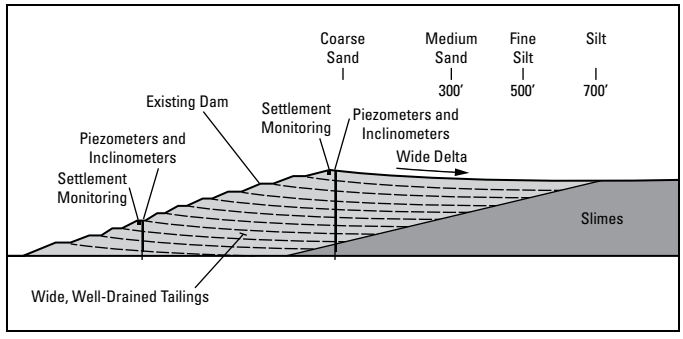


Figure 18.2 Typical taconite basin dam cross section

construction access for heavy equipment. When the ground thaws the following spring, consolidation takes place in the foundation beneath the completed lift.

The performance of the dam and tailings foundation is predicted before each lift, based on results of geotechnical testing and analysis. Predictions are made of pore pressure dissipation and strength, and the time needed to achieve the target values before the next lift. Similarly, the deformation or strain is estimated to properly predict the factor of safety against failure. The factor of safety is the ratio of the estimated strength of the structure to the design load. Then these same parameters (pore pressure dissipation, strength, strain, deformation) are monitored before construction, during construction as the dam is slowly raised, and after construction in preparation for the next lift. Over time, the iterative comparison of prediction and measurement has the effect of decreasing geotechnical uncertainty and improving predictions.

The observational approach is uniquely suited for tailings dams constructed by staged upstream construction methods because the tailings dams are constructed over decades and the rate of raising is slow, allowing ample time to collect data and evaluate the results. Formal documented performance reviews are conducted annually to confirm the design basis; to address the need for any additional testing, investigation, and analysis; and to incorporate any design modifications that may be required. Figure 18.3 illustrates the observational approach.

The observational approach requires that the original design of the dams incorporates provisions for "what ifs" as the dams are raised (Martin and McRoberts 1999). There must be options available to revise the designs and to safely store tailings in other cells if monitoring indicates that performance differs from predictions. For example, what if pore pressures do not dissipate at the expected rate, if strain rates increase, if piping develops, or if seepage impacts groundwater? Design provisions to address these problems may include enhanced drainage, seepage trenches, or relief wells along the downstream toe of the dams, additional buttressing, or

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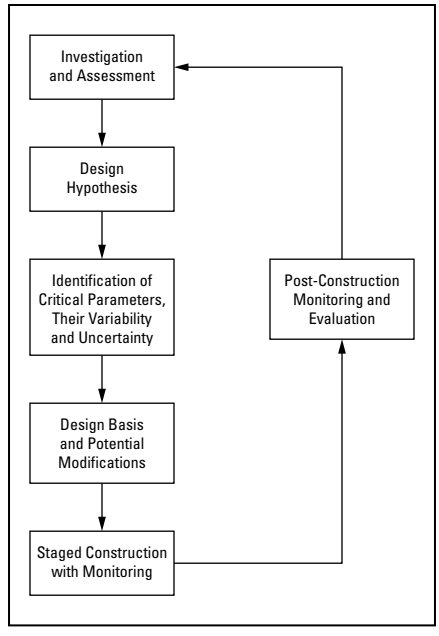


Figure 18.3 Observational approach

cessation of operations. Tailings basin designs that include multiple cells offer valuable flexibility to deal with "what ifs" in a safe and environmentally sound manner.

Monitoring, Testing, and Analysis

The observational approach relies extensively on monitoring, testing, and analysis. These activities must take place before construction, during construction, and regularly in the phases between lifts as a new tailings delta forms and drains. Monitoring and testing results are analyzed to verify dam design assumptions, plan timing of the lifts, and ensure dam safety. For example, results may identify the need for additional stabilization measures such as buttresses. Results can also be used to optimize performance. For instance, they may suggest the need for measures to accelerate the consolidation process, such as vertical drains (plastic flow channels encased in geotextiles) or surcharging (the temporary placement of a layer of fill to accelerate consolidation). The combination of instrumentation and regular geotechnical investigations to collect in situ measurements and samples for laboratory testing provides confidence in the data that is used to predict the performance of the dam. Performance is analyzed using sophisticated software that predicts the seepage, stability, and settlement and deformation (vertical and horizontal movements) of the dam as it is being constructed. The following paragraphs briefly describe monitoring, testing, and analysis using the observational approach.

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The main instruments used to monitor the dams are piezometers to measure pore pressures, inclinometers and alignment hubs to measure horizontal movement (deformation), and settlement plates to measure vertical movement. These instruments are installed at critical locations in the dams and then monitored frequently during and after construction to observe dam performance.

The staged construction procedure for upstream construction relies on piezometer readings to estimate when the next stage of construction can begin. Recently, pore pressure monitoring has been greatly enhanced by the use of fully grouted vibrating wire piezometers (Contreras et al. 2008). Consolidation is monitored by measuring the rate of pore pressure change in the tailings foundation during and after construction, and by measuring the settlement rate over time. As the dams are raised, the settlement/deformation is initially relatively rapid and the pore pressures initially increase. Over time, the settlement/deformation decreases and the pore pressures dissipate, as illustrated in Figure 18.4. The rate of pore pressure dissipation as measured by the piezometers is used to predict consolidation rates. The next stage of construction can take place when consolidation is more than 50% and preferably in the range of 90% complete.

Two types of testing are used, in situ and laboratory, to measure the geotechnical and hydraulic characteristics of the foundation, dams, and tailings. In situ geotechnical tests establish stratigraphy and correlate physical properties such as permeability, strength, and consolidation with the stratigraphic units. In situ testing is needed because of the heterogeneity within the actual deposits. In situ tests will typically include measurements for shear strength and pore pressure dissipation using devices such as piezocones, dilatometers, and vane and borehole shear instruments. The Cone Penetration Test (CPT) is useful for testing tailings in situ because it can measure parameters in very short intervals at low cost. The CPT can estimate the potential for contractive behavior that could lead to liquefaction and, as such, is especially useful at sites using upstream construction methods. See Dunnicliff (1993) and Lunne et al. (1997) for details on in situ geotechnical testing methods.

The geotechnical parameters measured in situ, such as material strength and permeability, are also tested in the laboratory using triaxial shear tests (consolidated undrained with pore pressure measurements), consolidation tests, and permeability tests. Laboratory testing augments the in situ measurements by testing the materials under controlled conditions so their physical properties (such as strength and permeability) can be correlated to conventional geomechanics behavior.

Monitoring and testing results are used as inputs to seepage and stability analyses. Seepage analysis develops a comprehensive understanding of the pore pressures and groundwater conditions within the tailings basin, and assesses how the groundwater conditions relate to dam stability. Seepage analysis uses results of piezometer readings, pond water level measurements, permeability data, and stratigraphic information. Seepage and pore pressure dissipation can be determined

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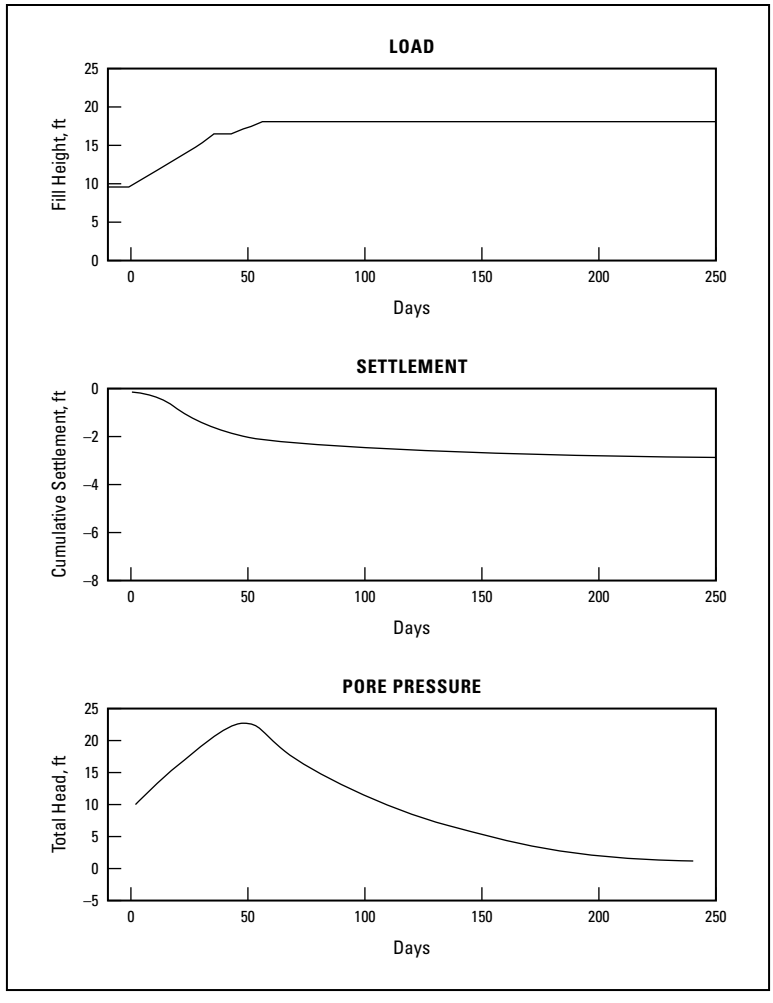


Figure 18.4 Relationship between load, settlement, and pore pressure

by monitoring, and predicted with calibrated models using the Darcy equation and analyses ranging from hand calculations to sophisticated flow models.

Stability analysis includes predictions of consolidation, settlement, and deformation; liquefaction triggering analyses; and shear/strain factor of safety calculations. Consolidation, settlement and deformation are predicted using models that can range from conventional hand calculations to sophisticated models. Recently, deformation-based analyses are being used to predict movements that ultimately lead to failure. These are especially useful since monitoring frequently involves inclinometers that can measure very small movements as a precursor to a failure, and these can then be calibrated to the deformation models. Other issues are hydrostatic uplift and

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piping. If analysis indicates potential for hydrostatic uplift or piping, then the dam design can be modified to include additional drains and filters.

Liquefaction triggering evaluations may be performed because of the potential contractive behavior of the fine tailings and slimes that form the base of the upstream constructed dam. Liquefaction can be triggered seismically, which is not a significant issue in Minnesota, but it could also be triggered by stresses during construction. If construction takes place too rapidly, excess pore pressure in the tailings foundation could cause monotonic liquefaction of contractive tailings layers.

Factors of safety are calculated using results of the seepage analysis together with the appropriate material strength parameters. The appropriate material strength parameters are determined using results of laboratory and in situ testing. Both the drained shear strength and the undrained shear strength of the dam materials are used in the calculations. The liquefied strength is calculated for contractive materials that have the potential to liquefy. Factor of safety is then modeled for drained, undrained, or liquefied conditions, as appropriate. Typically, deformation and/or limit equilibrium analytical methods are used to determine the factor of safety.

Factors of safety are used in several contexts. First, the overall dam is designed to achieve a chosen factor of safety. In Minnesota, dam safety regulators require that taconite tailings demonstrate a factor of safety for stability greater than 1.3 (using limit equilibrium methods of analyses) during construction and operations. The frequent observations and monitoring during operation have established that a factor of safety of 1.3 is protective for most taconite tailings dams. A higher factor of safety, usually in the range of 1.5, is necessary for long-term conditions at closure.

Factors of safety are also used as action limits during construction. As mentioned previously, the potential for liquefaction will increase if the pore pressures are not allowed to dissipate and consolidation to occur before the next lift is placed. Typically, action limits are placed on the pore pressures so they do not exceed a specific pressure during construction. A factor of safety of 1.3 is a typical action limit, and a factor of safety of 1.0 or less is unacceptable. If monitoring shows that consolidation is slower than anticipated or that conditions approach the factor of safety action limit, then additional vertical drains may be installed (such as "wick" drains) to accelerate the consolidation process and thereby maintain the target factor of safety and meet the anticipated staged construction schedule.

Finally, experience and engineering judgment are vital components in monitoring, testing, and analysis. Monitoring system design, sampling strategy, and analytical method selection are informed by experience at similar facilities. Performance is compared to similar case histories to properly evaluate dam safety. Engineers use all the available information in an iterative fashion, through the observational approach, to continually refine the design and the construction schedule. During this process, contingency plans are prepared so that alternative areas

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for dam raises and tailings deposition are available if the analyses show suitable conditions are not yet present for the next scheduled lift.

TAILINGS TRANSPORTATION AND DEPOSITION

Tailings transportation and deposition is a managed sedimentation process. The first step in tailings transportation is typically the separation of the coarse tailings from the fine tailings and slimes. Coarse tailings are typically separated at the processing plant and then transported to the basin for dam construction via truck and in some cases rail or pipeline. Fine tailings and slimes are usually transported to the tailings basin via slurry pipelines, even in very cold weather. In general, transportation of fine tailings by pumping (usually as a slurry) is the lowest-cost alternative, versus conveyor, truck haul, or rail. Methods are currently being developed to transport tailings as much thicker slurry or as a paste.

Design decisions regarding transportation and deposition of tailings present opportunities to achieve positive social and environmental outcomes by minimizing energy use and by enhancing dam safety. Economic considerations include cost and reliability.

Tailings Transportation

Pumping the tailings from the concentrator to the tailings basin is energy intensive and one of the major ongoing costs associated with tailings disposal. It is often necessary to pump tailings a considerable distance and to considerable heights, because geographic and environmental considerations often prevent the tailings basin from being located adjacent to the concentrator and also because the tailings basin increases in height and area over time. As a result, the energy and cost for pumping the tailings slurry is a major consideration in development of a tailings basin. Opportunities for energy savings and cost reductions involve maximizing the use of gravity flow and proper engineering evaluation of the pumping systems.

The slurry in the pipelines is typically the fine tailings and slimes mixed with water at between about 30% and 45% solids by weight. If a thickened or paste tailing is pumped, it is generally less than about 70% solids. Sizing the pumps and pipelines to accommodate a specific percentage of tailings solids is critical. A system that is undersized will require more energy to pump the same volume of tailings with greater velocity as compared to an ideal-sized system. A system that is oversized will need greater quantities of water to maintain a minimum velocity to avoid settling of tailings in the pipe and will upset the water balance in the basin. To optimize the system, multiple pumps and pipelines are used that can be controlled to accommodate the desired flow rate and percentage tailings solids.

Centrifugal and positive displacement pumps are used for transporting tailings. Pump choice depends on the hydraulic head of the system, the desired flow

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rate, and the "stiffness" of the tailings (yield stress, measured in units of force per area). In general, centrifugal pumps are best suited for relatively low heads, high flow rates, and tailings with lower yield strength. Positive displacement pumps are best suited for high heads, lower flow rates, and tailings with higher yield strength.

Centrifugal pumps are suitable for heads in the range of 690 kPa (100 psi), and can be staged in series to achieve higher pressures in the 4,000 to 5,500 kPa (600 to 800 psi) range. They are usually used when the yield stress of the tailings is less than about 50 to 100 Pa (0.007 to 0.015 psi). In general, centrifugal pumps have lower efficiency as compared to positive displacement pumps, but they are simpler to operate, with lower capital and maintenance costs. Centrifugal pumps are usually more economical for large volumes (McElvain 1973).

Positive displacement pumps are considered for low flow rates and for heads above 3,500 kPa (500 psi). They are usually used when the yield stress is greater than about 50 to 100 Pa (0.007 to 0.015 psi). Advantages of positive displacement pumps are their ability to produce high pressures and their relatively high efficiency. Disadvantages include the high capital cost and high rate of wear on internal parts. In general, capital and maintenance costs will be high, but power costs will be lower (McElvain 1973).

The pipelines used for transporting tailings are designed to meet the pressure requirements for the pumps. Further, because tailings pipelines are usually aboveground, their operating life can be extended by rotating them periodically (greater wear usually occurs along the bottom of the pipe). Also, aboveground pipelines can potentially freeze if there is a shutdown during the winter. Therefore, pipelines are usually installed on a slope so that if an upset occurs, they can be drained quickly before they freeze. Heat balances in the pipeline and basin must be understood to manage tailings transportation and deposition in cold weather.

Tailings Deposition

Tailings deposition systems use the natural sedimentation characteristics of the tailings. Larger particles are deposited on a wide delta, and finer tailings and slimes are carried to the edge of the delta where they settle out in the tailings basin pond. The delta of coarser particles creates a stable foundation for upstream construction of the dams, promotes dam safety, and results in lower costs. The fines and slimes must be deposited as compactly as possible to minimize the overall basin size and the consolidation time before future dam raises. Over time, the tailings solids raise the delta elevation and the slimes raise the water elevation such that the dams need to be raised. Deposition points are rotated around the basin as needed to raise the delta evenly. The slope of the delta and the volume of water within the basin govern the need for dam raises.

Deposition is generally by spigots along the dam crest or from a single discharge in the upper portion of the basin. Spigotting forms a wide, well-drained

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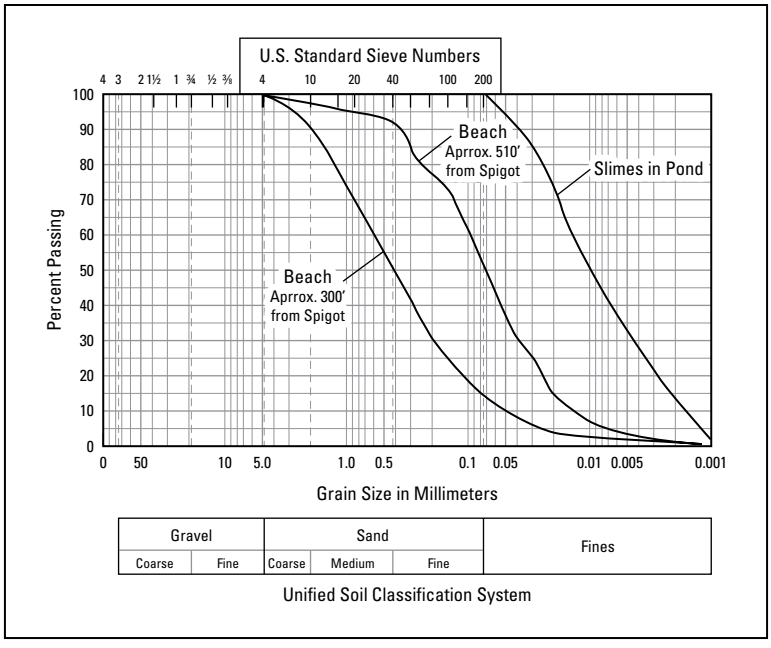


Figure 18.5 Typical taconite tailings basin grain size distribution profiles

tailings beach along the upstream portion of the dam. The beach is commonly 60 m (200 ft) wide or wider to allow the tailings to build a delta and to minimize seepage. During winter, the pumping distance should be minimized to prevent freezing within the pipes, and the return pumping structure should be close to the discharge to minimize freezing on the delta.

The geometry of the taconite tailings delta is primarily a function of the percentage of solids within the tailings, the grain size (assuming similar specific gravity), and the water elevation within the pond. In general terms, the coarser particles settle out closest to the discharge and assume a steeper slope as compared to the finer tailings deposited further away from the discharge. The overall tailings slopes are relatively flat, on the order of less than 2% and usually greater than 0.5%. At the water edge, the slope steepens as the delta moves forward into the pond where the tailings settle quickly through the water. In the pond, the fine tailings settle sooner, and the slimes are carried with the density currents and settle along the bottom of the pond. As a result, in general, the subaerial deposition of tailings is flat (less than 2%), the initial subaqueous deposition is relatively steep on the delta fore-set, and the subaqueous disposal of the slimes along the bottom is very flat. Figure 18.5 shows how the grain size varies across the delta at one of the taconite tailings basins in Minnesota.

Managing the volume of the fines and slimes deposits is challenging, especially those deposited subaqueously that will be a future foundation for upstream

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construction. Typically, the subaqueous-deposited tailings form loose deposits, composed of approximately 50% water by volume. Studies are underway on potential methods to achieve a higher density of tailings and thereby increase the available space within the basin. Options include using nonsegregating deposition techniques such as additional thickeners, filter centrifuges, and tremie diffusers.

TAILINGS BASIN OPERATIONS AND MAINTENANCE

Operations and maintenance practices include regular inspection, monitoring, and evaluation to document dam stability and environmental performance. In Minnesota, dam safety regulations require regular safety inspections, monitoring, recordkeeping, and reporting. Routine dam inspections occur daily and weekly, recording observations on any evidence of change indicating subsidence, structural deformation, instability, erosion, piping, unexpected seepage, or any other unusual conditions. Formal dam safety inspections occur at least annually. For a typical dam safety inspection, the design engineer conducts an on-site review where the entire dam is visually examined (both upstream and downstream), the monitoring and geotechnical data are summarized and evaluated, and the critical areas are analyzed to make sure that the dam meets performance criteria. The review is formalized in a report that is presented to the owner. The report includes a photographic history of the dam and recommendations for any modifications and operational revisions for the upcoming year.

For tailings dams with staged construction by upstream methods, ongoing evaluations also include monitoring performance related to consolidation, settlement/deformation, and pore pressure dissipation as part of the observational approach, previously discussed. The observational approach also makes use of the information collected for dam safety inspections.

Environmental monitoring typically includes evaluation of the quantity and quality of any discharge to surface water (as required by the NPDES/SDS permit). Monitoring wells are often installed outside of the perimeter of the basin to monitor any impact to groundwater from seepage. Visual observations of dust emissions are made daily, and, in some cases, ambient air monitoring of particulates is also conducted.

Dust control is an important part of operations and maintenance—important environmentally and to the quality of life in local communities. To reduce dust, permanent vegetation is established as soon as possible (progressive reclamation) and temporary cover is applied in other areas. On the exterior dam slopes, dust is suppressed through progressive reclamation (discussed later in this chapter). In the interior of the basin, dust is suppressed by alternating discharge points, temporary inundation, or placement of temporary cover.

Maintenance includes monitoring vegetation and removing any volunteer trees that take root on dam slopes. Trees on dams are undesirable because they can make

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it difficult to observe erosion and other problems; they provide cover for burrowing animals; their roots can provide preferential pathways for internal erosion after the tree dies; and if the tree is blown down, the scarp created by its root ball can trigger erosion.

Successful operations also include formal long-range planning processes. Most taconite tailings basins have a detailed 1-year plan, a more general 10-year plan, and a life-of-mine plan. Over time, information from ongoing monitoring, processing experience, and geotechnical evaluations is used to continually refine these plans. Use of such data decreases geotechnical uncertainty over time and allows the ongoing tailings basin design, construction, and operation to benefit from actual experience.

TAILINGS BASIN WATER MANAGEMENT

Water management centers on detailed understanding of the overall site water balance. Taconite tailings basins not only store tailings, they also serve as reservoirs for the water used in ore processing. Water carries the tailings to the basin, then clarified pond water is recycled to the plant for use as process water. Water management affects sedimentation on the tailings delta, the rate that dams must be raised, and the stability of the dams. There are several objectives that must be balanced when designing tailings basin water management features. Environmental and social objectives include ensuring stability and overall dam safety, minimizing impacts to nearby surface water and groundwater, reducing ecosystem disturbances, and minimizing visual impacts. Water levels in the basin must be carefully managed not only to provide adequate process water, but also to meet dam safety requirements, avoid surface discharge, and create tailings deposits that allow dam construction consistent with the overall tailings management plan. This section discusses strategies for minimizing discharge of water from tailings basins and limiting water consumption. It outlines water balance calculations and describes the importance of a makeup water source.

Taconite tailings basin water management systems are generally designed to make the basin as small as possible, to recycle process water, and to limit surface discharge. Smaller basin footprints not only reduce ecological disturbances, they also reduce land acquisition cost and offer greater design flexibility at the plant site.

Recycling water between the processing plant and the tailings basin limits the need for makeup water and minimizes the amount of water that must be stored. Using recycled water is necessary because surface water appropriations are usually limited, and permit requirements typically limit discharge of water from the basins into the environment. However, water recycling tends to degrade basin water quality over time, so the chemical balance in the recycled water must be monitored. Makeup water must be added as needed to maintain the concentration of salts,

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total dissolved solids, and other constituents at acceptable levels for use as process water and to minimize impacts to water resources.

Surface discharge from the tailings basin is prevented under normal operating conditions, and, at most, limited to controlled releases under extreme conditions. Limiting surface discharge minimizes potential environmental impact to surface water and meets social expectations because some stakeholders have come to consider zero discharge as a standard, no matter how clean the basin water is. Overall, minimizing discharge requires careful management of the tailings basin water balance.

The tailings basin water balance must be accurately estimated to design a tailings basin that can meet water management objectives. Water inputs come from makeup water and runoff. Runoff from the tailings basin watershed is the difference between the precipitation and evapotranspiration over the area of the watershed. Within the basin, evapotranspiration depends on vegetation, the amount of active delta, and the temperature of the water coming out of the plant. Because precipitation slightly exceeds evaporation in Minnesota, water can accumulate in the basin. However, during a drought or when the basin is frozen, there may be a shortage of water.

Methods to estimate runoff have evolved over the past decades. Early methods used average annual runoff measured at U.S. Geological Survey streamflow gauging stations, adjusted for watershed-specific factors such as geology, vegetation types, and percentage wetlands. The design of many Minnesota taconite tailings basins relied on runoff estimates calculated using the Meyer method, which uses standard Weather Bureau data and a monthly time step. Currently, there are many choices for modeling runoff, even on a daily basis (e.g., GoldSim and METSIM). Whatever model is used, it should reflect the wide variation in runoff and be flexible enough to model watersheds that are undergoing major changes.

Water outputs include consumption during processing, seepage, and water trapped in the voids of the tailings deposited in the basin (Figure 18.6). Plant consumption should not be confused with the circulating water, most of which is reclaimed and recycled through the process. Actual consumption is limited to evaporation from ore processing. The most evaporation takes place in the pelletizer. Originally, it was assumed that evaporation from the pelletizer could be estimated as the change in moisture content of the pellets multiplied by their mass. Now, more accurate estimates are made using direct measurements of air flow and moisture in the pelletizer stacks collected during stack testing associated with environmental monitoring. The best estimating method likely varies from plant to plant depending on design details.

Estimates of plant water consumption must take into account intermittent flows and plant availability. Many of the water flow rates shown on typical plant construction drawings are intermittent. This may include sprays at the crusher

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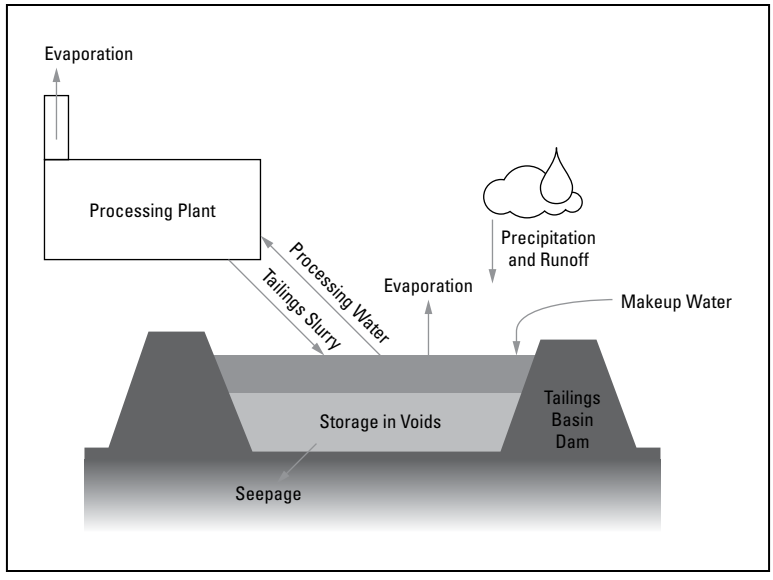


Figure 18.6 Tailings basin water balance

and the load-out bins, water trucks, and so forth. More importantly, the surplus from these sprays may find its way to the tailings basin, never having left the basin watershed at all. Therefore, these sprays do not necessarily indicate consumption, and they should be tracked to their ultimate destination. Water balance calculations must also factor in the actual plant availability, including shutdown periods.

Water is also lost to seepage through or under the perimeter dams and through the bottom of the basin. Seepage will often appear downstream of the dam and would be expected to decrease after basin closure. Deep seepage to lower aquifers may also occur. The amount of water lost to seepage can vary significantly, depending on site geology, the nature of the tailings, dam design, use of liner materials, and seepage recovery systems. At the taconite mines in northern Minnesota, seepage typically is on the same order of magnitude as plant consumption.

A significant loss to the system is the water trapped in the voids of the tailings deposit. Because of the way fine tailings and slimes are deposited, the porosity in the center portions of the basin may be as high as 50%. It is typically assumed that the entire tailings deposit is saturated. The amount of water in the voids is generally larger than the plant consumption. It is in permanent storage and no longer available for plant use. Water storage in the voids is mainly a function of the production rate, so it varies less from site to site than does seepage, which is a function of geology and tailings basin construction. Of course, a thickened tailing will reduce the amount of water trapped in the voids.

Water balance issues specific to the climate at the site must also be considered. For example, in arid climates, evaporation may result in greater water losses. In

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northern climates, ice formation is a significant temporary water loss from the tailings basin. On the Minnesota Iron Range, ice formation can be several meters thick on ponds. Even thicker ice deposits can develop on tailings deltas where the circulating water flows over the surface of previous delta ice deposits. During the winter, most Minnesota operations deal with the ice issue by seasonally discharging through a pipeline running to a deep-water portion of the tailings basin. Other approaches include accumulating additional water in the basin in the fall, using a shorter or more direct route through the tailings basin to the reservoir, and having outside water sources available as an emergency supply in the winter.

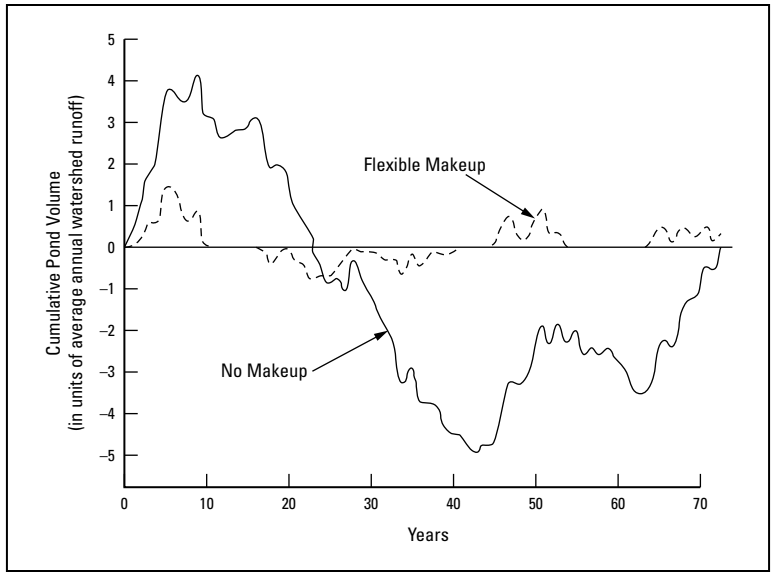
Having considered each of the water inputs and outputs individually, a design for a satisfactory water balance can be determined. The outputs of plant consumption and loss to voids are very constant unless there are production changes. Seepage losses vary but can be managed by operating a seepage return system. A seepage collection-and-return system may include ditches to intercept seepage or flowing relief wells to relieve water pressures just beyond the dam toe. Liners and containment for seepage are not practiced at taconite facilities in Minnesota due to the age in which they were constructed.

In contrast, the primary input—the runoff— is highly variable. In northeast Minnesota, runoff may vary from approximately 0 to 50 cm (20 in.) per year over a 100-year period. Runoff variability resulting from climatic conditions is not controllable, but long-term average runoff is primarily determined by the size of the basin watershed. Runoff can also be affected by choice of vegetation and the size of the wet delta. Minimizing the size of the tailings basin watershed can help control runoff variability.

Climactic variability and potential plant shutdowns create tension between the need to supply adequate process water, the desire to keep the basin as small as possible, and the goal of limited surface water discharge. A very large basin would be needed to accumulate enough water to support processing during a drought and over winter months. A large basin would also be needed to hold runoff, since annual precipitation exceeds evaporation by approximately 15 cm (6 in.) on the Iron Range, and to hold water from spring snowmelt, major storm events, or during shutdowns.

The solution to balancing the tailings basin water management objectives is having a flexible outside source of makeup water. Access to a large and flexible makeup water supply gives operators the best control of the overall tailings basin water balance. Makeup water sources can include rivers, reservoirs, groundwater, old mine pits, and mine dewatering. Pumping from these sources can make up for drought periods while at the same time minimizing the volume of water that must be accumulated in the tailings basin. In some cases, the tailings basin watershed can also supply makeup water. If a tailings basin has an upper tributary watershed, then a diversion system can direct runoff into the tailings basin during droughts

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Source: Adapted from Skoglund and Hanson 1979.

Figure 18.7 Tailings basin water balance example with and without makeup water

and away from it during wet periods. For makeup water strategies to work, there must be a coordinated plan among the various stakeholders within the watershed.

The usefulness of a controlled makeup water source and a smaller watershed can be seen in Figure 18.7, which was developed for a hypothetical operation on the Minnesota Iron Range (Skoglund and Hanson 1979). Over a 73-year period, the estimated average annual runoff was approximately 20 cm (8 in.) with extremes of 0 and 53 cm (21 in.). The "No Makeup" line shows pond volume fluctuation for a hypothetical operation where average runoff is just balanced by water losses and no makeup is used. The maximum variation in pond volume is equal to 9× the average annual runoff, requiring significant basin storage and presenting a problem in accumulating sufficient start-up water. Pond volume fluctuation for the same operation, analyzed with the watershed size reduced 25% and a makeup water system added, is shown by the "Flexible Makeup" line. System outputs (plant loss, loss to voids, and seepage) are all subtracted from runoff in this example. Makeup is then added, based on water balance needs and the physical restrictions on makeup rates. Cumulative net surplus or deficit in the pond volume is determined for each year. Assuming that makeup can be varied from zero to twice the average required rate, pond volume fluctuation is reduced to 2¼× the average annual runoff for the original watershed. This illustrates the flexibility gained by reducing the tailings basin drainage area and using a variable outside makeup water source. It also shows how the pond volume would fluctuate widely between dry and wet periods in a system without a makeup source.

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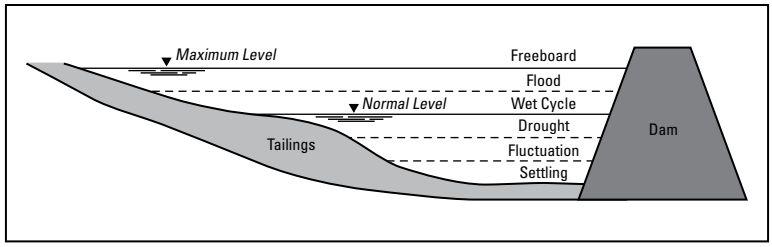


Figure 18.8 Tailings basin water storage

On the Iron Range, minimum surface water discharge systems are possible if basins are designed with no excess watershed and a large annual tailings deposition thickness. Because taconite tailings deposits are approximately 50% water by volume, annual deposition of 30 cm (12 in.) of tailings will effectively store 15 cm (6 in.) of annual runoff.

The previous discussion covered long-term accumulations or shortages of water in tailings basins. The following discussion covers shorter terms, such as storms of less than a day to droughts of 5 to 10 years. The relative tailings basin volume needed to manage short-term water variability is illustrated in Figure 18.8. To begin, a tailings basin must have a minimum volume of storage available to provide for deposition of tailings and settling out the fines. In addition, there must be enough water to maintain that minimum settling volume despite the fluctuations caused by the seasons and by the daily variability in precipitation. Also, unless there is access to an alternative makeup water source, there must be enough capacity to store water against a multi-year drought. At this point, we are at the desired water level. Additional storage must be available in case of a wet cycle. Further storage volume must be maintained in case of an extreme short-term storm. Finally, there should be adequate freeboard to prevent waves from overtopping while efforts are made to recover from a wet cycle or extreme precipitation.

Availability of makeup water and design features to manage pond level fluctuation also have implications for dam construction and dam safety. If the water balance is positive, the dams will have to be raised faster. Furthermore, water levels must not be allowed to rise such that thick layers of slimes are deposited against the dam (because that will adversely affect stability) or such that water overtops the dams during flood conditions (or wet climatic cycles). If the water balance is decreasing, water must be added to allow the tailings to settle and the water to clarify for recycling back to the plant (especially during dry climatic cycles). These considerations are examples of the close coordination that is needed between water management, tailings deposition, and dam construction.

In reclamation and closure, considerations for water management focus on managing potential overflow. In Minnesota, where precipitation minus evaporation is slightly positive, overflow following closure will occur. Overflow can be limited

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by minimizing the size of the watershed; however, in most cases, it is necessary to have a permanent outlet from the basin in closure. Postclosure efforts to prevent erosion of the tailings typically include revegetation and maintenance of small settling basins at the outlet.

EMERGING TAILINGS STORAGE METHODS

Most emerging tailings storage methods, such as paste tailings storage and dry stacking, are designed to minimize the amount of water deposited with the tailings and make the tailings deposits more compact. In general, these methods add process steps to dewater the tailings, recover the water, and recycle the water back to the concentrator. These methods are expected to produce environmental benefits such as reduced water use, reduced energy use for heating process water, smaller tailings basin footprints, reduced impacts to groundwater and surface water, and improved dam stability. These techniques are not yet widely practiced because they cost more up front than hydraulic tailings deposition (additional expense to dewater the tailings) and because some of the technical issues related to transportation and deposition of the dewatered tailings are still being optimized. Some of the dewatering cost can be recouped through energy savings if tailings are dewatered near the concentrator and the warm water is recycled.

Water is removed from the tailings using thickeners or cyclones. Research for confidential clients indicates that if the fine and coarse tailings are separated, then the fines can be dewatered to a paste of about 60% to 75% solids (by weight) and pumped through pipelines to a tailings basin (Barr Engineering, personal communication). Pipelines appear to be the least costly method to transport paste tailings. Technical issues still under development include selecting the appropriate grain size for separation, determining the solids content for disposal, and predicting the resulting slope of the tailings delta. Coarse tailings may be either stacked and dewatered by gravity, or transported by truck or rail to the tailings basin for use in building dams. Methods to dewater the coarse tailings are also emerging, especially in cold climates where the water may freeze with the stacked coarse tailings before it can drain.

Paste storage and dry stacking have shown special promise for arid regions, but historically there have been few incentives for their use at Minnesota taconite facilities, where there is generally an adequate water supply and sufficient space for tailings basins, and where the tailings settle well. However, recent emphasis on energy recovery, water treatment, wetland mitigation, and water appropriation have made paste or dry stacking thickened tailings a more viable option in Minnesota. Another emerging method being explored for taconite tailings is alternative discharge technologies, such as the tremie diffuser, that reduce the grain size segregation in the tailings deposits. The objective of the tremie diffuser, or other alternative discharge methods, is to reduce the velocity of the tailings at the end

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of the pipeline, allowing the fines to settle within the matrix of the coarse tailings. If the fine and coarse tailings are less segregated, the tailings deposit will be more dense and compact. This offers advantages in terms of reduced storage volume requirements and improved dam stability. Other tailings storage methods under consideration in Minnesota (primarily for future copper nickel mines) include placing tailings in inactive mine pits or returning tailings to underground mines.

TAILINGS BASIN RECLAMATION

Reclamation is not an afterthought. Reclamation planning begins during initial tailings basin design so that design decisions consider the ultimate long-term uses of the land and water resources. In Minnesota, the Mineland Reclamation Act requires that a reclamation plan be developed to obtain a permit to mine from the MDNR, and it provides the statutory authority for the Taconite and Iron Ore Mineland Reclamation Rules (Minnesota Administrative Rules 2013b). Reclamation of the taconite tailings is accomplished by sloping and grading the tailings dams to design specifications and then establishing vegetation over the tailings to control erosion, suppress dust, and provide an attractive area compatible with future land use. Vegetation creates habitat, controls erosion and dust, provides phytostabilization and sometimes phytoremediation, and influences the tailings basin water balance.

It is essential that reclamation be carried out incrementally as the mining progresses. This is generally more economical, because reclamation can occur when the mine is making money, leaving less work and expense for reclamation at final closure. In Minnesota, progressive reclamation is required on mining areas no longer scheduled to be disturbed, and experience shows that the greatest benefits are gained by reclaiming as soon as possible. During operations, exterior slopes should be permanently reclaimed following each dam lift, and inactive beaches should be provided temporary cover. Progressive and permanent reclamation improves dam safety by preventing erosion and lessens environmental impacts of the tailings basin by controlling runoff and suppressing dust.

Dust is especially problematic in spring and fall. On the Mesabi Iron Range in early fall and in late winter, the days are quite warm with bright sun but the nights are freezing. If there is no snow, the exposed tailings surfaces thaw during the day and freeze again at night. This freeze–thaw cycle loosens a very thin layer of tailings, and wind may cause a dust lift-off from a tailings basin. Good dust control through vegetation and temporary cover is very important during freeze–thaw cycles.

Permanent Reclamation

Permanent reclamation starts on the exterior slopes of the perimeter tailings dams. It is most desirable to do this reclamation as the dams are constructed and

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is favorable for upstream dam construction. Permanent reclamation is the least expensive in the long run and reduces dust and erosion. As the basin continues to rise, subsequent back slopes must be vegetated with a permanent cover that meets reclamation standards. Vegetative cover has proven to be an effective method of stabilizing the surface of taconite tailings basins. Low-forming vegetation, such as grass and legumes, has been most effective. Although trees might be valuable as a windbreak and appealing to wildlife, Minnesota regulators strongly discourage planting them on tailings basin dams because when they die they could weaken the dams.

Reclamation includes contouring, fertilizing, selecting the plant mix, seeding, and mulching. Dam slopes are usually built to an overall slope of about 3H to 1V or flatter. However, with upstream construction, the intermediate slopes between benches are sometimes steeper. The advantage is that when the intermediate slope is completed, it can be reclaimed. Topsoil or cover soil are generally not provided since the tailings themselves—once fertilized, seeded, and mulched using proper techniques and maintenance—are able to sustain vegetation.

Early on, the tailings should be analyzed to find out what elements are present, those needed for vegetative growth and any others that may be detrimental to vegetation. It is also important to measure the pH of the tailings since this will influence plant selection. Taconite tailings are inherently low in nitrogen and phosphorus, and tend to be alkaline with pH of around 8.0. As a result, fertilizer must be applied to grow a satisfactory cover of vegetation. A good supply of nutrients can be provided by the use of commercial fertilizer or by using biosolids obtained from water treatment plants. Biosolids have been very effective in plant establishment on tailings slopes; usually 100 to 200 lb nitrogen are applied per acre (110 to 220 kg per hectare). The amount of fertilizer depends on the need as shown in the tailings analysis. The fertilizer or biosolids should be worked into the slopes to mix the nutrients into the tailings. Biosolids application must follow specific environmental regulations for land spreading (e.g., the amount of nitrogen applied is generally limited), and they must not be applied close to wetlands.

Reclamation seed mixes use combinations of native and introduced species chosen to grow well on tailings and provide an attractive area compatible with future land use. The seed mix should be selected to produce good early cover and long-lived attractive vegetation. Use of indigenous plants could provide ecosystem benefits, but to date in northern Minnesota, native species generally have not proven able to meet reclamation performance requirements, particularly the need to grow well in crushed rock and completely cover the tailings in less than one growing season. Much work has been done to identify plant species that are adaptable to growing well in taconite tailings. In the early days of mine reclamation, more than 100 plant species were tested. Experience shows that there are many

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Table 18.2 Species used in seed mixes for taconite tailings permanent reclamation

Type of Cover	Species
Nurse grasses	Annual rye, oats, wheat, winter wheat (best choice varies by season)
Permanent grasses	Big bluestem*, bluegrass (Canada or Kentucky), brome grass (meadow*, fringed* or smooth†), Canada wild rye*, little bluestem*, poverty oat grass*, red fescue, redtop, side oats grama*, switch grass*, timothy, wheatgrass*
Nitrogen fixers	Alfalfa, birdsfoot trefoil†, clover (red, alsike, white†, sweet†)

*Native to Minnesota.
†Currently on the Minnesota invasive species list.

commonly used introduced plant species that will produce good early cover and reduce the repair of eroded dam back slopes. Although Minnesota regulators have accepted that non-native species are needed for successful reclamation, they have identified certain species as invasive and produced guidelines aimed at meeting the goals of mineland reclamation without promoting invasive species on a large scale (MDNR 2012).

Reclamation seeding mixes are similar to a good pasture mix, consisting of a fast-growing nurse crop, several legumes or clovers, and several permanent grasses. The nurse (or cover) crop provides short-term cover to reduce erosion and protect the perennial seedlings as they are establishing. The legumes or clovers provide the nitrogen needed by the other types of vegetation. When legumes or clover are planted, their seeds or the slopes should be treated with nitrogen-fixing bacteria. This can be done using a hydroseeder. Examples of species that can be blended to create a reclamation seed mix are shown in Table 18.2. The MDNR offers general recommendations on the composition of the seed mix and discusses potential species substitutions driven by site characteristics, seed cost, and seed availability (MDNR 2012).

The timing of the planting is very important. Mid-May through early June is usually a good planting season because there is usually enough precipitation to promote germination. Fall planting is possible, but any legumes or clover should be planted by mid-August so they will be hardened off before hard frosts. Right after the seeding is done, the seeded area should be covered with mulch. This will allow the tailings to retain moisture, keep the planted area cooler, and reduce erosion on the newly planted sites. Hay or straw are economical mulches that can be blown on the planted area. The area should then be disced with a lightweight slotted disc. This will anchor the mulch into the tailings and reduce the loss of mulch due to heavy winds. Hay or straw mulch has also been applied by helicopter to cover areas where ground equipment cannot be used. Figures 18.9 and 18.10 illustrate fertilizing, seeding, and mulching during taconite tailings dam reclamation. Figure 18.11 shows an exterior slope of a tailings basin dam, taken approximately 40 years after planting with a standard seed mix. It shows dense vegetative cover with some tree invasion.

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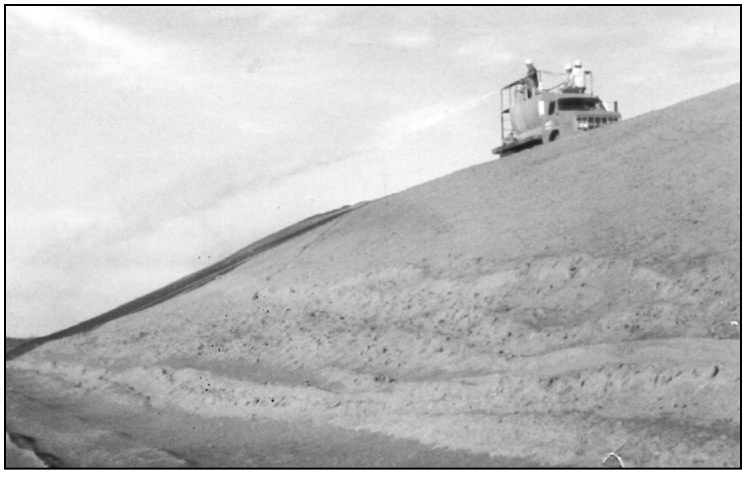


Figure 18.9 Hydroseeder broadcasting fertilizer or seed mix



Figure 18.10 Mulching the backslope with straw

Temporary Cover

The central tailings basin needs temporary cover because the area is usually too wet to support ground equipment and because it cannot be permanently revegetated until tailings deposition is finished. To prevent windblown dust, temporary cover must be applied to beaches that are not receiving active tailings deposition. As tailings deposition progresses, the discharge points are rotated around the basin and the temporary cover will be buried beneath additional tailings layers as the overall height of the tailings basin increases.

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Figure 18.11 Exterior tailings basin dam slope approximately 40 years after reclamation

Temporary cover can be planted in late winter, while the frozen tailings can still be worked with ground equipment. Since the tailings are frozen, the seeds can be covered with mulch, which aids in seed germination. Annual plants can be used because the plants will only be needed for a year or so. Annuals also need less fertilizer, which is an advantage because it is important to minimize use of fertilizer within the basin. Annuals that have been successfully used for temporary cover in taconite tailings basins include barley, rye grain, millet, oats, and wheat. These plants also provide food for migrating waterfowl, which are attracted to tailings basins. Figures 18.12 and 18.13 show how temporary cover can make the interior of the tailings basin attractive to wildlife.

In areas where no planting can be done, hay or straw can be used as temporary cover to suppress dust. They can sometimes be applied with ground equipment, or a helicopter can be used in places that will not support ground equipment.

Use of Trees

Trees are effective in reducing the speed of the wind and work well in shelterbelts. Trees can also be used to screen operations and to provide wildlife habitat during operations and after mining ceases. In Minnesota, regulation prohibits planting trees on dams, so most forest shelterbelts need to be located outside of the pond area in permanently inactive portions of the basin. Trees should be planted only where water levels are not so close to the surface that they will inhibit tree growth.

Shelterbelts should include a variety of conifers and deciduous species that are hardy to the area. Conifers have the best resistance to wind; however, they generally prefer soil pH values ranging from 5.5 to 7.0, and so can be more sensitive to the higher pH tailings. Some selected hardwoods tend to grow faster than conifers

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Figure 18.12 Waterfowl over an active tailings basin, showing temporary cover of rye grain, barley, or millet



Figure 18.13 Temporary cover in active tailings basin creates a habitat for white-tailed deer

and tolerate the tailings soils. Plants that are subject to browsing by wildlife are not desirable. In northern Minnesota, useful trees for reclamation include tamarack, red pine, white spruce, balsam fir, balsam poplar, white birch, and hybrid poplar. Experience also shows that some native woody species will volunteer onto established reclamation sites. Examples include willow, aspen, balsam poplar, and paper birch. It is important to use a good variety of trees so shelter belts are resilient against insects, diseases, and climate extremes.

Trees are usually planted in rows at right angles to the direction of prevailing winds. This maximizes wind control on the basin and causes any dust to be

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deposited on company-owned property rather than carried to adjoining lands. Rows of trees are usually about 2.5 m (8 ft) apart, and trees are planted about 2 m (6.5 ft) apart in the rows. Eight rows are often used for a shelterbelt, and multiple shelterbelts can be planted if needed. Nutrients must be added to promote tree growth. Biosolids work well where available. Fertilizer pellets can also be used. Nutrient needs should be considered during planting, and plantings should be laid out with sufficient space to refertilize and maintain the trees.

Reclamation of the Pond

Upon closure, the basins are dewatered. Modification of existing basin reclaim structures or construction of new outlets allows the basin to dewater and the pond volume to stabilize at a greatly reduced level. The tailings settle and consolidate as the basin dewaters. Giving some thought to closure during the original design leads to improved closure outcomes.

One example of pond reclamation at a tailings basin pond in northern Minnesota used biosolids mixed with the dewatered tailings to promote vegetation. After closure, this basin now produces good hay. This is especially beneficial because two materials that are individually considered wastes (tailings and biosolids) are converted into a quality material for growing hay or other vegetation.

CONCLUSION

The observational approach—an adaptive engineering practice that links dam design, staged basin construction, tailings deposition, and water management through regular monitoring, testing, and analysis—has been the foundation of responsible and successful taconite tailings management in northern Minnesota for more than 50 years. The methods developed for taconite tailings disposal are adapted to the cold climate and net neutral to positive water balance of the Mesabi Iron Range. But the observational approach that makes them successful can be adapted to improve social, environmental, and economic outcomes for tailings basins in other regions.

Notably, the final reclamation of the taconite tailings basins in Minnesota will represent one of the first major reclamation projects of tailings basins in the world. As the need for mining low-grade iron ore becomes more critical for sustaining a viable iron resource in the world, reclamation experience in Minnesota can inform the development of best practices for reclamation of taconite and iron ore tailings basins. Experience to date shows that permanently reclaimed tailings basins can provide pasture, timber land, recreational opportunities, and wildlife habitat.

Finally, the initial tailings basins built more than 100 years ago during mining of high-grade iron ore are now being re-mined, using new process technology, for the iron that was disposed with the tailings. Technology and the price of iron have made these legacy tailings a valuable resource that is now economical to

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mine. Further, the taconite tailings have qualities that make them useful for other purposes, such as road construction. As technology develops and the demand for materials with unique properties increases, taconite tailings basins may provide useful deposits that are not unlike the natural deposits of ore formed by nature. Thus, tailings basins that are managed and operated appropriately represent a resource that can be used in the future for the benefit of society.

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CHAPTER 19

Responsible Management of Acid Mine Wastes: Geochemical and Microbiological Resources

Andrea R. Gerson, Jun Li, Roger St.C. Smart, Christopher P. Saint, Michael D. Short, and Russell C. Schumann

INTRODUCTION

The responsible management of acidic and metalliferous drainage (AMD) from mine wastes, as waste rock, process tailings, and in water release, is central to the social license to operate mining companies have with government and communities adjacent and downstream from mine sites. There have been many examples of sites where inadequate or incorrect geochemical planning and management have resulted in major damage to a community's health and welfare as well as the environment.

The mining industry has begun to learn from the mistakes of its past, and AMD control is now a top priority in greenfield mine planning, operating, processing, and in planning for closure. The high economic, social, and environmental costs of AMD management failures in pre-planning and operations are now recognized by the major global companies. Consequently, 10 of the largest global mining companies set up the International Network for Acid Prevention (INAP) to coordinate studies to reduce and treat acid generation from mine wastes. INAP has produced the most recent, comprehensive description and direction to best practices in the *Global Acid Rock Drainage Guide*, or GARD Guide (INAP 2009). The economic scale of these costs and the business case for their containment can be illustrated by examining one of these companies. For example, the global closure liability of Newmont Mining in 2005 was estimated to be "several hundred million dollars" (Dowd 2005). Approximately two-thirds of this was in management of

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mining wastes, with the largest proportion to be spent on prevention and treatment of AMD from waste rock dumps, tailings storage facilities, and stored water. "Just 10% reduction" in AMD translates to tens of millions of dollars in net asset value to the company (Dowd 2005). Thus, reduction in AMD with responsible AMD management can reduce not only the social and environmental damage but also the overall economic risk to the company.

Along with managing economic risks, AMD management is essential to mitigate long-term environmental risks and impacts. Historically, the consequences of lack of recognition or neglect of AMD management resulting in social and environmental damage are severe and even disastrous in some places. One example illustrating the difficulties in controlling AMD after it has started is the historic mine at Mount Lyell in Australia, which is no longer operating. Mount Lyell in western Tasmania is a 100-year-old copper mining operation where large quantities of sulfide-rich ore rock have been exposed to weathering and discharged as tailings into the Queen River and then King River. These rivers have a history of severe stream sedimentation and poor water quality (low pH and high metal concentrations). The King River discharges into Macquarie Harbour, where salmon farming is a major local industry requiring strict monitoring. Strong correlations between AMD-sourced pollutants (copper, manganese, iron, sulfate, and acidity) and different forms of environmental damage were observed in the King River. Assessment of sites in these rivers indicated that macroinvertebrate communities were all highly or extremely impacted by these pollutants together with substrate concretion and sedimentation. There appear to be no resident fish in the lower King River in contrast to a high abundance and diversity of fish species found in the adjacent lower Henty River (Davies et al. 1996). A program of AMD reduction and release control is now in place at the mine, but the historical damage in these rivers will require many decades to be reversed.

Through responsible management of AMD before and during mining, widespread contamination outside the mine site can be avoided. Responsible AMD management can effectively minimize environmental impacts, the potential social impacts that could have been caused by the environmental damage, and the long-term economic costs of associated remediation efforts. In addition to the GARD Guide, there are already many review articles and guidance documents that give good overviews on acid rock drainage (ARD) generation as well as current and recommended management strategies, which are referred to in this chapter.

In principle, however, a sustainable approach to this type of management in pre-planning or in operation should be to use, where possible, geochemical and microbiological resources available at the mine site to sufficiently reduce the acid generation rate (AGR) so that neutralization (using site materials) can match the AGR in rock and tailings disposal before final rehabilitation. This matching of acid and neutralization rates in kinetically controlled processes is, in principle,

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the only sustainable option for long-term closure. This approach for improved site management is described in this chapter, with case studies illustrating different parts of the overall strategy that have been implemented to date.

ORGINS OF AMD

In mining operations, acidic drainage with associated dissolved metal species (such as iron, aluminum, manganese), some damaging to human health and toxic to biota (e.g., Cd, Cu, Pb, Zn, As, Hg, Se), can result from the oxidation of sulfide minerals in mine wastes, principally as waste rock and process tailings. The waste-rock dumps from overburden and low-grade sections of the deposit, usually hundreds to millions of metric tons, constitute by far the largest source of acid drainage if they contain significant sulfide mineral content. The most common acid-generating sulfide minerals are the iron-containing minerals, including pyrite (FeS_2), pyrrhotite (FeS), marcasite (FeS_2), chalcopyrite ($CuFeS_2$), arsenopyrite (FeAsS), and pentlandite ($(Ni,Fe)_9S_8$). The primary acid-producing reaction has three steps: oxidation of sulfide to sulfate (Equation 19.1), oxidation of ferrous ion to ferric ion (Equation 19.2), and precipitation of ferric hydroxide releasing most of the acid (Equation 19.3).

$$FeS_2(s) + 7/2O_{2(g)} + H_2O_{(aq)} \Leftrightarrow Fe^{2+}_{(aq)} + 2SO_4^{2-}{}_{(aq)} + 2H^+_{(aq)} \quad \text{(EQ 19.1)}$$

$$Fe^{2+}_{(aq)} + 1/4O_{2(g)} + H^+_{(aq)} \Leftrightarrow Fe^{3+}_{(aq)} + 1/2H_2O_{(aq)} \quad \text{(EQ 19.2)}$$

$$Fe^{3+}_{(aq)} + 3H_2O_{(aq)} \Leftrightarrow Fe(OH)_{3(s)} + 3H^+_{(aq)} \quad \text{(EQ 19.3)}$$

The process is illustrated in the equations above for pyrite; however, the same basic equations apply for the iron-containing fraction of the other sulfide minerals. At pH below 3.5 and after initial oxidation, dissolved ferric ion can replace oxygen as the primary oxidant in these equations, with acceleration of the rate by factors up to 5 orders of magnitude (Rimstidt and Vaughan 2003; Williamson et al. 2006; Schumann et al. 2008). Microbial action (e.g., *Thiobacillus ferroxidans*) at low pH to reoxidize ferrous to ferric ions can also accelerate the reaction sequence by 2 orders of magnitude (Johnson et al. 2013). For acid neutralization and precipitation of toxic metal species, it becomes clear that assessment and management of AMD must be focused on rates rather than quantities alone (the primary focus of current procedures) to provide effective long-term management.

Other common non–iron sulfide minerals in wastes, such as sphalerite (ZnS) and galena (PbS), do not produce acid on oxidation but release dissolved Zn and Pb and other species in reaction with acid produced from iron sulfide oxidation. Hence, it is essential to understand the mineralogy, microbial populations, and

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reaction sequence of the sulfide minerals in these wastes. Several compilations of procedures for assessment of rock and tailings materials provide basic information on the acid-producing potential or neutralizing potential of waste-rock and tailings materials. These assessments are essential requirements in planning dumping schedules and neutralization treatments. The AMIRA *ARD Test Handbook* (2002) provides standard, practical, laboratory-based procedures for these tests. Critical analyses of and improved procedures for these tests can be found in the Mine Environment Neutral Drainage (MEND) report titled *Prediction Manual for Drainage Chemistry from Sulphidic Geologic Material* (MEND 2009) and in Smart et al. (2006). Where these primary assessments show that the waste is non-acid-forming, there are well-accepted designs for its containment in dump planning and tailings storage facilities with cover design and revegetation for closure (e.g., Huang et al. 2012). For waste assessed as acid-forming, the planning and management issues become acid generation prevention, reduction, and mitigation.

A critical requirement remains to understand, measure, and control relative rates of acid generation and neutralization, with the goal of matching them in long-term management. In these standard procedures, kinetic tests of AGRs and acid neutralization rates (ANRs) are normally limited to kinetic leach columns where the AGR and ANR are combined and the tests can take years to yield reliable information on likely reaction evolution of waste dumps and tailings. These tests also take no specific account of microbial action other than uncontrolled combination with geochemical reactions. A need remains for separate short-term estimation of AGR and ANR, not only in the acid waste material, but also in identifying suitable neutralizing mineralogy on-site that may be available from materials not currently included in mined and processed wastes. This has been partly addressed in current research (e.g., Smart et al. 2006; Schumann et al. 2008), but much remains to be done for this to be used effectively in mine planning and operation.

REDUCTION IN ACID GENERATION RATES

In principle, AMD management involves strategies, at any level from molecular to site-storage scales, to minimize the interaction of reactive sulfide surfaces with air and/or water. At the site-engineering scale, minimization and control strategies selected will be influenced by a range of factors including climate, topography, hydrology, mine geology, geochemistry and mineralogy of waste rock, tailings, and available neutralizing materials. In general, current practice includes

- Assessment of waste materials as acid-forming high-capacity, acid-forming low-capacity, non-acid-forming, and acid neutralizing (using the lab-based procedures described in the previous section and later in the "Assessment of Silicate Neutralization and Sulfide Oxidation Rates" section);
- Selective placement of waste materials;

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- Blending and co-disposal with limestone or other non-iron carbonates;
- Construction of waste-rock piles using combinations of different waste categories;
- Construction of tailings storage facilities to maintain saturation limiting oxygen access;
- Water covers or saturation where possible to reduce oxygen transport and solution concentrations; and
- Designed store/release cover materials to maintain saturation.

These strategies are summarized in the Australian Government's Leading Practice Sustainable Development Program handbook *Managing Acid and Metalliferous Drainage* (2007) and in chapter 6 of the GARD Guide (INAP 2009). This chapter outlines some alternative approaches to AMD reduction using knowledge about chemical reactions at the sulfide mineral surfaces, and microbial actions at these surfaces and in effluent that have been trialled with some success (described in the case studies) or are in current development.

Acid Neutralization and Buffering by Silicate Minerals

The importance of carbonate minerals, particularly non-iron carbonates, in neutralizing acidity generated through sulfide oxidation has long been understood, but the role that silicate minerals can play in providing significant acid buffering has only been recognized more recently (MEND 2009). At the same time, and given the abundance of silicate minerals in mine wastes, the widespread occurrence of AMD shows that in many circumstances, silicates in the absence of carbonates do not provide neutralizing capacity at a sufficiently fast rate to neutralize acidity resulting from sulfide oxidation. Hence, two additional requirements are needed to match AGR and ANR. The AGR (sulfide oxidation) has to be reduced, and the ANR, both carbonate and noncarbonate (mainly silicate), needs to be measured to ensure that the rates are matched.

Can this matching be done with site silicate minerals alone? Blodau (2006) reviewed AMD from the viewpoint of rates of acid generation and neutralization. He noted that at pH 5 and 25°C, pyrite oxidation was 3 orders of magnitude slower than carbonate (calcite and dolomite) dissolution. Hence, pyrite oxidation in the presence of excess carbonates results in neutral-pH pore waters. Dissolution rates of silicates are typically 2 to 3 orders of magnitude slower than pyrite oxidation. However, even if the available neutralizing capacity of the silicates can match the amount of acid generated by the pyrite, the pH of the resulting waters can often be in the range of 3 to 6 because of hydrolysis of dissolved metals (e.g., Al, Fe) that control the final pH of the solution. Silicates can offer significant buffering in this pH range, as demonstrated by Mattson (2009) who showed that in a granodiorite from which carbonates had been previously removed, hornblende and epidote buffered the leachate to between pH 4.5 and 6. This is promising if the AGR can

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be reduced as well, but different silicate minerals have very different neutralization rates (Palandri and Kharaka 2004) so that a method of measurement of the ANR of a waste material is essential to this strategy. The current stage of this development is discussed next.

Assessing Silicate Neutralization and Sulfide Oxidation Rates

Silicate ANRs and sulfide oxidation rates can be estimated from kinetic tests such as humidity cell tests or kinetic leach column tests. However, these tests can be very time-consuming (lasting from months to years), leading to obvious time and resource constraints for the use of this approach. In addition, it can be difficult to separate out the neutralization of carbonates and silicates when both types of neutralizing materials are present, while precipitation reactions can also infer lower oxidation and neutralization rates than actually occur during weathering in situ.

Several studies have attempted to determine silicate ANR at time scales significantly shorter than the traditional kinetic methods. Most of these are based around combining mineralogical assessment and dissolution rate data of individual minerals. Eary and Williamson (2006) combined mineral dissolution rate data from Palandri and Kharaka (2004) with solution speciation modeling to examine dissolution of a number of theoretical rocks, with silicate mineralogy ranging from silicic through to mafic and containing 0–3 wt.% pyrite. Their results suggested that mafic minerals such as anorthite, forsterite, augite, and hornblende may dissolve quickly enough to neutralize acidity from pyrite oxidation, but felsic minerals, such as K-feldspar and albite, will not provide sufficiently fast neutralization to avoid low pH as a result of pyrite oxidation. A similar mineralogical approach was used by Miller et al. (2010), wherein silicate ANRs derived from mineral dissolution rates were compared with rates calculated from leachate analysis of solutions obtained from long-term kinetic leach column tests in which any carbonates had been previously exhausted. They found good agreement between the rates derived from mineralogy and those obtained from leach column tests when the pH was below 3. However, at greater pH (≈4), ANRs calculated from mineralogy generally exceeded those calculated from leach column testing. In a similar approach, Morin and Hutt (2011) compared silicate ANRs derived from mineralogy with those obtained from humidity cell tests. They found that the rates calculated from mineralogy were similar to, or substantially less than, the measured values.

Ciccarelli et al. (2009) added the kinetic dissolution cell method to the assessment of silicate ANRs. Samples containing carbonate must first be treated to remove these minerals, so that the measured neutralization originates only from silicates. They compared the silicate ANR values obtained from the kinetic dissolution cell method with those calculated from mineralogy and kinetic leach column tests. At low pH (2), there was close agreement among the three methods, but in other cases where the measured rates were smaller because the pH was higher (≈4),

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agreement among the methods was not as close. Recent investigations (Ciccarelli 2012) have shown that the silicate ANR measured by the kinetic flow cell method is flow rate dependent, and this constraint must also be taken into consideration when comparing rates determined using different approaches. Both the kinetic flow cell method and the mineralogical estimates provide ANR values that, with consideration of errors, can be used to compare with AGR for waste-rock-dump planning. Refinement of the methods and site testing are still requirements for this part of the matching and sustainable AMD management.

Like rates of silicate neutralization, AGRs from sulfide oxidation can be determined from kinetic methods such as humidity cell and kinetic leach column tests. However, as with the determination of ANR, the assessment of AGR using these methods requires extended time and can be significantly influenced by precipitation of secondary sulfate minerals. A laboratory-based method that can be performed in a relatively short period of time and at low cost involves the measurement of oxygen depletion within a sealed chamber in which the waste-rock sample has been placed. The mass of oxygen consumed over a defined time period allows the rate of sulfide oxidation to be calculated based on the stoichiometry of the reaction between the particular sulfide and oxygen.

Hollings et al. (2001) used the oxygen consumption method (OCM) to evaluate the pyrite oxidation rate in waste-rock samples of low sulfur (<0.5 wt.%) content. They compared the results with AGRs determined from sulfate leached from the sample immediately following the OCM analysis and with rates calculated from sulfate measured during humidity cell tests. There was good agreement between the AGR calculated from the oxygen consumption and sulfate leached from the OCM sample, suggesting that oxygen consumption is a good indicator of pyrite oxidation rates.

In another study, Sracek et al. (2006) measured pyrite oxidation rates in a mine waste-rock dump based on oxygen and temperature profiles measured in situ and from pyrite content profiles measured in drill core samples. These results were compared with oxygen consumption measurements made in the laboratory. They found good agreement among all three measurements when the oxygen consumption tests were conducted on weathered samples. The authors concluded that small-scale test methods such as OCM may provide oxidation rates comparable to field measurements in regions where oxygen transport is not limited, that is, close to the dump slope, or where gas transport is dominated by convection. They noted that other laboratory-based measurements such as humidity cell tests or mesoscale column tests generally overestimate sulfide oxidation rates in comparison to field-based measurements. Again, estimates provide AGR values that, with consideration of errors, can be used to compare with ANRs for waste-rock-dump planning and refinement of the methods when site testing is required for sustainable AMD management.

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Reducing Acid Generation Rates (Passivating Sulfides) and Using Silicate Neutralization for Controlling AMD

As previously noted, sulfide oxidation rates will in most cases exceed silicate neutralization rates. Therefore, in the longer-term, once any carbonate present in mine wastes is consumed, pore-water chemistry is likely to have low pH and elevated metal concentrations. However, if there are silicate minerals of sufficient reactivity present in the waste material, and if the AGRs can be controlled to match the silicate neutralization rate, then attenuation of acidity generated as a result of sulfide oxidation may be achieved.

In examining the leachate chemistry of several long-term kinetic leach column tests, Miller et al. (2010) found that the silicate ANRs appeared to match the AGRs when the latter decreased to around 10 to 15 mg $CaCO_3$/kg/week. When the ANRs exceeded the AGRs, leachate pH was always above 3 and generally above 4. Based on these results, they concluded that silicates are likely to buffer in the region of pH 4.5 when the ANR is greater than or equal to the AGR in a waste. Although they concede that pH 4.5 may still be too low for environmental regulations, they concur that acidity loads, proton and particularly iron, will be significantly reduced. They therefore concluded that if the AGR can be controlled to below 10 to 15 mg $CaCO_3$/kg/week, then silicates present in wastes are likely to offer long-term mitigation to acidity generated in the waste.

As an example of AGR control, Miller et al. (2010) also examined the design of the degree of saturation and thickness of covers to inhibit oxygen diffusion and reduce AGR to around 1 mg $CaCO_3$/kg/week as a conservative design target. They show that by manipulation of the cover thickness at site-saturation levels that can be maintained, oxygen diffusion can be limited to reduce the AGR to the design target of 1 mg $CaCO_3$/kg/week at which silicate neutralization rates are likely to control seepage pH to 4 or above. Given appropriate climatic conditions and waste emplacement construction techniques, limiting oxygen diffusion to achieve the necessary reduction in AGR has been realized in practice (Miller et al. 2012).

The addition of carbonates (where available on-site) in covers and layers is recognized as the preferred method of AMD control in acid rock dumps (INAP 2009). Although carbonates, such as limestone and dolomite, are often thought of as simply neutralizing acid that has already been generated through sulfide oxidation, laboratory (Schumann et al. 2009; Huminicki and Rimstidt 2009; Nicholson et al. 1990) and field (Li et al., 2011, 2012; Miller et al. 2009) studies show that under the neutral pH conditions with added carbonates, pyrite oxidation rates can be reduced by 1 to 2 orders of magnitude. The mechanism for the reduction in sulfide oxidation rate is through formation of continuous, coherent, iron oxyhydroxide coatings that develop on the surface of the reacting sulfide and reduce oxygen diffusion rates to the surface (Huminicki and Rimstidt 2009; Nicholson et al. 1990). The nature of these surface-passivating layers has been extensively investigated (Smart et al. 2010; Schumann et al. 2009). Under circumneutral pH conditions, multilayered coatings

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of iron oxyhydroxide develop that incorporate silicate, sulfate, and carbonate. These thin, continuous, and conformal coatings are amorphous and often overlaid with a thicker (≈2 μm) coating of (semi-) crystalline goethite-like material. Where clay minerals are present in the waste, strongly adhering particles with micaceous texture can form a further armoring layer (Miller et al. 2009). Recent studies have investigated the role that pH and dissolved silicate play in stabilizing these passivating layers (Zeng et al. 2013). Results indicate that pyrite oxidation rates are reduced most significantly when the pH is maintained above 6 and when the surrounding solution contains dissolved silicate (≈10–20 mg/L as Si). It appears that in the presence of dissolved silicate, the iron oxyhydroxide layer formed during pyrite oxidation retains its amorphous structure; whereas in the absence of silicate, conversion of the layer to the more-crystalline and less-passivating goethite-like material occurs. If initial alkaline amendments can be made so that these passivating layers can be formed and maintained, then for wastes with low-to-moderate AGRs containing some reactive silicates, AGRs may be sufficiently reduced (more than 90%) to be matched by silicate ANRs in the long term. Under these conditions, further amendment with carbonates may not be required. This sulfide passivation, with the use of reactive silicates from site rocks, forms the basis of the geochemical strategy for sustainable AMD management.

Microbial Actions

Much of the geochemistry of the production of AMD is well understood, and the role microorganisms play in these processes has also been well documented. What is not well characterized is the role microorganisms can play in remediating the waste products formed from mine waste or, indeed, how microorganisms can be used in a preventive treatment to control AMD. Remediation can be on-site treatment by establishing conditions that permit heterotrophic bacteria to gain the ascendency and create conditions that are nonconducive to metal sulfide oxidation and acid production with associated dissolution of metals (e.g., Lindsay et al. 2012). It can also be in the form of a constructed bioreactor for specialized treatment of wastes (e.g., Baldwin et al. 2012).

Several of the case studies described later in this chapter show that the action of heterotrophic bacteria (naturally present in all mining wastes) in consuming oxygen is effective in limiting access of oxygen to sulfides in the top layers of rock and tailings wastes and also in reducing AMD. The majority of heterotrophs are chemoorganoheterotrophs (often referred to as simply "heterotrophs"), meaning that they use organic carbon sources for growth and energy, and oxygen for respiration. In contrast, the chemolithoheterotrophs, which include sulfate-reducing bacteria (SRB), use inorganic substances (rather than oxygen) to provide energy for the production of adenosine triphosphate (from adenosine diphosphate and a phosphate group) while still requiring organic carbon to provide the basic growth building blocks. In the case of SRB, sulfate, sulfite, thiosulfate, or elemental sulfur

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may be used to generate energy. These bacteria are anaerobic and produce sulfide wastes via dissimilatory sulfate reduction. SRB are effective in the anoxic zone below the surface in limiting sulfide oxidation, controlling pH above 6 and precipitating toxic metals.

Amendments: Organic Waste and Phosphate

Organic amendments have been used for years to stabilize mine wastes with the intention of "capping" the waste and establishing plant growth above. Depending on the level and types of organics, these amendments can greatly stimulate the growth of heterotrophic bacteria. An early study by Kalin et al. (1993) recognized the importance of heterotrophic bacteria in this process. The types of organic amendments and their applications are reviewed by Kelly (1996). There are several recent studies where the types of organic amendment and the composition of the covering layer have been related to the types and abundance of the key microbial groups present. Depending on the level of previous processing of the organic amendment, heterotrophic bacteria can be introduced or the amendment may merely promote the growth of indigenous heterotrophs.

Adams (2012) and Baldwin et al. (2012) have shown that the different microbial groups, including heterotrophic, acidophilic (autotrophic), SRB, and Archaea, are present in differing populations at pH 2–7 in mining wastes and post-treatment bioreactors. The relative populations and their corresponding actions depend on zone characteristics and micro-environments and can be changed by different C:N:P:S ratios and pH. The specific action of heterotrophic bacteria in oxygen uptake and pyrite oxidation inhibition may be targeted in this methodology.

Tests for the presence and action of heterotrophic bacteria have been carried out in fresh tailings from a Cu:Zn base metal mine (Kalin et al. 1993). Treatment of the tailings surface with addition of molasses and Osmocote fertilizer was used for effective grass germination in full site trials. Following molasses addition, heterotrophic bacteria counts increased from 1.4×10^6/g of the tailings beach to 6.75×10^8/(g tailings) and were particularly abundant in the root zone of the germinated grass in the neutral tailings. The experiments show that it is possible to vegetate fresh tailings (and, by implication, fresh acid rock waste) with microbial assistance.

The Role of Microbial Technology

Adams (2012) presents a review of several case studies that strongly suggest that the proportions of microbial types, including the acid-generating species, appear to vary depending on the site geology, geochemistry, and site conditions. In doing so, however, he also acknowledges the limitations of enumerating bacteria by culture, because it is well known that less than 2% of microbial species are at present culturable. This fact is key when considering where the future application of molecular

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biology techniques is likely to take us in the coming years. A better understanding of the types and relative abundance of microorganisms involved in these processes is fundamentally important for improving the future management of AMD. Equally important is having a means by which to monitor, in an ongoing fashion, the key microbial population(s) of the system, or "microbiome," to ensure that it remains conducive to passivation or removal objectives.

Since about 1995, the development of molecular typing techniques has permitted their application in a wide range of environments. Although direct application of molecular techniques does not inform the investigator that identified microorganisms are necessarily viable, when these studies are conducted over time and the relative abundances of microorganisms change in relation to other key physical and chemical characteristics, this can provide prima facie evidence of cause and effect. The importance of these molecular techniques can be illustrated with the comparable industrial example of recent efforts to analyze the population dynamics of wastewater-activated sludge systems; this work has led to a paradigm shift regarding the groups of microorganisms involved in the key treatment processes and has opened up avenues for potential future 'bioengineering' of these systems' microbiology (Seviour and Neilsen 2010). SRB are key components of wastewater treatment systems, and the problems they cause are particularly evident in sewer systems with acid production causing significant infrastructure damage. One of the earlier studies where molecular techniques were intensively applied to SRB was with these issues in mind (Ito et al. 2002). In that study, a combination of fluorescence in situ hybridization, density gradient gel electrophoresis, and 16S rRNA gene-sequencing analysis was used to analyze the successional development of SRB community structure and in situ sulfide production within a biofilm growing under microaerophilic conditions in the presence of nitrate. The molecular techniques also lend themselves to laboratory-based studies where a range of different mesocosms can be established under different treatment regimes. A recent study by Nancucheo and Johnson (2011) used 16S rRNA gene sequencing to identify and quantify the predominant groups of bacteria following amendment and microbial inoculation of pyrite mine tailings in a series of 60 mesocosms.

A particularly exciting recent development that will permit detailed and more convenient analysis of environmental microbial communities is a technique known as pyrosequencing (Marguilies et al. 2005). Previously, to estimate the microbial types present within a sample, DNA needed to be extracted and cloned into a suitable vector for subsequent amplification in *Escherichia coli*. This amplification protocol permitted sufficient DNA to be obtained to complete DNA sequencing of the cloned fragments. Where the population of microorganisms is diverse and complex, this was a long and laborious process. Also, it is only in recent times that the computing power has become available to permit large-scale analysis of genetic information conveniently, a science known as genomics combined with

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bioinformatics. The future application of this technique will be highly instructive in the analysis of the microbiome of mining waste microbial communities.

The application of molecular biology techniques in combination with the on-site monitoring of key physical and chemical parameters over time will lead to new insights into the role that microorganisms play in controlling the key chemical reactions found in mine waste sites. This information will result in confirming the conditions that are required to be established and maintained to continue amelioration of such sites and give an early warning of deterioration, permitting the necessary intervention to quickly reestablish optimum conditions to be taken.

However, there has not yet been a site trial in which the full application of these molecular biology techniques have been used in a planned, instrumented (e.g., pH, Eh, oxygen, microbial DNA, biofilm formation, AGR reduction etc.), optimized trial with organic amendments. Some parts of a full trial have been examined, as in the East Sullivan, Benambra, and Elliot Lake case studies that follow, but the full value of AGR reduction from control of microbial action remains to be realized.

CASE STUDIES

Five examples of specific approaches to AMD understanding and control have been chosen to illustrate the application of the principles previously discussed in real site management. They encompass current operations and legacy, long-term acid rock dumps, and tailings. Most of these and other complex case studies of site implementation are published in peer-reviewed AMD conference proceedings as well as government and consultants' reports (rather than mainstream journals), but they are now equally accessible from various Websites. All of these examples represent planning, management, and control only introduced after the mining operation had started or, indeed, finished. Management and closure of potentially acid-producing wastes from new mining operations can only be responsibly planned in full greenfield geochemical evaluation of minerals, sulfides, carbonates and reactive silicates, all site rocks for use in rock dump design, tailings storage, and rehabilitation. Historically, this full assessment of non-value site rocks and minerals has not normally been required for license or carried out in mine evaluation. However, in many cases, this has resulted in major remediation costs and liabilities before closure. Now, mining companies in the United States conduct more extensive testing of their waste rock for new metal mines although this is not always the case in other countries.

Savage River Rehabilitation Program: On-Site (Silicate) Neutralizing Rocks

The Savage River iron ore mine is located in northwestern Tasmania, Australia. To date, mining operations have generated in excess of 50 million m^3 of ore and 300 million m^3 of waste rock since about 1975. Current mining plans allow for the

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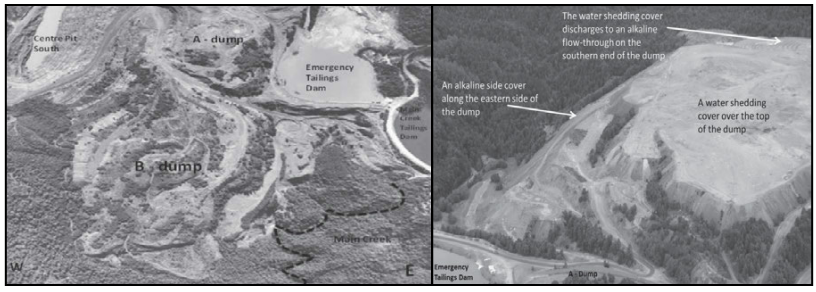


Figure 19.1 The legacy Savage River B-dump with Main Creek flow line in May 1999 (left); B-dump in October 2006 with addition of the water-shedding top cover, A-type alkaline side cover (eastern side), and flow-through barrier at the base on the southern end (right)

potential of a further 100 million m^3 of waste rock over the next 15 years; however, ARD, emanating from legacy (sulfide-containing) waste-rock dumps at the mine site, which flows into Main Creek and the Savage River, has caused environmental harm to the river and its tributaries. It was reported that the ARD has changed the original water quality and sediment characteristics, has eliminated 90% of the major taxa (families) of aquatic macroinvertebrates, and has decreased overall invertebrate abundance by 99%, with severely depleted native fish fauna in the river to about 30 km downstream from the mine site (Hughes et al. 2009).

The historic B-dump was identified as a significant source of ARD at the site. One objective of the Savage River Rehabilitation Project (SRRP), which was initiated in 1996 as a cooperation between the Tasmanian government and current owners Grange Resources Ltd., is to develop and implement a strategy to reduce the acid load from this dump (Rumble 2005; Hutchison et al. 2009). See Figure 19.1.

The waste rock at Savage River mine has been assessed as belonging to four categories:

1. A-type: alkaline materials non-acid forming very durable igneous rock
2. B-type: effectively neutral
3. C-type: clay or highly weathered rock
4. D-type: potentially acid forming (PAF)

The D-type PAF waste is responsible for the major part of the AMD issues in B-dump. From early 1970 to 1996, about 13 Mt (million metric tons) of D-type waste rocks were placed into the B-dump from which approximately 40% of the total Cu load emanated to flows down the river through Main Creek. The A-type neutralizing wastes include reactive chlorite-calcite schist (the main waste rock), dolomite, magnesite, and some chlorite-albite schist. To reduce environmental harm to the river, combined water-shedding and alkaline (A-type calcite-chlorite schist) covers were constructed over the dump in 2006 for long-term ARD control. A total of 15 Mt of A-type rocks were used in the water-shedding cover and the alkaline

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side-dump cover. The water-shedding cover, constructed using B- and C-type materials and well-graded A-type waste rock, has significantly reduced infiltration from 90% to 3%–8% of incident rainfall for B-dump top area and subsequently reduced the seepage load of acid drainage to Main Creek. The southern alkaline flow-through comprises about 1.2 million m^3 of A-type material fill over an area of 86,000 m^2 with an average depth of 13.2 m on the southern end of B-dump. This area was shaped to provide a soakage zone for runoff from the water-shedding cover. It provides benefit in water dispersion and alkalinity addition. The alkaline side cover allows rainwater infiltrating the cover to take up alkalinity from the A-type material, and this alkalinity can then react with, and neutralize, existing acid drainage.

A survey of B-dump was carried out to investigate the performance of the covers by combined excavation and drill core sampling of the dump in conjunction with water monitoring after the cover had been in place for about 5 years. The details of the investigation can be found elsewhere (Li et al. 2011, 2012). The covers have effectively reduced the sulfide oxidation rate within the dump by about 43% over the past 5 years. Alkalinity from the covers has been migrating down into the PAF waste and forming passivating layers of silicate-stabilized iron oxyhydroxide on pyrite grains. Sulfate, Al, and Cu flux in Main Creek have been decreased by 50% after B-dump was capped. The discharge from Main Creek to the river has neutral pH, low sulfate (218 mg/L) and metal concentrations (e.g., Al 200 μg/L and Cu 30 μg/L) that are below the SRRP fish target, allowing biota 20 km back up the river (Hughes et al. 2009).

East Sullivan Mine: Bark Cover and Effluent Recycle

The East Sullivan mine (Cu, Zn, Au, and Ag) in northwestern Quebec, Canada, operated from 1946 to 1966 with the Quebec government inheriting responsibility for the site in 1980. In the 1980s, East Sullivan was recognized as one of 28 sites in Quebec posing major hazards to public health and the environment. In particular, 15 Mt of acid-producing tailings were left untreated from 1966 to 1980. This waste was assessed in acid–base accounting testing (MEND 2009) to have an acid potential of 108.9 kg $CaCO_3$/t and a neutralization potential of 4.1 kg $CaCO_3$/t, that is, net acid producing. More complete details of the site and wastes can be found in Tassé et al (1994) and Germain et al. (2013).

In 1984, an organic cover of coarse wood chips from forestry wastes was added to the tailings based on the suggestions at that time (Reardon and Poscente 1984) that oxygen is consumed by the oxidation of carbon in wood chips, resulting in reducing conditions. At East Sullivan, methane was measured in pore gases from surface layers, confirming anoxic conditions (Tassé et al. 1994). Water collected over the impoundment was near-neutral pH. As discussed in previous sections, this is likely to have been largely due to the combined action of heterotrophic SRB

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rather than chemical reactions alone, although the microbial population was not measured or characterized.

A second stage was introduced in the early 1990s in which the acid seepage at pH 3.0–3.5 (from pyrite oxidation by ferric ion deep in the dump) around the tailings impoundments was collected for passive "bioreactor" treatment in successive reservoirs with recycle to a 120 m dispersal zone over the oldest bark cover. Alkalinity values exceeding 2,500 mg/L $CaCO_3$ have been found beneath the bark-covered areas, whereas they were below 500 mg/L in uncovered areas. Mean pumping rates in the period 1998–2005 were close to 5,000 m^3/d. Following this second stage, groundwater monitoring found that pH returned above 6 from the passive treatment of this acid seepage. Returning alkaline and reducing solution in recycle produced geochemical conditions sustaining (inferred) pyrite passivation, sulfate reduction, and metal precipitation. This two-stage treatment, with costs much reduced from previous effluent treatment, was continued until, in 2006, the effluent quality met regulatory specifications, including toxicity tests on rainbow trout and Daphnia (Germain et al. 2013). Recycle was discontinued, and effluent could be safely released thereafter.

The East Sullivan case study presents an example of the combination of geochemical and microbial actions to maximize AGR reduction and establish and maintain a long-term environmentally safe treatment. This multibarrier approach in practice, however, still needs initial testing and ongoing monitoring of the microbial populations, as well as chemical monitoring for safety assurance.

Benambra Legacy Tailings: Limestone/Organic/Water Cover and Anaerobic Wetland Effluent Treatment

The Benambra underground Cu-Zn mine in East Gippsland, Victoria, Australia, operated from 1992 to 1996, closing without rehabilitation and leaving nearly 700,000 t of sulfidic tailings in a tailings dam. Overflow and seepage from this dam enters Straight Creek and then the Tambo River 3.8 km downstream. The Tambo River is a source of drinking water for communities downstream and discharges into the Gippsland Lakes near the southeastern Victorian coast. The Victoria government assumed responsibility for the site in 1998 and, with Earth Systems P/L (Oxley et al. 2008), set up a successful rehabilitation program. Mineralogy and acid–base accounting tests found very high sulfide content including pyrite (65 wt.%), chalcopyrite (1–2 wt.%), and sphalerite (1–8 wt.%), and the potential to generate up to 700,000 t of H_2SO_4 (sulfuric acid) and 20,000 t of soluble Zn at an annual AGR of 200 g H_2SO_4/t of tailings for hundreds of years. This AMD was also likely to have low pH and elevated Fe, Cu, Mn, As, Cd, and Al concentrations precluding release. Hence, the primary objective of the site work was to minimize oxidation in the tailings dam to minimize the AGR and soluble metal species.

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The original Benambra tailings dam was engineered as a competent water-retaining structure and, prior to rehabilitation, contained about 160 million L of supernatant water, with near-neutral pH but elevated Zn, Cu, As, Pb, and Mn levels. The primary strategies of site rehabilitation were to create a permanent 2-m-deep water cover over the tailings and use passive treatment systems for long-term water quality control. To illustrate this approach, the full plan (Oxley et al. 2008; Australian Government Department of Industry 2007) included

- Initial pH control and flocculation of colloidal metal species in the dam water,
- Partial discharge of dam water to permit rehabilitation work,
- Disposal of other sulfidic material from the site into deeper water of the dam,
- Leveling of the tailings to ensure at least 2 m of water cover overall,
- A limestone sand layer on tailings to minimize oxygen access and resuspension,
- An organic material cover over the limestone to promote reductive microbial action,
- Installation of alkaline dams in upstream creeks to precipitate metals and neutralize acidity,
- Removal of upstream diversion channels to maximize flow to the tailings dam,
- Buttressing of the tailings dam wall to increase water depth and strengthen walls,
- Construction of a spillway for dam wall safety,
- Revegetation of dam surroundings for sustainable leaf litter feed to microbial action, and
- Installation of a vertical upflow anaerobic wetland to treat AMD before discharge.

These rehabilitation works at the tailings dam were implemented over a 5-month period in 2006. A permanent water cover now exists over the tailings with automated water quality monitoring in place. Vegetation growth around the dam perimeter and establishment of a self-sustaining biological remediation system within the dam to ensure long-term passive water treatment through natural biological processes is well underway. In 2009, monitoring showed that dam seepage pH was raised from 5.7 to 6.4 and As, Pb, and Mn species met specifications at the key location for water release. Cu and Zn discharge at the dam wall seepage wetland were already below specification levels (0.0014 and 0.008 mg/L, respectively; Oxley et al. 2008).

Waite Amulet Tailings Storage: Reactive Silicates and pH Stabilization

Acid forming tailings (5.9 Mt) from the Waite Amulet mine (Cu-Pb-Zn) in northwestern Quebec, Canada, were produced between 1929 and 1962 and stored in

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an elevated impoundment. In the early 1980s, 45 t/ha of limestone and 2.2 t/ha of agricultural fertilizer were added to enable a vegetative surface cover to be established. Acid and metalliferous drainage from runoff and seepage is treated with lime before release. This site was extensively studied in the Canadian MEND project, supported by mining companies during the period from 1986 to 1996 with documentation of mineralogical, hydrogeological, and hydrogeochemical information and interpretation (Blowes and Jambor 1990; Nesbitt and Jambor 1998; Jambor et al. 1999). In addition to outlining the sulfide oxidation profile in the tailings, a particular focus has been the nonsulfide (mainly mafic silicate) minerals that have reacted to partly neutralize acidity and control pH below the vadose zone. The water table varies between 1.5 and 2.1 m below the top surface. Below 2 m, oxidation of sulfides is minimal, but above this level, the tailings are unsaturated. Sulfides (pyrite and pyrrhotite) in the unsaturated zone were extensively oxidized from 1962 to 1986 with the top 0.5 m containing mostly the oxidation product goethite (FeOOH). Pyrite was still found below 0.6 m, with pyrrhotite mainly found in the saturated zone. This is consistent with studies by the chapter authors showing that pyrrhotite oxidizes nearly 10 times faster than pyrite but produces only half the acid due to elemental sulfur formation (Robertson et al. 2011).

The mineralogical studies at Waite Amulet have shown that in this unsaturated zone, relative rates of weathering reactions are approximately 10:4:2:1:1 for sulfides (principally pyrrhotite)/chlorites/other mafics (pyroxene, amphiboles)/feldspars/quartz (Nesbitt and Jambor, 1998). These ratios are similar to those measured by the chapter authors using their ANR methods and to those quoted in compilations (Palandri and Karakha 2004) and recent studies on silicate dissolution rates (Jambor et al. 2006; Miller et al. 2010; Ciccarelli et al. 2009) at pH 2–5. The pore water profiles to 3 m depth showed that, below the top surface acid runoff, the pH was close to 4.5 from a 0.5-m depth in the unsaturated zone to the saturated zone (2 m) and then increased into the 5–7 range. Sulfate and Ca were also stable with Fe (ferrous) decreasing across the unsaturated zone. Mg and Al, however, increased steadily from a 0.5-m depth to the saturated zone. Careful analysis of the mineralogy and solution speciation (Nesbitt and Jambor 1998) shows that as the acidic sulfate solution from the top 0.5 m enters the oxygen-deficient layers beneath, the pore waters evolve toward Mg-sulfate-rich waters and pH stabilization near the equilibrium with silicate dissolution (Mattson 2009). The abundant faster-reacting phyllosilicate mineral group of chlorites act as solid bases to partly neutralize the acid released (Lowson et al. 2007). The Fe, Al, and Si hydroxy species equilibrate with their precipitates leaving the Mg-sulfate-rich waters.

The rate of reaction of chlorite is not initially sufficient to match that of the pyrrhotite, but when the AGR is reduced by oxygen deficiency, this becomes possible and the pH can stabilize at the silicate equilibrium near 4.5. Although it is not a complete solution, this mechanism, occurring naturally at Waite Amulet,

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suggests that a combination of oxygen reduction with reactive silicate minerals should be explored to reduce AMD and post-treatment costs in acid rock dumps as well as tailings. The previously mentioned SRRP example suggests that this combination is effective.

Elliot Lake and Copper Cliff Tailings: Microbial Actions and Phosphate Addition

An early case study illustrates the potential for beneficial microbial action not yet fully tested. Waste natural phosphate rock (NPR) and horse manure (HM) were mixed into old uranium tailings surfaces at Elliot Lake and on fresh pyrrhotite tailings at Copper Cliff, Ontario, Canada, using a rototiller specifically to stimulate beneficial microbial action (Kalin et al. 2002). The Elliot Lake tailings originated from uranium mining between 1958 and 1964. In 1993, surface stabilization was marginal and the tailings had a pH ranging from 1.9 to 2.5. As part of the tailings management practice at the Inco Copper Cliff operation, pyrrhotite tailings formed a separate waste stream. A set of test plots was set up from this stream with initial pH 4–7 (again, consistent with pyrrhotite reaction). Over a period of 8 years, higher additions of HM (10 Lm^{-2}) and NPR (30 kg m^{-2}) raised the pH in the top 15 cm from pH 2–3 to above 7; decreased acidity, Al, Cu, and Zn concentrations by more than 99% and Fe by 98%–99%; and improved the pore water quality in both tailings types. Lower additions of HM (1.6 Lm^{-2}) and NPR (3 kg m^{-2}) were much less effective in raising pH and reducing acidity and metals (Table 19.1). The P nutrient and the organic material appeared to be necessary for the most effective AMD control. No significant improvement occurred in levels below 15 cm, suggesting aerobic bacterial action was confined to the surface layers. This study, with others by Kalin and co-workers (e.g., Kalin et al. 2012, 1993) on control of AMD using microbial activity, provide the incentive to incorporate this mechanism of sulfide oxidation control with geochemical passivation to reduce AGRs on-site.

A SUSTAINABLE STRATEGY: THE COMBINATION OF GEOCHEMISTRY AND MICROBIOLOGY

It is clear that management of tailings and waste rock should be planned at start of mine for the most cost-effective and environmentally beneficial outcomes. For optimal implementation, this must involve a thorough geochemical examination of not just the value components of the ore, as is usually the case, but also carbonate and silicate minerals in site rocks not necessarily mined to enable full use of local materials for AMD control and remediation. This then enables engineering and geochemical planning of layering, blending, and cover strategies; however, this level of forward planning has rarely been carried out to date.

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Table 19.1 Pore water samples from tailings plots treated with natural phosphate rock and horse manure after 8 years*

Treatment	pH	Acidity	Al	Cu	Fe	P	Zn
Copper Cliff tailings, 0–15 cm							
No NPR, no HM (control)	3.1	6715	870	0.69	43	0.22	9.3
No NPR, high HM	3.1	5639	730	1.0	23	0.20	13
Low NPR, no HM	3.2	3864	520	1.3	19	0.16	8.5
High NPR, no HM	3.8	1090	120	17	0.10	6.9	5.3
High NPR, high HM	7.8	10.7	BDL	0.04	0.22	BDL	0.01
Elliot Lake tailings, 0–15 cm							
No NPR, no HM (control)	2.7	656	50	0.59	18	0.03	0.98
No NPR, high HM	2.7	558	34	0.42	12	0.02	0.29
Low NPR, no HM	2.8	491	18	0.59	56	0.62	0.45
High NPR, no HM	4.5	39	2.8	0.01	0.26	2.5	0.08
Low NPR, high HM	6.8	39	BDL	BDL	0.01	0.05	BDL
High NPR, high HM	7.4	9.7	BDL	0.01	0.26	0.16	BDL

Source: Adapted from Kalin et al. 2002.
*Elemental concentrations mg L^{-1} and acidity in mg $CaCO_3$ L^{-1}. BDL = below detection limit.

Nevertheless, it is clear from the case studies provided that geochemical remediation has been successfully implemented for active and historic waste rock and tailings with clear evidence in some cases (e.g., SRRP) of pyrite passivation having occurred so that not only was the pH of the effluent raised, but the rate of oxidation was also markedly reduced. Alternate organic amendment strategies encouraging beneficial microbial action, largely based on heterotrophic and sulfate-reducing bacteria, have also been implemented, resulting in increased pH and decreased metal(loid) effluent concentrations. Again, this would ideally involve locally available, low-cost sources of organic carbon. To date, what appears not to have been implemented is a conscious strategy with full monitoring that combines these two approaches; geochemical and microbial control mechanisms may have occurred in some instances (e.g., East Sullivan mine), but this remains to be fully verified.

On the basis of the variables and case studies reviewed herein, the development and implementation of the simultaneous dual controls (shown schematically in Figure 19.2) may, in many cases, provide the most environmentally sound strategy for reduction of AMD using practical on-site methods. The dual controls are

- Microbial action to reduce oxygen ingress into the dump and via biofilm formation to the sulfide minerals present, as well as sulfate reduction to reform sulfide species; and

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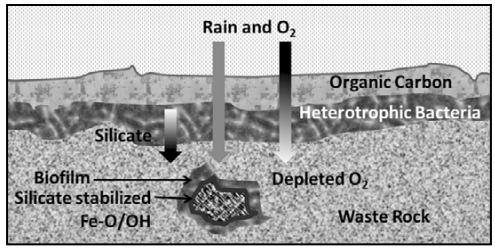


Figure 19.2 Dual-barrier system for reduced rate of AMD

- Sulfide surface passivation through the formation of silicate-stabilized iron oxide/hydroxide surface layers.

This dual implementation strategy requires further implementation with full investigation to enable definition of establishment rates for the system. To establish the conditions necessary for sulfide surface passivation (pH >6) may require, for instance, the initial application of neutralizing materials. Long-term maintenance requirements also need to be fully defined, particularly for systems containing relatively fresh sulfidic materials. These requirements are the subject of current research and development projects with site testing.

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PART VII

RECLAMATION, CLOSURE, AND LAND-USE PLANNING*

Madan M. Singh

One of the main reasons that mining has acquired a poor reputation is because the landscapes of former mines have been scarred with small mine openings and piles of waste material when they were abandoned after the mineral being mined was exhausted or the economics were no longer conducive to mining. In the past, there was a lack of understanding—by the miners, the community at large, and the regulatory authorities, if any—of the deleterious effects of such acts on the groundwater and future land use. Impacts on wildlife, migratory birds, and flora were not regulated. The expansion of urban and suburban areas, enhancement of mobility affording easier access to remote regions, advances in the understanding of the environment, and progress in technology have brought the dilemmas associated with derelict mines into focus. Attention to mine closure has gained increased prominence.

With the focus on sustainability, it becomes incumbent on present society to reclaim and restore mined lands postclosure. Appropriate steps to reclaim mined lands has become an integral part of the complete mining cycle. In most jurisdictions in the developed world, measures for reclamation need to be specified in the permitting application, before commencing any mining.

* The views and conclusions contained in this introduction are those of the author and should not be interpreted as necessarily representing the official policies or recommendations of the Bureau of Land Management, U.S. Department of the Interior, or the U.S. government.

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Chapter 20 points out that mine closure is a complex issue and, in spite of recent developments in rehabilitation of mined lands, it remains a challenge for mining companies and regulators. After mining has terminated, the expensive mine infrastructure is deemed an ecological and economic liability. In 2011, the Government of Western Australia published *Guidelines for Preparing Mine Closure Plans*, which provides an integrated prescription for mine closures and reduced costs. These guidelines advocate the following postmining land-use hierarchy:

1. Reinstate "natural" ecosystems as similar as possible to the original ecosystems.
2. Develop an alternative land use with higher beneficial uses than the pre-mining land use.
3. Reinstate the pre-mining land use.
4. Develop an alternative land use with other beneficial uses than the pre-mining land use.

It is apparent from these guidelines that priority should be given to restoring the pre-mining ecosystems. The authors propose that the facilities in place, such as for transportation, communication, power, and water supply, should be considered an asset that can be used by future generations, and so their title should be transferred. This concept requires a "paradigm shift" in current thought, even though it is providing the local community a means to build an economic base for other enterprises.

Traditionally, the goal for rehabilitating mined land was to restore it to the predisturbance land use or ecosystem as indicated in Chapter 21. The replacement of retained bioactive topsoil, containing indigenous seed and beneficial microbes, facilitates reestablishment of native vegetation. This is effective where the biogeochemical composition of the postmining landform and substrates are not substantially different from the predisturbance environment. Mining causes severe impacts to the landscape, which results in biotic and abiotic adjustments to the affected area, many of which may be irreversible. These impacts have led to new thinking on the reclamation of mined lands. Depending on the severity of disturbance, the feasible rehabilitation may be the restoration of natural or near-natural (i.e., historical) systems, development of hybrid systems (i.e., somewhat different but retaining many of the attributes of the historical system), or development of novel systems (i.e., a new combination of physical and biological attributes). To achieve such modifications to the reclamation procedure, however, the constraints imposed by regulators need to be amended.

Chapter 22 provides an example of variations in local conditions and authorized specifications. The authors present a reclamation case study of an area that was mined 155 years ago during the gold rush in the state of Victoria, Australia, resulting in significant heavy metal contamination. Using the normal approach of restoring the original "natural" vegetation without consideration of ecological

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differences was not realistic. Measurement of success should cover composition, structure, function, and monitoring of invertebrates, because all of these are important components of the ecosystem. This 10-year field trial concluded that (1) only hard seeds survive the pressure of being entombed in stockpiles, so soil should be used soon after stripping to maximize recruitment and diversity; (2) appropriate criteria should be employed for mined sites, especially tailings facilities, with the objective of reverting these to self-sustaining ecosystems; and (3) future projects should include variables, such as indices of diversity within the ecosystem attributes and at least two reference sites, to suitably portray the ecosystem variation. The authors also discuss how environmental legislation should be based on the ecological settings of the area.

Chapter 23 provides the case study of a region in Appalachia where it is desirable to rehabilitate the mined lands with the original "natural" vegetation. Coal-mined sections in Appalachia are primarily governed by the Surface Mining Control and Reclamation Act, which does not stipulate that the original vegetation be restored. Hence, many mined lands are covered with herbaceous vegetation that stabilizes the soil but inhibits colonization by forests. The original forests comprise abundant and varied flora and fauna, produce saleable wood commodities, and offer a variety of ecosystem services (such as carbon storage, watershed and water quality protection, and environment for a multiplicity of plants and fauna). To rectify this situation, the Forestry Reclamation Approach (FRA) was developed, which is a five-step routine crucial for healthy reforestation. Because establishment of the FRA was not adequate to implement the strategy, the Appalachian Regional Reforestation Initiative (ARRI) was created by the state and federal agencies involved, along with several other stakeholders. The objective of ARRI is to promote the FRA concept and to persuade industry to adopt it. Initially, however, ARRI had to surmount cultural, technical, and regulatory barriers to effective reforestation of mining operations. This chapter presents three case studies that have applied the FRA effectively in practice.

Chapter 24 discusses responsible land and resource management in northeastern Minnesota, where iron ore mining has been a dominant industry since the mid-nineteenth century. Direct shipping ore was mined originally, but as that became depleted, beneficiated ores were marketed. In the mid-twentieth century, pelletization of magnetic ores (taconite) started to take over, and since the 1990s, efforts have been devoted to using mined wastes. Because the region's economy has been unequivocally dependent on the mining of iron to date, several government agencies as well as public–private partnerships have evolved to sustain the industry, develop new ventures to augment iron ore mining, and assist in novel reclamation efforts.

Chapter 25 describes an adaptive environmental management plan (AEMP) that entails an iterative process for making decisions when significant uncertainty

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exists, as is the case in many mining projects. The AEMP is contingent on an investigatory and educational process that reduces uncertainty and delivers results, which serve as input for the next iteration. The chapter discusses how the plans and practices underpin regulatory agency approvals and permitting, traverse the entire life-cycle of mines, and cope with uncertainty. These plans and practices further assist in focusing on mining impacts and legacy concerns. AEMPs and related practices are helpful in dealing with the uncertainties involved in recognizing, assessing, and managing the effects of any projected new and/or modified facilities for review. After project approval, the AEMP serves as a living document that is continually revised and updated, and helps in evaluating environmental impacts as the operations progress through closure into post-reclamation. The closure process may necessitate long-term monitoring of the groundwater and surface water, fauna and flora, and other ecological factors. Financial assurances (bonds) are often required by the permitting agency, so that in the event that the mine operator is not able to do so, the agency can close the mining operation, perform the requisite reclamation, and conduct all mandatory long-term monitoring.. The AEMP affects the cost estimates, timelines, and related topics that are involved when the operator requests release from all or part of the financial guarantee with the agency.

From the range of subjects dealt with in these chapters, it is obvious there is considerable debate as to how mined land reclamation should be conducted. Local conditions and stakeholder desires play a significant role in determining which types of rehabilitation should be performed. Whereas the fundamental principle of rehabilitating the mined lands is valid and should be obligatory, the specific approaches and desired end results remain a local decision. Several mined areas have been recovered with office parks, shopping malls, golf courses, and other beneficial uses, but these are only viable if they are in proximity to urban areas. Several mountaintop areas have been converted to airfields, examples of which include Logan County Airport in West Virginia; Big Sandy Regional Airport in Martin County, Hatcher Field Airport in Pike County, Julian Carroll Airport in Breathitt County, Wendell H. Ford Airport in Perry County, all in Kentucky; and Lonesome Pine Airport and Grundy Airport in Virginia (Gardner and Sainato 2007). On the other hand, when Australia's BHP Billiton wanted to turn over a wastewater treatment plant to the community of San Manuel after the mine was closed, the residents rejected the offer (TucsonCitizen.com 2007).

Broad guidelines for mine closure are helpful, but these should be flexible enough to incorporate local conditions and community input. Government regulations and enforcement mechanisms are necessary to ensure that certain minimum criteria are met.

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CHAPTER 20

Global Implications and Challenges of Evolving Mine Closure Requirements in Western Australia

Nina Hall and Steve Hall

INTRODUCTION

Western Australia (WA) is one of the world's leading mining jurisdictions, and Australian companies and professionals, many based in Perth (the state's capital), are involved in global resource project development. Other jurisdictions have adopted elements of the legislation governing the Western Australian mining industry, including those applicable to mine closure. Recent innovation in the legislation is described and critiqued in this chapter, in particular where it might hinder community acceptance of a possible outcome other than replacement of the original environment. A paradigm shift is required to regard the mine void as an asset to enable it to be the foundation for ongoing productive activities; however, examples from Western Australia and other parts of the world demonstrate what is possible in the supply of water and energy, contributing to food security and tourism.

SUSTAINABLE DEVELOPMENT AND MINE CLOSURE FRAMEWORKS

Sustainable development in the mining sector was initially focused on the economic sustainability of the mining companies. Under societal pressure for the companies to improve their safety, environmental, and social performance, it was later extended to include impacts of mining operations on communities and ecosystems. Ensuing complexity emerged since each stakeholder—industry, business, employees, community, and government—could define *sustainable development* in its own way (Waye et al. 2009). Divergence in perspectives such as protecting the

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environment for the local community, sustaining profits for businesses, sustaining revenues for the government, and sustaining mining jobs for workers was further confounded by diverse sectoral interests bringing more complexity to the endeavors to operationalize the concept.

Increasingly, mining companies world over are embracing the need to incorporate sustainable development into projects and governance. A study of the sustainability initiatives implemented by Anglo American, BHP Billiton, CVRD, Inco, and Rio Tinto (Lins and Horwitz 2007) shows that there is a business case for sustainable mining. The implemented initiatives included the use of new technologies to reduce energy; conversion of wastewater into potable water; preservation of water resources by conservation, recycling, and minimizing pollution; reduction of emissions and waste products; reuse of waste materials in smelting operations; local employment; reclamation of biodiversity in areas impacted by mining operations and maintenance of existing biodiversity in land holdings; provision of training programs and health care for the community; and identification and protection of subsistence-related resources of local communities with a focus on water, plants, and wildlife.

Although the term *business case* is not defined, to the authors of this chapter it means investing resources into an initiative or an enterprise with a view to yield a significant return. As such, it validates the argument put forward by Lins and Horwitz (2007) that there is a business case for sustainable mining: greater attention to social and environmental concerns can add value to a company and protect its "social license to operate."

Past closure requirements (if any) or minimal community expectations have left a legacy of global mining and smelting sites that feed the negative perceptions of the industry. Historically, mine closure happened when advanced exploration or mining ceased and the disturbance was left as abandoned sites—typically as an "eyesore" with dangerous physical hazards (e.g., shafts, pit faces, unusable land, tailings dumps) and often with significant negative long-term environmental impacts (e.g., acid mine drainage, subsidence, and dust). Many such sites around the world have become tourist attractions and continue to compound the impression of poor environmental performance by the mining industry, both current and future. Such a negative perception together with media sensational reporting of mining accidents leaves much of the general public with a negative image of the industry. The resultant public opposition to mining often clouds the development benefits that society has reaped from mining over many centuries in many nations and leads to greater costs to the mining industry during the approvals process.

Abandoned mine sites are named by the United Nations Environment Programme (UNEP) as one of the major outstanding international environmental problems related to mining and represent a legacy of centuries-old practices of inadequate, insufficient, or nonexistent mine closure (UNEP 2001). The closure cost was not the only reason for delayed action by industry, government, and

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communities: the absence of clearly assigned (or assumed) responsibility and the standards of rehabilitation played a part (UNEP 2001).

Appropriate regulations not only provide for comprehensive mine closure and the establishment of obligations, rights, and responsibilities for every party, but they also assist in defining postmining activities. According to the International Institute for Environment and Development (IIED), governments should ensure that mine closure planning also includes consideration of economic activities in affected communities, opportunities for displaced workers, social infrastructure, and other appropriate issues (IIED 2002). Diverse agendas of the involved stakeholders call for well-defined legislative and fiscal regimes. According to a number of sources (ICMM 2008; IIED 2002), however, the legislative frameworks in a majority of mining countries are affected by inadequate policies, fragmentation, and lack of resources for monitoring and enforcement.

Government's role in mine closure primarily revolves around being a guardian and a regulator. Through legal mechanisms, government acts as a guardian for the environment and the community, and is effectively the regulator of the mining industry. Within the context of sustainable development, the scope and dimensions of governmental responsibilities are moving up and down the temporal scale. Now government has to cover environmental, social, and legal matters in the present, future, and, in many cases, the past to deal with the legacy of abandoned mines and mines that met expected standards of closure of previous generations but are unacceptable today.

Recognizing that mine closure is a significant part of the mine's ultimate contribution to an area's social, economic, and institutional development, the International Council on Mining and Metals (ICMM) produced practical guidance, *Planning for Integrated Mine Closure* (2008), to deal with technical and management challenges. The document is structured according to the mine life cycle with a focus on better planning, financial assurance, and legacy issues. It takes into account the perspectives of financial institutions, mine operators, and governments; and covers funding, regulation, partnership, and local community participation. The ICMM recommendations are based on the closure practices and examination of financial regulations in the environmental domain across the sector. The mining industry is being encouraged to consider closure planning as a part of its core business and to contemplate changes of social, environmental, and economic outcomes for the community after closure (ICMM 2008).

In Australia, there are three levels of government: federal, state, and local. On the federal or Commonwealth level there is no national regulatory framework for mining, so governments in each state and territory have produced mining legislation for their jurisdictions (Australian Capital Territory: Land [Planning and Environment] Act 1991; Northern Territory: Mining Act 1980; New South Wales: Mining Act 1992; Queensland: Mineral Resources Act 1989; South Australia: Mining Act 1971;

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Tasmania: Mineral Resources Development Act 1995; Victoria: Mineral Resources Development Act 1990; Western Australia: Mining Act 1978).

States and territories have the authority to legislate for mineral resources located within their boundaries; however, the Commonwealth Parliament's powers can supersede any inconsistent state legislation. As to local administration, Worrall et al. (2009) note that the local government has very little ability to influence mining-related activity but is often forced to deal with the consequences, particularly social consequences.

In Australia, *Mine Closure and Completion* (DITR 2009) and *Mine Rehabilitation* (DITR 2006) form part of the Leading Practice Sustainable Development Program for the Mining Industry (LPSDP). The program was launched in 2006 and is administered by the Department of Resources, Energy and Tourism (DITR). Within the framework of the LPSDP, working groups of government, industry, research, and community representatives have developed an internationally successful series of 15 handbooks. The handbooks promote sustainable development and industry self-regulation through adoption of leading practice principles and encourage a shift in attitudes and technologies.

Although the principles guiding leading practice are often generic, they can be used to support site-specific sustainability planning (DITR 2006). Companies are required to submit mine closure plans at the beginning of the approval process, together with financial bonds held against any failure to comply with regulated closure requirements. Closure planning should continue throughout the life of the mine and include activities such as access road construction, drilling, bulk sampling, trenching, building of associated infrastructure, extraction and processing of ore, and management of waste rock and tailings. This approach not only enables better environmental outcomes but also exemplifies good business practice, avoiding the need for costly remedial earthworks late in the project life cycle (DMP and EPA 2011).

As stated in *Mine Closure and Completion* (DITR 2009), taking a more integrated approach to mine closure planning, and doing it earlier, can achieve effective mine closure and ameliorate the negative effects of unexpected or unplanned closures. Any completion plan should ensure that future public health and safety are not compromised, environmental resources are not deteriorating, adverse socioeconomic impacts are minimized, and the postmining use of the site is sustainable in the long term (DITR 2009).

MINE CLOSURE IMPACTS

The extractive nature of mining generates impacts with lasting consequences. Environmental and, to a certain degree, social concerns over mining impacts were discussed as early as five centuries ago when a German scholar, Georgius Agricola, created the classic mining text *De Re Metallica* (1566). Writing in Latin, Agricola

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presented everything known about mining at that time, including mine site selection, machinery and equipment, digging and surveying methods, assaying ores, smelting, beneficiation, mine management, and mining law. Agricola looked at qualities necessary to become a miner as well as the risks, hazards, and work-related diseases of the profession that, in his view, was an honorable and respected occupation. Criticism that mining can bring damage to vineyards, destroy forests, and contaminate brooks and streams was well acknowledged; however, Agricola came out with some strong arguments in favor of the extractive industry:

- Deforested land can be used for cultivation.
- Mining occurs in remote places far from pastures, olive groves, and crop fields.
- Game and foul will move to another location.
- Mining creates more wealth than agriculture.
- Society needs mining products.

Knowledge of mining impacts has greatly expanded since Agricola's time, but his arguments are still being used today to highlight the benefits and value of mining to the economy and society. Many significant, positive changes have taken place in mining practices, bringing transformation to the areas previously neglected. One such area is mine closure. Challenges, however, did not disappear and they remain present at every stage of the mine life cycle, given that population growth is causing conflicting demands on land usage globally.

Environmental concerns associated with mine closure include impacts on terrestrial (flora and fauna) and aquatic ecosystems, surface water, and groundwater; off-site discharges from mine wastes storage; and potential pollution (airborne particulate matter, acid and metalliferous drainage). Presence of artificial landforms such as waste dumps; soil erosion, pit lakes, and pollution of groundwater; biomagnification; potential species extinction; and spread of weeds are among the key impacts of mining. Examples of extreme negative impacts are well known: itai-itai disease caused by heavy metal pollution from the Kamioka mine in Japan (Kaji 2012); river pollution resulting from copper mine tailings at the Ok Tedi mine in Papua New Guinea (Banks and Ballard 1997); and the Baia Mare tailings disaster in Romania (Rico et al. 2008).

Rehabilitation is the principal process employed to mitigate long-term environmental impacts. Its objectives can vary from simply converting an area to a safe and stable condition, to a complex restoration of natural ecosystems and establishment of the premining settings as closely as possible to ensure the future sustainability of the site. The mining method will differ greatly between commodities (e.g., a large, open pit, bulk commodity extraction compared to low-volume, high-value, near-surface subsoil extraction), as will the ecosystem value and proximity to population. For example, the rehabilitation objective of Alcoa—whose Australian operations represent the world's largest integrated bauxite mining, alumina

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refining, aluminum smelting and rolling system—has been the restoration of the unique jarrah forest ecosystem. It is regarded as a successful operation (Koch and Hobbs 2007) conducted to high standards of environmental performance and mine rehabilitation. At a cost of A$34,000 per hectare (Gardner and Bell 2007), a self-sustaining jarrah forest and its recreational and conservation values have been restored within 75 km of Perth, Western Australia's state capital. On the other hand, economic rehabilitation solutions to remote, large open pit gold and iron ore mines might never be found.

Benefits of progressive rehabilitation include time-saving cost reduction by the use of on-site resources, distribution of rehabilitation expenditure over the life of mine, and better rehabilitation outcomes. Otto (2010) indicates that many mines will undertake progressive rehabilitation work during mining operations, whether required to do so by regulation or not, because the scheduling of reclamation activities throughout the life of the mine (progressive rehabilitation) will result in less onerous final closure costs.

MINE CLOSURE COSTS

Estimates of closure costs can vary from broad approximations to detailed estimates (AusIMM 2012). It is recommended to outline the method used to estimate closure costs and ongoing activities, and provide a description if indirect costs, contingences, allowances are included. It may be necessary to express rehabilitation, redundancy costs, and salvage and scrap values as functions of the closure date, if the evaluations will vary parameters that will change the mine life.

Many mines have projected lives of 20 to 50 years, and the focus of economics is to maximize the financial returns to investors by moving into profitability as soon as possible. The nature of such modeling detracts from any emphasis on significant closure costs in this period. The ongoing liability might be lost on the current generation of shareholders who can sell their shareholding at any time should they so desire. The ongoing liability might even be planned by the current owners to be passed onto other owners via a sale at some time in the future. However, this assumes that new owners can be found to take on such liability, though this would be factored into the price. Figure 20.1 demonstrates that current economic modeling using the time-value-of-money concept (net present value, NPV, and internal rate of return, IRR) is very minimally impacted by closure costs years into the future of any operation.

Unfortunately, all mines are impacted by fluctuating mineral prices. Increase in price can prolong the operation period of a mine (i.e., increase the "reserves" or tonnage that can be profitably mined). A price decrease, especially over extended periods of time, can result in premature closure (i.e., decrease the "reserves" that can be economically mined). Definition of reserves forms the basis for mine planning and reporting of mineral assets. According to Taylor et al. (2012), determinants of

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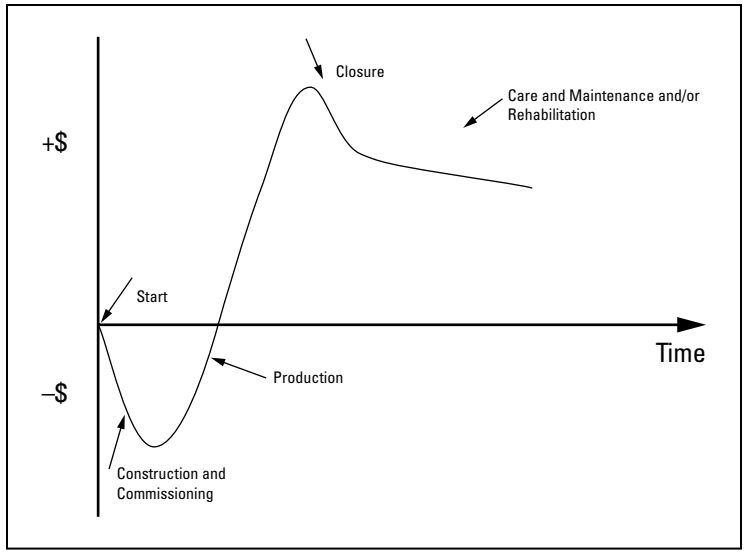


Figure 20.1 Stages of mine site operation and impact on cumulative cost

reserves disclosure for the Australian extractive industries are positively associated with factors relating to corporate governance, foreign listing, existence of reserves in foreign jurisdictions, pledging of reserves in debt covenants, leverage, and external audit, followed by company size, shareholder concentration, and the development/production stage.

Reserves are evaluated from extensive and expensive exploration drilling that continues as a mine develops. Although the financial regulator (i.e., global stock exchanges) closely defines these reserves, operating mines rarely have more than a few years of production characterized. Reserve definition continues along with production. Hence, in recent Western Australian legislation, mining companies of proposed and current mining operations are required to submit a closure plan based on their current reserves, even though they know or suspect that further reserves will be delineated to extend the mine life well into the future.

This is a complexity of the industry that the general public cannot be expected to appreciate; however, the media will gladly run "Mine to Close in 5 Years" stories once a closure plan by the local mine has been lodged. Narratives of this type impact community confidence in their employment, property values, and any feeling of permanency and sense of place. Many abandoned mining communities around the world allude to the only one certainty about any mine: that it will close; yet many mines have closed more than once. Laurence (2011) has reported that around 75% of mine closures in Australia during 1981 through 2009 were unplanned or premature—or that only 25% were planned. Worldwide, the estimate for the number of abandoned mines is well over 1 million (Wolkersdorfer 2008).

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ENVIRONMENT AND RESOURCES INDUSTRIES

Western Australia is one of the most biologically diverse regions in the world, ranging from subalpine areas to tropical rainforest and desert. The southwest of Western Australia is one of the world's 34 internationally recognized terrestrial hotspots for biodiversity and the only one recognized in Australia (Cole 2006). The state contains a 2.5 million km^2 mainland, more than 13,500 km of coastline, and more than 10,000 offshore islands. It is home to

- 141 of Australia's 207 mammal species, 25 of which are unique to Western Australia;
- 439 reptile species, 187 of which are unique to Western Australia;
- More than 1,600 fish species;
- Hundreds of thousands of invertebrate species;
- More than 12,000 species of vascular plants; and
- An unknown number of fungi, lichens, and other nonvascular plants (EPA 2013; Beard et al. 2000).

Large areas in Western Australia are available for exploration and prospecting for the mining industry; however, to meet government and community expectations, a minimal environmental impact and ongoing emphasis on environmental management are vital. The WA Department of Mines and Petroleum (DMP) is responsible for the regulation of the resources sector in the state and stands as the lead agency for all mining, petroleum, and geothermal projects. A key obligation of the DMP as a regulator is to ensure that environmental impacts associated with these projects are minimized (DMP 2011).

The main resources extracted in Western Australia are iron ore, liquid natural gas, gold, alumina, and nickel; however, more than 50 minerals are mined in Western Australia at nearly 1,000 mine sites, far more than any other state or territory of Australia. Underpinned by strong demand from Asia, in 2012 the industry was worth $97 billion and accounted for a substantial 87% of the state's total merchandise exports. Western Australia was the country's largest exporter in 2012, contributing 46% ($114 billion) to Australia's total merchandise exports. Over the past 10 years, royalties received by the WA government have increased 386%, reaching $5.1 billion in 2012 (DMP 2013a).

GUIDELINES FOR PREPARING MINE CLOSURE PLANS

A new contribution to mines closure was made in 2011 when *Guidelines for Preparing Mines Closure Plans* was released in Western Australia. The objective of the guidelines is to ensure that an effective planning process is in place throughout the life of mine, so mines can be closed, decommissioned, and rehabilitated in an environmentally sustainable manner, consistent with agreed postmining land uses and without unacceptable liability to the state (DMP and EPA 2011).

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The guidelines were jointly developed by WA government agencies of the DMP and the Environmental Protection Authority (EPA) after in-depth consultations with other regulators, industry, and the community. Aimed at advancing the performance of mine closure in Western Australia, this useful collaboration resulted in a comprehensive document designed to deliver improvements in environmental and social outcomes. By following an integrated approach to mine closure planning, the guidelines facilitate mining companies to produce closure plans and minimize costs. Another result of collaboration was rationalization of the process since the guidelines reduce regulatory overlap between the Mining Act 1978 and the Environmental Protection Act 1986.

The guidelines implement changes to the Mining Act 1978 as agreed to by the WA Parliament. Since July 2011, a mine closure plan has to be submitted as part of all mining proposal applications. Where a proposal is subject to a formal environmental impact assessment (EIA), the mine closure plan must be provided as part of the EIA documentation. After plans have been approved, they are to be made available for public consultation. Every approved plan must be reviewed every 3 years to ensure that it is relevant to the current status of the mine life cycle and the necessary data have been incorporated. If a mining company fails to fulfill its environmental obligations, the government would use the closure plan to rehabilitate the site.

The guidelines set out the structure and content of a mine closure plan. The plan should contain a register that identifies closure obligations and commitments under state and federal legislation; collection and analysis of closure data; individual tenement conditions; stakeholder consultation; postmining land use and closure objectives; provision for identification and management of closure issues; development of completion criteria; financial provision for closure; and its implementation, monitoring, and maintenance.

In regard to postmining, the guidelines stipulate that the mine closure plan must identify postmining land uses and set out site-specific closure objectives consistent with those land uses. The closure objectives must be relevant to the environment in which the mine is operating, achievable in the context of postmining land capability, acceptable to the key stakeholders, and ecologically sustainable in the context of local and regional development (DMP and EPA 2011).

Where possible, proponents are encouraged to achieve improved land management and ecological outcomes on a wider landscape scale, as well as to consider the potential for multiple land uses. According to the guidelines, it may be acceptable for provisional postmining land uses to be identified at the early stage of a mining project. This requires that there has been adequate initial consultation with the key stakeholders and that there is a clear process and timeline to further refine the agreed postmining land uses as part of the stakeholder consultation process. To determine postmining land uses, the guidelines put an emphasis on the following land-use hierarchy:

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1. Reinstate "natural" ecosystems as similar as possible to the original ecosystem.
2. Develop an alternative land use with higher beneficial uses than the premining land use.
3. Reinstate the premining land use.
4. Develop an alternative land use with other beneficial uses than the premining land use (DMP and EPA 2011).

As can be seen from the hierarchy, environmental reinstatement is given priority and the site is to be returned to as near a condition as possible to that existing prior to the commencement of mining. This, however, carries a strong possibility of ignoring or relegating to a lower category of preferred outcome an alternate use for the site. Moreover, it has been noted in the literature that rehabilitation of highly disturbed landscapes such as mine sites may not provide realistic opportunities for the ecological processes associated with ecosystem recovery to occur, and the target ecosystems may be quite different from prior to disturbance (Doley and Audet 2013).

Linguistically, the word *hierarchy* represents a ranking arrangement where items are categorized according to their status. The Cambridge Dictionaries Online (2013) defines *hierarchy* as a system in which people or things are arranged according to their importance. *Land-use hierarchy* implies that the first option is the best, and those listed below are less preferred. In this regard, WA guidelines are no different to legal requirements for developing closure plans in other countries (e.g., a majority of mine sites in Canada have to be returned to their premining uses, such as forestry). According to the guidelines, a mine closure plan is a "living document" (DMP and EPA 2011), so it should evolve to allow for innovation and changed circumstances; however, a predetermined hierarchy might, to some extent, inhibit this process.

As noted more than 10 years ago, the requirements tend to be heavily oriented toward environmental concerns, leaving socioeconomic aspects of closure as an externality (IIED 2002). Therefore, explaining to the community that the closure plan suggests solutions for postmining land uses down the bottom of the hierarchy will create unnecessary difficulties even if the fourth option can be the most appropriate solution for that location. Left as a list, all indicated postmining land uses would be seen as equally valid choices, reinforcing the integration of social considerations in mine closure planning.

To assist with plan preparation, the guidelines provide a comprehensive closure plan checklist to consult prior to submission. Any negative answer to the questions on this checklist suggests that a mine closure plan needs more work. A positive answer to every question signals that the plan has been prepared in accordance with the guidelines and that requirements of the DMP and EPA have been met. Although the checklist was developed for Western Australia, mining operators working outside this Australian state might find its questions applicable:

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- Is the plan site-specific, representing the characteristics of the area likely to be impacted by mining? Generic or "off-the-shelf" plans are not adequate.
- Is stakeholder consultation documented in the plan, including how stakeholder concerns have been addressed?
- Have the closure issues been identified, with workable management measures to address those issues?
- Have material and site characterization been undertaken to identify potential closure issues?
- Have appropriate closure outcomes been defined, including final land uses and objectives, closure criteria, and (where applicable) performance indicators and milestones?
- Has experience from other mine sites been applied at this site?
- Are there appropriate plans in place for further research and field trials (where applicable)?
- Are there appropriate plans proposed for progressive rehabilitation?
- Are there appropriate plans proposed for closure monitoring and maintenance?
- Are there appropriate plans proposed for unexpected closure, temporary closure, care, and maintenance? (DMP and EPA 2011)

The guidelines are regarded nationally as the best practice framework and are being used by Australian companies operating offshore, often to satisfy investors and shareholders in multiple jurisdictions (including where the mining operation is located). McCullough (2013) provides example of the guidelines recently applied in Laos.

The financial provisioning for closure is of particular importance since the economic indicators of NPV and IRR do not acknowledge the significant financial impacts of mine closure costs, especially of a long-life operation during which regulatory requirements and community expectations will change. According to the guidelines, a mine closure plan must contain a summary of costing methodology to demonstrate to the DMP and EPA that the costs of meeting closure outcomes as identified in the plan have been reflected in corporate accounts. The methodology must be transparent and verifiable. The cost estimates must take into account all aspects of rehabilitation and closure activities.

FINANCIAL SECURITY OF CLOSURE COMMITMENTS

To guarantee financial resources to deal with site restoration, mining companies have long been required to provide certainty to the government that money will be available for mine closure, even if unforeseen. The environmental financial assurance instruments include sureties, which are guarantees issued by a bonding company, an insurance company, a bank, or another financial institution that agrees to hold itself liable for the acts or failures of a third party.

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Examples of sureties are fidelity bonds, surety bonds, performance bonds, and letters of credit. Another form is a cash deposit with the responsible government agency (ICMM 2005). Details and types of environmental financial assurance are given in the appendix of the *Financial Assurance for Mine Closure and Reclamation* report (ICMM 2005). This report underpins one of its sustainable development principles, that is, "to seek continual improvement of our environmental performance," which includes a commitment to meet mine closure requirements financially (ICMM 2005) and emphasizes the need for policies that are effective in meeting environmental objectives and are compatible with a healthy investment climate.

In Western Australia, environmental bonds are used as a form of security to protect the state against financial liability. All Mining Act 1978 tenement holders are required to post bonds through their bank to cover site rehabilitation costs. However, over the years, it was found that the system of mining securities, based on unconditional performance bonds, was lagging behind the rising cost of rehabilitation. Despite previous increases in bond amounts, the DMP estimated that only up to 25% of total rehabilitation liabilities for a site were covered, so the government had to pay the rest in case of a closure obligations failure by a mining company. The use of bond money was restricted to a mine for which the security was held. Also not addressed was the legacy of abandoned mines—including physically altered landscapes, pit voids, spoil piles, open shafts, subsidence, surface tailings storage facilities, derelict plants, vegetation loss, and eroded landforms. In addition, money that could be used during the initial exploration stage was not accessible, sometimes precluding potential development.

To reform the system and achieve better environmental outcomes, the WA government considered several options. Another increase of bond value was rejected, and—following extensive discussions with mining professionals and environmental experts, as well as public consultations and independent reviews—a new system, the Mining Rehabilitation Fund (MRF), was proposed. The MRF is designed to secure rehabilitation obligations of tenement holders and clean up abandoned mines. It is expected that it will encourage progressive rehabilitation throughout the life of the mine.

As indicated by Western Australian Minister for Mines and Petroleum Bill Marmion, the MRF provides the opportunity to fix the mistakes of previous generations and will remove the risk of taxpayers having to fund rehabilitation work on abandoned mine sites. The MRF has been set up around an annual levy to be paid by mining companies, and it will largely replace the current system of unconditional performance bonds. This levy will not diminish the responsibilities of mining companies to meet their environmental obligations to properly rehabilitate their mine sites (Parliamentary Debates, August 13, 2013).

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The Mining Rehabilitation Fund Act 2012 (Western Australia) came into effect in July 2013. All tenement holders (Mining Act 1978) are required to pay an annual levy contribution into the MRF. New projects commencing operations prior to July 2013 may still be required to post a partial or full bond. New projects commencing after July 1, 2013, may choose to participate in the MRF and avoid supplying a bond. Contributions will be assessed by the DMP on a per-tenement basis rather than the whole of a project.

To estimate the total closure liability and rehabilitation costs, companies will submit data online to the DMP declaring the number of hectares of disturbed land and the type of disturbance in each tenement (DMP 2013b). The contribution rate is planned to be 1% of the rehabilitation liability estimate. Tenements with a rehabilitation liability estimate below a threshold of A$50,000 will not be required to contribute but will still have to report the disturbance data. Interest generated by the pooled contributions will be used to pay for administering the MRF and carrying out rehabilitation works on abandoned mines sites.

Currently, the DMP holds approximately A$1.15 billion in unconditional performance bonds across more than 5,000 tenements. The MRF means that A$1.15 billion will be available for mining companies to invest in Western Australia (Parliamentary Debates, August 13, 2013).

The DMP has indicated that a voluntary opt-in joining period will last for 1 year. After July 2014, joining MRF for the industry will become mandatory. If a company chooses to join during the voluntary period, it would not be paying an environmental bond and would get money it paid under the previous legislation refunded. For example, Horseshoe Metals, an Australian copper-and-gold-focused exploration company, has decided in favor of early participation and joined MRF, which the government has approved. The annual MRF levy charge for the company is calculated to be A$43,000. Its existing environmental bond was released, and the company gained around A$1 million cash. Now Horseshoe Metals has additional funding to potentially allocate toward the company's highly prospective Western Australian projects (Horseshoe Metals 2013).

Industry support for the MRF has been high: nearly 600 companies have, so far, expressed an interest in voluntarily opting into the fund (Parliamentary Debates, August 13, 2013). In contrast to the environmental bonds, mining companies will not receive a refund on their MRF payments upon completion of the rehabilitation work, but the new fund is still expected to be considerably cheaper for the mining sector. The DMP estimated that it will save the industry somewhere between A$300 million and A$500 million a year. It is seen as a win–win for industry, government, and the community.

As of July 31, 2013, nearly A$58 million of unconditional performance bonds has been retired, freeing up cash at a time when mining companies particularly need it (Parliamentary Debates, August 13, 2013). All in all, the innovative new

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regulations have now allowed much of this capital back to the sector, especially at the time of a difficult financial situation.

IMPLICATIONS OF MINE CLOSURE FOR COMMUNITIES

Implications for communities are complex and depend on many factors, including community structure, history, demographics, degree of reliance on mining, links with the regional economy, and economic diversification. Pearman (2009) observes that mines can provide a sense of cultural heritage, distinctiveness, and pride over generations, and a mine closure can devastate entire communities with one blow.

Employment, housing, municipal and other services are most likely areas where implications will emerge. The requirement for sustainable employment in the area impacted by mining is becoming an important issue in corporate social responsibility (CSR) and securing a "social license to operate." It is worth keeping in mind that while reinstatement of "natural" ecosystems through revegetation can create regional jobs, significant employment is unlikely to be sustained.

A considerable body of scientific literature relates to environmental impacts following mine closure; however, much less attention has been given to social and economic changes. As noted by Solomon et al. (2008), the relative scarcity of studies on closure, community engagement, and impacts measurement presents challenges for understanding key issues across contexts and for policy making more generally. Stacey et al. (2010) point out that mine closure in the context of developing countries differs from that which occurs in developed countries, in that alternative socioeconomic and environmental options are limited in the former. Yet for developed and developing countries, socioeconomic implications arising from closure pose unique challenges that call for collaborative linkages, working in partnerships, leadership, and building trust.

The authors of this chapter support the view that effective communication among various stakeholder groups, government agencies, and a mining company is critical in any context to achieve the best possible results in employment, services, and community development. This might require the community to develop a new identity and create an alternative social fabric, whether it becomes a retirement town (e.g., Rooiburg in South Africa) or a vibrant tourist and art destination (e.g., Broken Hill in Australia).

Rooiburg became deserted when the tin mine around which the town was formed closed down in the early 1990s; however, far from turning into a ghost town, it became an attractive place to retire, to visit, and even to raise a young family. Broken Hill was built on the world's largest silver, lead, and zinc mine run by Broken Hill Proprietary Company Limited (BHP), now Australia's largest mining company. Although the industry and mining services are still present, Broken Hill has become less reliant on mining as a source of employment and successfully promotes itself as an arts destination, heritage, and Outback tourism

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center. It appears that both places have resilience and strength to survive the impact of mining closure or a significant reduction in mining activity.

The community's capability to search for a new identity and purpose can considerably facilitate the process of rebranding. Conversely, "community" is a notoriously difficult term and concept to define (Littlewood 2013), made even harder by the increasing practice of long-distance commuting to mine sites. Many residents are economic migrants and will leave upon mine closure in pursuit of new opportunities. If communities are to continue after closure, alternate reasons for their existence have to be found. One of the challenges of future purpose can be identified in relation to health and education provision.

An updated *Community Development Tool Kit* (ICMM 2012a) states that, typically, mining companies seek to take immediate measures to alleviate poverty and address other community needs by building schools, clinics or hospitals, and by sponsoring external health and education service providers. For a number of reasons, constructing these buildings is the easiest thing for mining companies to do from their CSR budget. Undoubtedly, such efforts are appreciated; however, in many cases, communities do not have resources to continue these initiatives on their own after mine closure.

As recognized by the ICMM (2012b), the approach is not sustainable and such "donated" projects suffer a swift decline once external support has been withdrawn. Sirolli (2008) asserts that mining companies should look at building the capacity of the communities to survive long after the mine has gone. To do so, a parallel economy has to emerge that may be initially based on providing goods and services to the mine but that eventually would expand and diversify to provide the same to the community, the region, and the country.

Stacey et al. (2010) believe that the importance of social closure is underestimated in overall closure plans as well as recognition of human needs. The outcome of their study, which takes into account the apartheid legacy and was produced for South African closure practitioners and decision makers, reveals that closure is seen as a matter of compliance, not as a vehicle for sustainable development. Also, closure plans have not given much consideration to the developmental opportunities in land usage, infrastructure reuse, and the creation of alternative employment opportunities (Stacey et al. 2010).

The authors of this chapter argue that within the broader context of sustainability, social and economic factors should be given the recognition they deserve when postmining land uses are established. In many ways, such factors will determine the costs of closure and rehabilitation, so the appropriate choice will play a significant role in the future economic and social development of the surrounding communities. Although a mining company cannot be held solely responsible for the local economy, it can make a constructive contribution in its development and trigger positive changes after mining ceases. Expanding the options for postmining

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development can bring more benefits to local communities in the present, amend the legacy of the past, and contribute to the intergenerational equity in the future.

THE CLOSED MINE AS AN ASSET: A PARADIGM SHIFT

The Frazer Institute (2013) notes that along with usual practice to return mine sites to their premining land uses (wildlife habitat and forestry in Canada), the new concept of economic sustainability is finding its way into mine closure plans. Collaborative work of mining companies, regulators, land planners, investors, and citizens seeks to identify the most beneficial use of a mine site leading to the reuse of a number of decommissioned mine sites around the world.

Traditionally, mining infrastructure—including the void created by ore and waste extraction after any mine closes—has been seen as an environmental and financial liability. The authors of this chapter argue that given the millions, possibly billions, of dollars that have been invested in the mine site, it should be regarded as an asset that will last beyond the life of the mine and potentially create income for future generations.

Conversion from a socioenvironmental curse to a valuable asset and locating the pathways from liability to opportunity will require a "paradigm shift" (Kuhn 1970), or change of thinking, in many mining professionals and stakeholders. This innovative thinking—often focused around renewable energy technologies—might retain significant employment in the area, provide ongoing site management, and allow mining companies to transfer ownership of sites with productive capacity rather than incur the cost of management in perpetuity.

Innovative approaches to mine closure will typically evolve incrementally, thereby advancing "best practice"; a paradigm shift could be achieved by regarding the mine void and associated infrastructure as a potential asset in the early conceptual stages of mine planning. Operating mines create wastes and can expose materials that pose risks to the environment. Backfilling provides an opportunity to cover or encapsulate these materials cost-effectively. Following ICMM (2008) recommendations, a risk-assessment process should be used to minimize the negative consequences of closure and maximize the positive benefits, capturing opportunities for lasting advantages. Increasingly, mined voids are being looked at more holistically, as an asset that can reduce costs and postclosure land disturbance as well as minimize operational and closure risks.

A mine site offers significant advantages to any possible future activity. The advantages include security, transport, communication, power and water supply, skilled staff, and water supply within a supportive community. Environmental liability, in particular with regard to acid mine drainage and other fugitive emissions, and physical health and safety issues are potentially the major disadvantages to be addressed. Another factor that substantially impacts the economics of any future

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project is mine waste. Waste sites clearly have low value or negative value (i.e., it is accepted that money must be spent on the site conversion).

The placement of wastes, such as tailings, residues, and salts generated in the mining process, will often reduce postclosure financial and environmental risks. Placement of problematic mine wastes at significant depths in pits or underground voids as part of partial backfilling approaches can address these risks by increasing the path length from contaminant source to receptor and reduce risk by encapsulation. In addition, it is claimed that regulatory agencies and indigenous organizations are increasingly seeing backfilling as a way of returning land to a form that supports premining land use (Puhalovich and Coghill 2011).

Productive Uses of the Mine Site After Closure

Water

In arid regions of the world, quality water availability is a major issue. The growth in population and economy of Western Australia has been very much driven by the mining industry. The gold rush following the discovery in what became Kalgoorlie in 1892 quickly required the provision of drinking water to a relatively large community nearly 600 km from the capital city of Perth. Epidemics of diseases such as typhoid were a greater hazard than mining. The project to pump water through a 30" (75 cm) pipeline that opened in 1903 and is still in operation remains an amazing feat of engineering that opened a large area southwest of the state to agriculture, requiring further expansion of the rail system to handle and export grain (the area remains a globally significant wheat producer).

Mining operations are familiar with handling large volumes of, often saline, groundwater. Treatment of such water, including the recovery of contained salts, should be considered as a supportive activity. New technologies, often involving solar energy, are rapidly being developed (Randell et al. 2011) that can selectively produce salts from highly saline waters. The supply of water to communities, including agricultural uses thus supporting food security and for sustaining productive revegetation, should be considered as part of holistic closure planning.

The interactions between agriculture and mining should continue to develop integrated solutions to community issues, and this conversation is just starting (Crawford Fund Conference 2013). Rio Tinto's innovative use of surplus water from the recent commencement to large-scale, below-water-table iron ore mining operations has resulted in an inaugural bumper hay crop in 2013 from its pastoral leases in the Pilbara (Western Australia).

The Hamersley Agricultural Project (HAP) covers 835 ha of land and takes advantage of surplus water supply generated from nearby Marandoo mining operations to grow pasture for cattle stations operated by Rio Tinto across the Pilbara. The remainder is used to support mine operations, provide water supply for Tom Price township, or is reinjected into the Southern Fortescue Borefield.

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HAP is the first project of its kind in the Pilbara, relying on 35 km of mild steel pipe, 22 pumps, and large-scale associated pumping infrastructure. The completed project uses very large center pivots, each able to irrigate 40 to 50 ha of pasture land (Rio Tinto 2013).

The majority of pivots are now operational, with 15 of the total 17 pivots currently irrigating around 750 ha. One small 7-ha pivot is reserved for growing native seeds for future mine-site rehabilitation.

Renewable Energy

Any mine has a significant requirement for supplies and services, including energy and water. The mine site is a logical location for renewable energy installations, initially as a backup or auxiliary supply to the mine and later potentially as a producer for export from the site, including beyond mine closure. When searching for a renewable asset site, solar and wind farm developers generally focus on land control and land availability—two features that mines have in abundance. Also, mine water can provide a source of low-grade geothermal energy that might be used locally (Malolepszy et al. 2005).

Recent advances within the renewable energy sector have considered connecting opportunities with mining operations in many parts of the world, including, in many instances, legislation changes and economic incentives such as research and development grants. A good example is a multi-stakeholder project in Nevada as one of six demonstration projects within the U.S. Mine-Scarred Lands Initiative (USEPA 2005).

Gold mining operations ended in 1999 at the Bullfrog mine of Barrick Gold, who transferred two mining properties (27 ha and 6 ha) for reuse to the town of Beatty in June 2005. Reuse ideas that have been considered include renewable energy production (e.g., wind and solar), tourism, residential, light and clean manufacturing, warehousing, an industrial park, and automotive testing. Elsewhere in Nevada, Barrick Gold has developed a $10 million, 7,404 solar-panel facility, generating about 1 MW—required under state law to meet a portion of generating needs from renewable energy when users move to become generators. This is part of the change introduced in 2005, allowing large power users to develop their own sources of power. The solar project complements a 115-MW gas-fired station constructed by the company to make it independent of the supply grid, reducing production costs by a reported US$9 an ounce (Seelmeyer 2008).

The U.S. Environmental Protection Agency's RE-Powering America's Land Initiative, commenced in 2008, encourages development of renewable energy on potentially contaminated lands, landfills, and mining sites. The initiative identifies the renewable energy potential of these sites and supports the transformation of liabilities into assets for surrounding communities. Since RE-Powering's inception,

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more than 70 renewable energy projects have been installed on contaminated sites or landfills (USEPA 2013).

Innovative thinking can provide further ideas that might link mine sites and renewable energy, such as a solar thermal tower concept. High winds may create operational problems for the mirror array of the tower; however, placing the mirrors on the benches of an open pit and locating the collector within the pit could remove the need for a tower. Gwiazda and Di Bella (2005) advance a concept of "Pit Power Tower," a new power production technology that combines a solar power tower and a pneumatic power tower in an open pit mine. They point out the considerable number of open pit mines in good solar locations throughout the world (e.g., Australia, South Africa, and Chile).

The use of open pit mines and quarries for waste disposal such as landfills, has long been practiced in many countries. Bell and Donnelly (2006) report that former clay pits are frequently used for disposal of domestic and industrial waste. The decay of organic material generates methane gas that can be captured and combusted for power generation with employment continuing long after mining ceases. For example, around 400,000 t (metric tons) of waste per year is sent by rail from Sydney to the Woodlawn landfill, previously a copper, lead, and zinc open-cut mine. The void has been used as an in situ bioreactor since 2005. Over this time, the bioreactor has taken in more than 2.2 million t of waste from the Sydney metropolitan area as well as producing up to 3 MWh of green electricity using the methane created by the resultant waste (Pickin 2009).

Biomass, Biofuel, and Carbon Sequestration

Crawford et al. (2012) report on the potential of rehabilitated mine areas to grow biofuel crops, pointing out that the costs associated with production are likely to decline with the progression of technology. The advance of fast-growing biofuel crops such as willow via short rotation coppicing on coalmine waste sites has been proposed in the United Kingdom. Since the biofuel is produced near to coal-burning power generators, co-combustion is an economic option; however, the prime driver is the disposal of sewage sludge. In this case, land spreading of sludge does not involve the crop entering the food chain, given that the heavy metals contained in sludge are of concern. A revenue stream can be derived from the disposal of sewage possibly following composting. However, there might be community opposition to it becoming a waste disposal site.

Recent work in Sudbury, Canada, has shown that biofuel crops such as canola, soy, and switchgrass can be grown in layers of waste materials from paper manufacturing on highly sulfidic tailings dams. The concern again is of metal transfer to the food chain via the biomass; however, initial research is showing little transfer of metals to the biomass (Hargreaves et al. 2012; Abedin et al. 2012). Only

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those locations with a significant area of mine waste and tailings might be able to generate sufficient biomass to command a dedicated biofuel production plant and associated employment. On the other hand, the mining activity might trigger a regional development or provide a guaranteed user of a large quantity of product. Many examples exist of mining companies developing biofuel crop projects across many parts of the world.

Research into phytoremediation (uptake of metals by plants) has been conducted as a means of removing metals from otherwise potentially productive agricultural land following the spreading of the sewage sludge (Maxted et al. 2007) or from mine wastes and subeconomic materials (Abedin et al. 2012). In isolation, such projects—including possible metal recovery from biomass—might not be economically viable, but as part of a more holistic view of mine closure, they should be considered.

Amichev et al. (2008) report on the good potential of mine soils to sequester and store significant amounts of atmospheric carbon. Findings of their study reveal that recently rehabilitated mine sites accumulated nearly as much carbon in the tree and litter layer biomass as that sequestered in trees on adjacent, nonmined sites.

Aquaculture

The advancement of alternative sustainable livelihoods for local residents through the development of aquaculture in flooded pits and tailing ponds could contribute to sustainable development. When BHP's Island Copper mine in Canada closed in 1995, the mine was instrumental in attracting and encouraging entrepreneurs who used buildings, dock facilities, and water from the tailings ponds to establish wood-processing and aquaculture operations; that is, sustainable industries were made viable by the availability of the mine's infrastructure (Veiga et al. 2001). The growing significance of aquaculture was highlighted by Otchere et al. (2004), who explored the benefits and barriers to transforming flooded pits and impoundments into aquaculture operations after mine closure.

Miller (2008) reports conversion of two colliery sites into a productive aquaculture facility and a fishing park for which the infrastructure from a water treatment plant is used. The plant was constructed in the mid-1980s to treat acid mine drainage from the underground coal mine. Now the site is open to the public and provides an exceptional catch per unit effort. It is well stocked with healthy warm-water species such as channel catfish, largemouth bass, and bluegill sunfish, and used for community recreation and education. Another example discussed by Miller (2008) is the usage of the water from a closed coal mine to produce commercial rainbow trout.

In both reported cases, the result was financial savings in the range of a quarter to a half million U.S. dollars. Collaboration among diverse organizations was an additional bonus. Economic and social benefits from this innovative postmining

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land use included increased land values, positive media attention for coal companies, new secure water sources, and community recreation.

Tourism and Recreation

Abandoned mining communities in many parts of the world are promoted as tourist attractions. In Western Australia, a nearly 1,000-km Golden Quest Discovery Trail visits many communities that did not survive the closure of the local mining industry. Similarly in the United States, the ghost towns of Colorado tell a similar tale. In west Cornwall (United Kingdom), a United Nations Educational, Scientific and Cultural Organization (UNESCO) World Heritage Site has been declared where much of the landscape was transformed in the eighteenth and early nineteenth centuries as a result of the rapid growth of pioneering copper and tin mining. Its deep underground mines, engine houses, foundries, new towns, smallholdings, ports, and harbors, and their ancillary industries, together reflect prolific innovation which, in the early nineteenth century, enabled the region to produce two-thirds of the world's supply of copper. Many other UNESCO World Heritage Sites (or tentative sites) exist around the globe that have hosted former mining activities.

Pit lakes can provide recreation (Geller et al. 2012) and tourism options such as boating, water skiing, and bathing (Doupé and Lymbery 2005). Tourism is one opportunity; however, for the remote locations, especially in the developing world, projects beyond the preservation and retention of mining heritage may not be viable. One of the most successful projects that has redeveloped a former mine site into a tourism attraction is the Eden Project in Cornwall, England, which is a remarkable story of postmining regeneration (Pearman 2009). Less well appreciated is the extensive work that was done to the soil transformation—a continual site-specific challenge in mine-site vegetation. However, again, a transfer of process engineering skills available in mining regions can offer an innovative and competent work force.

Also, as noted by Conlin and Jolliffe (2011), the transformation process of the mining sites into a tourist attraction presents not only potential but practical challenges for the planners and tourism managers. These include the preservation of the physical site and community mining heritages as well as the health, safety, and environmental factors.

SUMMARY

Mine closure is one of the few certainties in the mining cycle, and many mines have closed more than once. The immediate impact on the local community and environment is self-evident; however, the medium- to long-term impacts on both could be negative and severe. This will reflect poorly on the mining industry promoting opposition to future mining projects.

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Better consultation with associated communities will be beneficial; nonetheless, whether these will be the same communities during mining or at the closure stage can be debatable. Significant inward migration can be expected by wealth creation, direct and indirect employment opportunities, and access to services (e.g., health and education in developed and developing worlds).

Recent industry guidelines and regulatory changes are requiring companies to undertake progressive rehabilitation of sites that allows for the return of financial assurances that this will be completed as outlined in detailed (but not too onerous and costly) plans lodged (and regularly updated) with the regulator. Low-cost satellite imagery and geographic information system tools, together with site monitoring, allow for detailed but often remote monitoring of compliance to accompany on-the-ground community engagement by the mining company.

Innovative solutions to mine closure that value a mine site as an asset rather than a liability beyond mining might assist with the longer-term sustainable future of the communities. Outstanding examples already exist that promote energy, water, and food security that, together with tourism, can provide a very different and positive view of the postmining scenario.

It is anticipated that such innovative solutions will become the norm rather than the exception. The drivers will be community expectations, shared best practices, and stronger local governments. However, the latter will require a fairer share of the mining royalties and taxes to be returned to the impacted communities than has been experienced in the past. It is only through such actions that mining can truly claim to be contributing to sustainable development.

ACKNOWLEDGMENTS

The authors offer sincere appreciation to the book editors and thank Michelle E. Jarvie-Eggart for her continuous support and advice. The authors acknowledge the Department of State Development, the Department of Mines and Petroleum, and the Environment Protection Agency of the Government of Western Australia for their contributions to sustainable mining practices and mining education in Western Australia.

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CHAPTER 21

Identifying Natural and Novel Ecosystem Goals for Rehabilitation of Postmining Landscapes

David Doley and Patrick Audet

INTRODUCTION

Traditionally, the goal for the rehabilitation of mined land (among other disturbance impacts) was to restore or reinstate the predisturbance land use or ecosystem (e.g., Australia DRET 2011). More recently, and in light of shifting priorities in the field of ecological restoration (Shackelford et al. 2013b), acceptable levels of biodiversity and ecosystem function within a range of historical fidelity can be negotiated to promote transparency between the mining proponent and regulator (e.g., ICMM 2013; MAC 2012). In either case, it is commonly assumed that the essential physical resources assembled during the rehabilitation process (namely landform, lithology, and soil) will closely resemble conditions of the predisturbance environment. Although this assumption can be valid for certain less intensively degraded landscapes—such as agricultural, forest, or pastoral lands (Ferris et al. 2000; Chazdon 2008; Bullock et al. 2011; Tongway and Ludwig 2011) and the notable extinguishment of a bauxite mining lease in Western Australia (Gardner and Bell 2007; Koch 2007a, 2007b)—the same may not be applicable to the majority of mine sites where there are radical changes to almost every component of the landscape as well as persistent nonnatural landscape attributes (e.g., open pits, waste heaps, tailings storage facilities) that represent considerable obstacles to restoration (Hüttl 1998; Bell 2001; Cooke and Johnson 2002; Bens and Hüttl 2005; Norman et al. 2006; Herath et al. 2009; Tozer et al. 2012).

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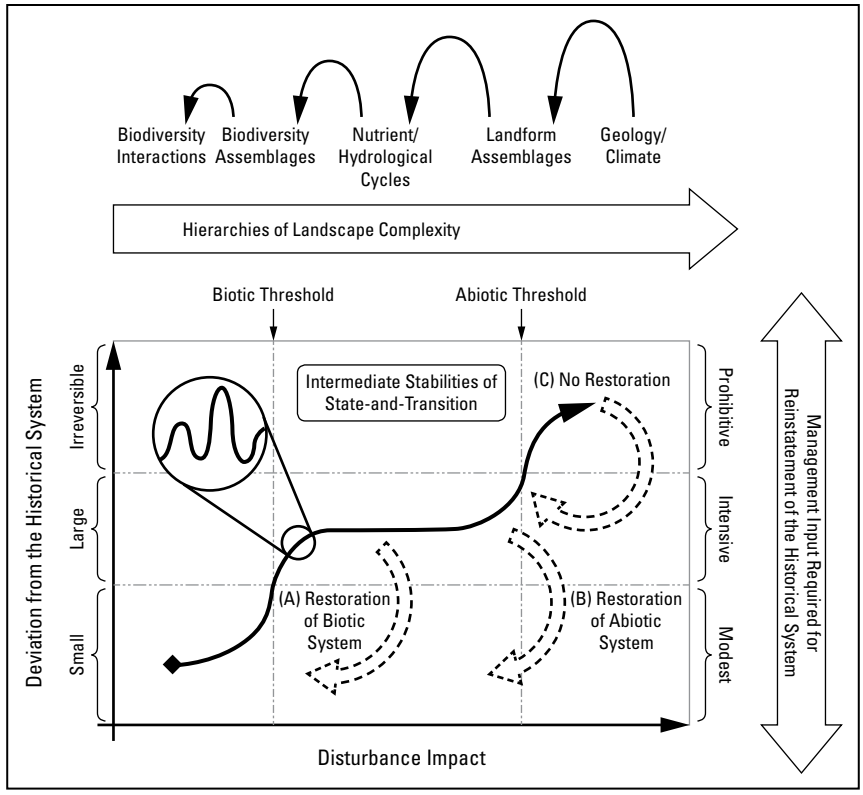
Axiomatically, land rehabilitation becomes progressively more difficult with increasing size and severity of the disturbance impact. Hence, many authors have justifiably questioned whether targeting historical and/or predisturbance ecosystems should always represent the most appropriate restoration goals in these postindustrial environments, particularly within the range of feasible biological and socioeconomic outcomes (Harris et al. 2006; Choi 2007; Seastedt et al. 2008). Likewise, the increasing occurrence of rehabilitated environments for which there are no natural analogues, compounded by consequences of climate change (e.g., shifting ecological boundaries and effects of climate vulnerability; Audet et al. 2013a; Chen et al. 2011), has influenced opinions on whether we should move away from traditional notions of restoration and revise the manner in which rehabilitation goals and trajectories should be addressed (Jackson and Hobbs 2009; Harris and Hobbs 2001). Still, within the context of mined land rehabilitation, suitable alternatives that meet the needs of conservationists (including the broader public and local traditional landowners), practitioners, and regulators in light of these unavoidable challenges remain elusive. This contributes to the risk that rehabilitation activities may not lead to the successful extinguishment of mine leases but rather to the possible under-rehabilitation of postmining landscapes.

A major advancement in the field of ecological restoration and its overarching theories has been the depiction of ecosystems (Figure 21.1) in terms of transitional stability (or state-and-transition) in relation to the integrity and fidelity of biotic and abiotic system components (Grant 2009; Hobbs and Suding 2009), as opposed to simply using indicators of ecological form, function, or biodiversity criteria to describe recovering ecosystems. From this additional perspective, it can be illustrated how increasing size and severity of disturbance impacts affect various hierarchies of landscape complexity (e.g., biodiversity interactions < biodiversity assemblages < nutrient and/or hydrological cycles < landform assemblages < geology and climate). As such, our latest understanding suggests that the degree to which disturbance impacts cause irreversible changes to any or all of these landscape components has a direct effect on the likelihood that rehabilitation activities should result in

- The restoration of natural or near-natural (near/natural) systems (i.e., reinstating a system within its historical range of variability);
- The development of hybrid systems (i.e., being slightly different in form and function, yet sharing many attributes with the historical system); or
- The development of novel systems (i.e., having new combinations of physical and biological attributes as a result of novel conditions within the postdisturbance environment).

This so-called natural–novel ecosystems paradigm (pioneered by Hobbs et al. 2006) is valuable for depicting the general recovery pathways of a range of postdisturbance ecosystems and the management inputs required to reinstate (if

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Source: Doley and Audet 2013.

Figure 21.1 Intermediate stabilities of state-and-transition for ecosystems subjected to increasing size and severity of disturbance impact

practicable) the historical and/or predisturbance system (Jackson and Hobbs 2009). Notably, this depiction implies that the nature of certain disturbance impacts and/or environmental drivers can result in circumstances that prevent a system from "going back to the past" and achieving veritable restoration, particularly when higher-order components of landscape complexity have been affected. In this regard, considerable investigative attention within the context of natural–novel ecosystems has already been directed toward the potential effects and active mitigation of invasive species and climate change on the form, function, and stability of ecological processes (e.g., Harris et al. 2006; Chazdon 2008; Suding and Hobbs 2009; Higgs and Roush 2011; Firn et al. 2013; Hobbs et al. 2013; Monie et al. 2013; Shackelford et al. 2013a). However, there has been some reluctance in approaching the rehabilitation of landscapes following highly assertive anthropogenic activities from a novel ecosystems perspective, possibly for fear of lowering rehabilitation standards (Perring et al. 2013; Standish et al. 2013). This apprehension is especially acute regarding activities such as mining that assert drastic environmental impacts,

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incur high ecological liabilities, and whose postdisturbance landscapes have so few parallels in the natural realm; that is, short of volcanic activity, fire, or catastrophic flooding (Foster et al. 1998). Consequently, there is a clear knowledge gap and incongruity between public expectations and requirements for mine sites (i.e., that highly disturbed landscapes should be returned to their previous level of ecological fidelity relatively soon after disturbance) versus the biological realities preventing veritable restoration; that is, due to the extent to which ecosystems are disturbed in an era of pervading human activity (Hobbs 2004; Rudzitis and Bird 2011).

Given the unifying theme of this volume on responsible mining and its primary objective of establishing how the concept of "sustainability" should be applied within the mining industry, the clear definition of high but still realistic rehabilitation standards must reduce the risk of rehabilitation failure and the consequent physical, financial, and social costs of such a failure. When attempting to restore near/natural landscapes in relation to small-to-moderate disturbance impacts, functional associations between the physical environment and the ecosystems that may persist within it can be used to predict the patterns of distribution of desired plant communities and habitats (Box 1996; Franklin 1998; Kühner and Kleyer 2008; Austin et al. 2009; Kim and Yu 2009; Maestre et al. 2009; Meier et al. 2010; Orwin et al. 2010; Hallett et al. 2013). Yet, because of the severity of disturbance often associated with mining, it may not be realistic to attempt to replace the predisturbance ecosystem that occurred at a particular location.

This contentious issue underlines the necessity and inherent challenge of evaluating landscape design and ecosystem progress toward appropriate rather than aspirational rehabilitation goals (Grant and Koch 2007) while still maintaining the highest standards of biological conservation and ecosystem stewardship (Chapin et al. 2010). Hence, the practice of ecological restoration in the twenty-first century must recognize that novelty and novel ecosystems are an unavoidable and ever-present reality of the contemporary landscape (Ellis 2013), especially postmining environments. To optimally manage or mitigate environmental, social, and economic risks associated with the rehabilitation of mined land, it is emphasized here that a necessary first step should be the acknowledgment that traditional approaches may no longer be appropriate and that long-term ecological outcomes may ultimately differ from the historical or predisturbance system in light of this novelty.

THE NATURAL–NOVEL ECOSYSTEMS PARADIGM

The definition of ecosystem conditions associated with disturbance and recovery has been clarified greatly by Hobbs et al. (2013), having evolved over a decade of consideration regarding assembly rules and ecosystem state-and-transition (Hobbs and Suding 2009). The terms used here to define *novel ecosystems* and to contrast

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them from *near/natural* or *hybrid systems* derive specifically from Mascaro et al. (2013) referring to ecosystems that are not

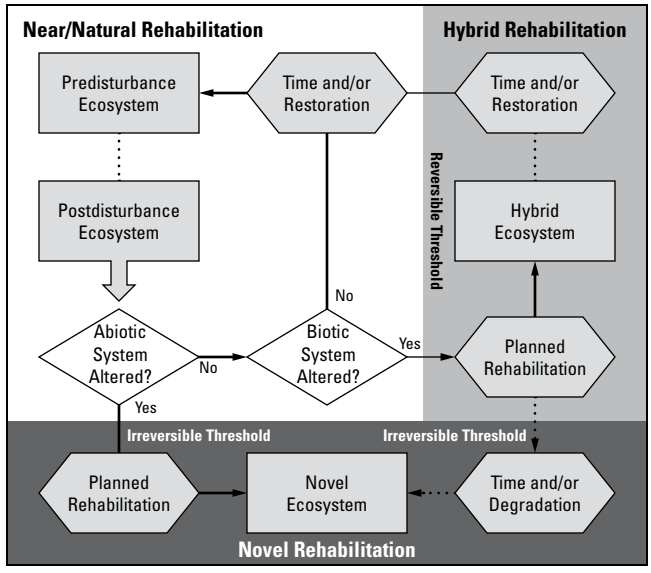
1. A [historical ecosystem] that would have occupied that space in the past (i.e., part of a historical range of variability);
2. A system managed intensively for specific production or built over; or
3. A [hybrid ecosystem] managed with the purpose of reproducing the historical ecosystem (i.e., classic restoration).

Central to this concept is the nature of thresholds between ecological states (Hobbs et al. 2009; Suding and Hobbs 2009) and whether transition across a threshold as a result of disturbance is reversible or not (cf. Figure 21.1, hierarchies of landscape complexity). Although this may not be the case universally, it is common that the size and severity of mining disturbances (or similar) result in the crossing of biotic and abiotic thresholds. Therefore, obvious and subtle changes to nutrient and hydrological cycles, landform assemblages, and, ultimately, geology and climate typically represent considerable barriers to the reinstatement of historical systems. To guide activities on intensively managed lands, the goals of restoration or rehabilitation need to be clarified and, where possible, quantified. This is especially true pertaining to the feasibility of attaining a particular rehabilitation goal in light of the integrity of biotic and abiotic system components (Grant 2006; Choi 2007; Bullock et al. 2011).

In spite of the close relationships between the physical and biotic components of stable landscapes, many mine closure criteria have been expressed in very general terms relating primarily to desired ecological end points such as predominant vegetation assembly and habitat, and not, for example, the collective geologic, climatic, and biological conditions that underpin the form and function of these end points. Often, these criteria are inconsistent with the realities and barriers identified even among *more successful* rehabilitation scenarios (Lindenmayer and Hobbs 2007). Evidently, even within a conceptual realm, the delineation of potential rehabilitation pathways for mine sites would be helpful for establishing why some disturbed mine sites can be returned to their historical status whereas others cannot. Consequently, Doley et al. (2012) and later Doley and Audet (2013) derived a framework (Figure 21.2) for postmining land rehabilitation in Australia in hopes of reconciling relevant aspects of the natural–novel ecosystems theory (Hobbs et al. 2006, 2013) with existing guidelines for land rehabilitation (e.g., Australia DRET 2011), being mindful that such a framework could have similar implications across the mining industry.

Possible development pathways of postmining landscapes were identified (based on existing state-and-transition depictions of ecosystem recovery—cf. Figure 21.1) in relation to the severity of the disturbance impact and the design of rehabilitation approaches. Notions of threshold irreversibility were later added according to Hallett et al. (2013) to distinguish among the respective domains of near/natural

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Source: Doley and Audet 2013.

Figure 21.2 Natural–novel ecosystems paradigm: a conceptual depiction of the development of near/natural, hybrid, and novel ecosystems

restoration, hybrid rehabilitation, and novel rehabilitation. Notably, the intention of the framework was not to redefine hierarchies of land-use or suitability criteria, but rather to identify conditions preventing veritable restoration so that alternative ecological outcomes could be negotiated and optimized at the earliest stages of planning. Within this scheme, ecological and socioeconomic scenarios were described that extended the definition of natural vs. novel ecosystems to the end points of mine site rehabilitation (cf. Doley et al. 2012), culminating in a basic depiction of potential mining outcomes in relation to disturbances and rehabilitation inputs.

Against a backdrop of alternative stable-states theory and state-and-transition modeling (cf. Hobbs and Suding 2009; Grant et al. 2006, 2009), the assumptions of this conceptual framework were simple: under circumstances where the maximum disturbance impact did not exceed the thresholds of ecological resilience (both biotic and/or abiotic), strict adherence to progressive ecological management practices and environmental monitoring could, over time, provide a pathway leading to the successful reinstatement of the predisturbance ecosystems. Consequently, veritable restoration of mine sites can be a legitimate outcome only if the integrity of all of the essential biotic and abiotic system components were not compromised and/or could be restored to predisturbance fidelity. However, more often than not, disturbance impacts associated with mining result in the crossing of at least one (if not more) biotic and/or abiotic thresholds. For example, obvious abiotic

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thresholds (or obstacles to restoration) may include the production of large pits, waste heaps, or tailings storage facilities that alter fundamental landform aspects of the postmining environment, or the development of totally different lithologies occurring at the new or rehabilitated land surface—all of which affect higher-order components of landscape complexity. Meanwhile, more subtle biotic thresholds that characterize the inherent resilience of functional ecosystems may include the loss of soil viability and fertility due to stripping and stockpiling of topsoil (i.e., that should contain native plant seeds and beneficial microbes) or the fragmentation of remnant ecosystems.

Indeed, crossing of each of these respective thresholds will entirely depend on the nature of the mining activity, and this should be tempered by local variations; but the manner in which these determinants of ecosystem function can be managed or mitigated (if at all) will determine the likelihood of veritable restoration versus the development of a hybrid or novel ecosystem. Therefore, under circumstances where abiotic system components (e.g., landform, nutrient, and hydrological cycles) are not significantly altered but biotic components are affected (e.g., above- and belowground biodiversity and assemblages), the postdisturbance environment will often share some attributes of the natural system but also novel ones resulting in the development of a hybrid system.

Over the long-term, these subtle differences can be manifested by a slightly different assembly of dominant species (including nonnatives) and/or the persistence of intermediate (hybrid) stages of development. Then again, where the abiotic and biotic systems are significantly altered or where hybrid systems are allowed to degrade (such as derelict or under-rehabilitated sites), crossing of irreversible thresholds inevitably and quintessentially results in novel ecosystems having an alternative stable state defined by new assemblages of biotic and abiotic system components. Notably, within a novel ecosystem, it is possible to have either biotic or abiotic conditions that are very similar to those of a historical ecosystem; however, no sufficient amount of time or management input could enable a veritable reinstatement of the historical systems.

Under most current ecological management regimes, the development of hybrid or novel ecosystems (albeit sometimes inevitable) is deemed a failure. To the contrary, it is view of the chapter authors (among others) that these systems are an inevitable outcome of pervading human activity in the Anthropocene (Crutzen 2002; Ellis 2013). In this regard, it should be recognized that hybrid or novel ecosystems are not necessarily ecologically undesirable and/or dysfunctional, but their existence certainly challenges traditional styles of ecological management that always (under all circumstances) target the reinstatement of historical systems (Lindenmayer and Hobbs 2007; Hobbs et al. 2013; Perring et al. 2013). Therefore, it is necessary to deal with these realities appropriately and honestly to avoid undesirable outcomes.

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Consequences for Mine-Site Rehabilitation

Determining the pathways and conditions under which ecosystems become natural, hybrid, or novel may appear rather trivial, especially for practitioners who are legislatively tasked with rehabilitating expansive postmining landscapes. Yet, putting theoretical considerations aside, many mining permits still require that preexisting vegetation and sometimes fauna associations are returned to the postmining landscape. This is required prior to any earnest assessment of site conditions within the actual postindustrial landscapes and the range of possible ecological outcomes that may arise in light of these conditions.

During and following land rehabilitation, standardized ecological end-point criteria (biodiversity, structure, function, etc.) can be used to monitor the trajectories of postdisturbance ecosystem development toward desired reference community conditions (e.g., Grant 2006; Gardner and Bell 2007; Koch 2007a, 2007b), and these activities can be guided by landscape and ecosystem functionality analyses that evaluate essential biotic and abiotic conditions for a given regional ecosystem or land use (cf. Tongway and Ludwig 2011). Indeed, this approach has been recommended throughout the mining industry (e.g., ICMM 2013; MAC 2012) as a beneficial step to promote highest standards of ecological stewardship and transparency between the mining proponent and regulator. However, it is not clear whether many of these initial conditions would be satisfied on most mine sites due to the size and severity of the mining disturbance, thereby putting into doubt whether achieving near/natural restoration is possible—unless, of course, "restoration" criteria are grossly oversimplified.

In many cases, the incongruity between rehabilitation expectations and the actual conditions of the postdisturbance environments could account for some of the onerous and often costly procedures required when applying conventional restoration approaches (i.e., that are usually reserved for less assertive disturbance impacts) to highly disturbed postmining environments. Nevertheless, members of the public may prefer to see a mine site restored to its original condition rather than for another undisturbed area to be maintained as an offset (Burton et al. 2012). As a result, even for bauxite mining, which causes relatively little change to major landscape features and does not drastically alter the physical and chemical properties of the site, 85% of the total rehabilitation cost (>US$15,000 per acre) can be associated with engineering works such as reshaping the landscape, as well as ripping and replacing topsoil and woody debris (Burton et al. 2012). For sites where more extensive material movement or chemical treatments are required, the costs of engineering works will be astonishingly greater; paradoxically, the likelihood of reinstating a historical or predisturbance status is much lower.

Companies perceive costs of environmental work as a commercial necessity (Tilt and Symes 1999), so it is necessary that it should be as efficient as possible. To achieve this efficiency and minimize the risk of failure, the costs associated with the execution of earthworks mean that this stage of rehabilitation must be supported

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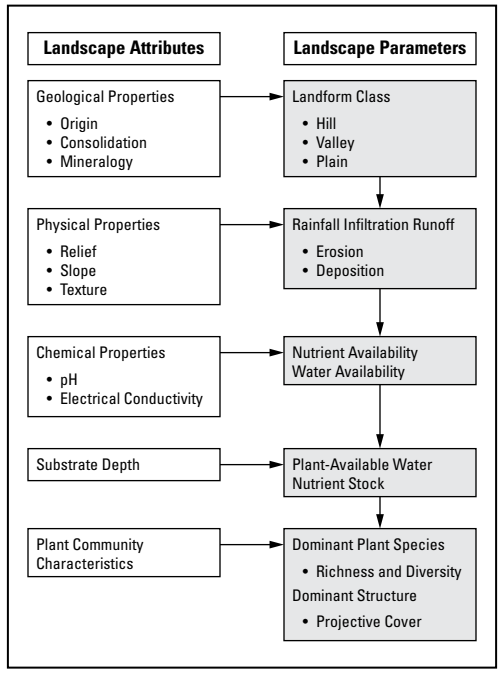


Figure 21.3 Determinants of ecosystem structure and function

by very careful planning and design. For these reasons, mined land rehabilitation planning would benefit from the identification of attainable condition descriptors of postdisturbance landscapes and a careful delineation of the range of ecosystems that may be established under these conditions, rather than an idealized or aspirational target.

Because of the significant requirements of landform reconstruction and extensive topsoil management, these site characteristics need to be addressed in a hierarchical fashion prior to any considerations for more subtle and complex components of ecological function (e.g., biodiversity interactions and assembly). For example, Figure 21.3 presents a summary of this hierarchy whereby, within a given climatic zone, the geological conditions determine feasible landscape, soil, and vegetation conditions. This arrangement of attributes does not mean that every combination results in a unique ecosystem, as there is ample evidence of particular vegetation types occurring on a range of soils and landscapes (e.g., Sattler and Williams 1999; Burgess 2003). Instead, examining conditions of the postmining landscape enables a more thoughtful approach to determining *what range of outcomes is achievable on a mine site rather than what is desired of it.*

By adopting this general approach or something similar, a decision tree (Figure 21.4) ideally supported by large data sets can summarize the tests that identify conditions for restoration (Hobbs et al. 2013) and also the optimal management actions in cases where hybrid and novel ecosystems could represent more practicable

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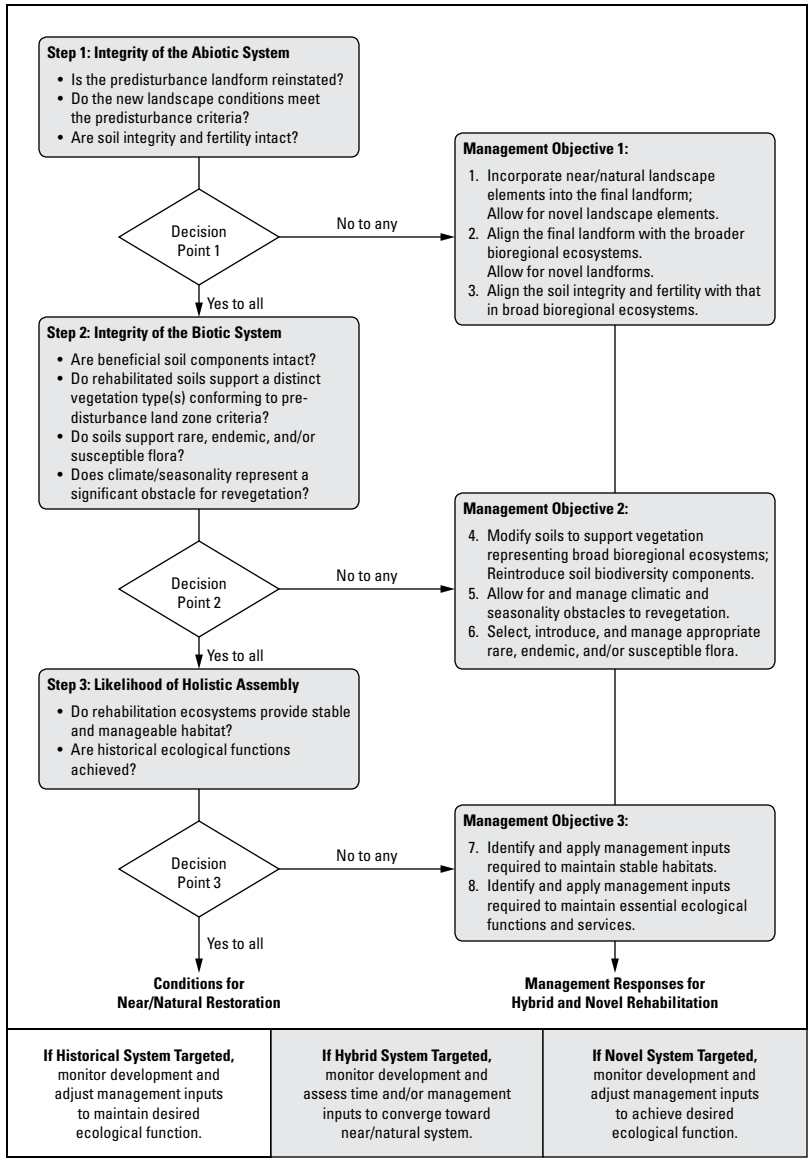
rehabilitation outcomes (Doley and Audet 2013). Figure 21.4 displays conditions, requirements, and likely management responses for near/natural restoration versus the development of hybrid or novel systems used to inform Figures 21.1 and 21.2. Responses to decision points distinguish between the likelihood of achieving near/natural restoration versus hybrid or novel systems. Under better-than-average circumstances, this approach should serve to guide restoration activities where the integrity of the abiotic and biotic system is maintained and reinstatement of the historical or predisturbance landscape is possible. Meanwhile, where the abiotic and/or biotic systems are significantly or irreversibly affected, the carefully planned installation of hybrid or novel ecosystems could represent predictable and achievable options for highly degraded, under-rehabilitated, or even derelict mine sites.

As reiterated by Perring et al. (2013), a key advantage of this approach is that commitments to rehabilitation can be assessed and adjusted ad hoc based on the characteristics and limiting capacities of the postdisturbance landscape. This can be accomplished while also providing opportunities for the incorporation of, for example, novel ecosystem services and enhanced land-use value and valued ecosystem function otherwise not found within the historical or predisturbance ecosystem (Bullock et al. 2011). Nevertheless, being mindful of hubris (Standish et al. 2013), one precondition is that all stakeholders (operator, regulator, and community) are involved in setting and accepting the parameters for decision making—whether the final outcome is deemed to be near/natural, hybrid, or novel (Doley et al. 2012; Doley and Audet 2013). Acceptance of these shared goals and agreed procedures allows for timely evaluation and modification of activities and conditions. It also contributes substantially to the minimization of risk for the operator, regulator, and community.

DETERMINING NATURAL–NOVEL ECOSYSTEM GOALS USING DETERMINANTS OF ECOSYSTEM TYPE

The practice of nominating a particular vegetation association as a goal for land rehabilitation (e.g., remnant vegetation community adjacent to the area of disturbance) assumes that all of the required abiotic and biotic conditions can be reinstated to that of the predisturbance condition. These components of landscape complexity (cf. Figure 21.5) have been described hierarchically by Sattler and Williams (1999) and later by Tongway and Ludwig (2011) and provide an in-depth summary of the factors and physical properties that define functional landscapes, including the stability, toxicity, and persistence of their geology and the quantitative attributes that define their respective land zones. Although any such list would be nonexhaustive due to the complexity of natural ecosystems, a similar approach can be used to define biological attributes that include species richness, diversity, "nativeness", endemism, and so forth. Even though predominant vegetation assemblages and broad-scale bioregional descriptors are often used to

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Source: Doley and Audet 2013.

Figure 21.4 Restoration/rehabilitation decision tree for postmining environments

rapidly define ecosystems, a more accurate depiction (Figure 21.3) would include all (or the essential) of these components for assessment of ecosystem form and function since these criteria would need to be satisfied in order to claim veritable restoration (and not simply a transitory veneer of imposed vegetation).

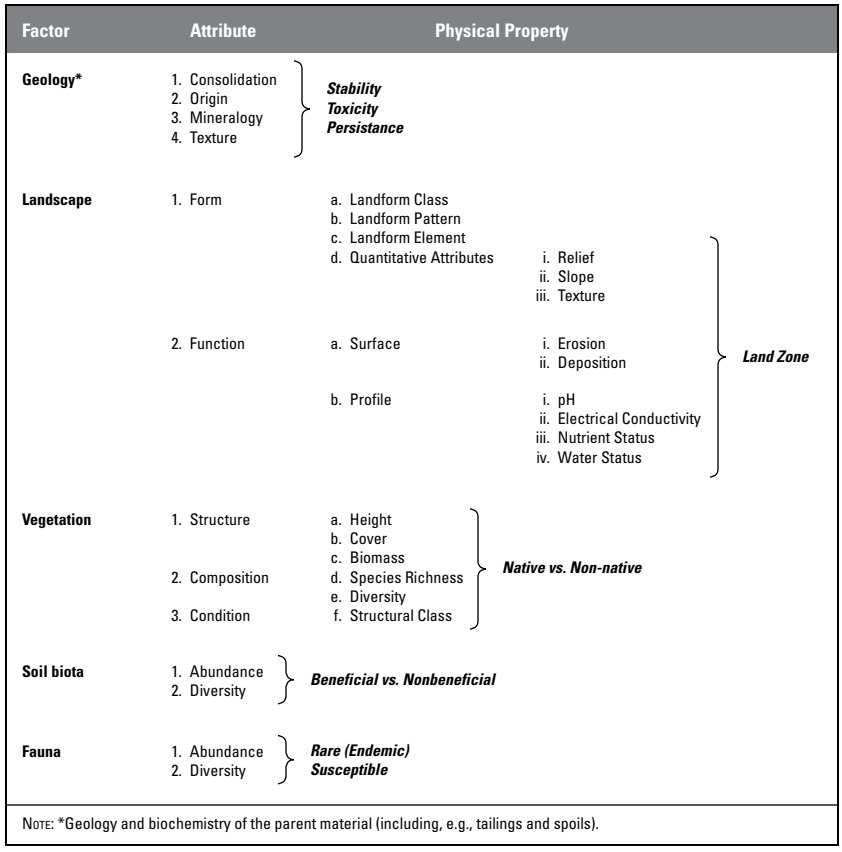
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As emphasized throughout this chapter, it is not clear that these conditions would be satisfied for many mine sites. Under these circumstances, the authors of this chapter suggest that the basis for rehabilitation planning should be determined according to the integrity of existing components within the postdisturbance environment (i.e., in relation to broader bioregional characteristics) rather than relying on idealized ones estimated from the nominated predisturbance environment or adjacent communities (Lindenmayer et al. 2011). Admittedly, conceptual frameworks such as those described by Doley et al. (2012) and Doley and Audet (2013) can only contribute to the planning of mined land rehabilitation by operators and regulators if objective descriptors can be used to determine the degree to which postdisturbance ecosystems may be considered natural or novel, and then derive suitable management responses for such conditions. In this regard, the hierarchical assembly and interactions of climate, geology, landform, and soil on the occurrence of a particular vegetation type have been described (Guisan and Zimmermann 2000) along with the physical and biological attributes that may limit the distribution patterns of species (Franklin 1998; Austin et al. 2009; Blackard and Dean 1999; Foody 1999; Černá and Chytrý 2005; Arnold et al. 2013). Therefore, it is reasonable to apply similar techniques toward the identification of suitable targets for reconstructed landscapes, provided that the physical parameters fall within the recorded range of conditions.

Abiotic Management: Significance of Climate, Geology and Landform

Climate is a global determinant of vegetation development (Harris et al. 2006) and is, of course, critical in reconstructed environments such as postmining landscapes (Audet et al. 2013a). Notwithstanding that recent warming has displaced latitudinal ranges of some species by about 10 mi per decade (Chen et al. 2011)—and the reality that long-term planning of disturbed landscapes (>100 years) must now build-in some flexibility in light of this uncertainty—these climatic changes are likely to be overshadowed by severe and possibly even radical changes in the states of land zones (e.g., degree of consolidation, origin, and geomorphology), all of which hierarchically influence ecosystem patterns and processes for a given vegetation type (cf. Sattler and Williams 1999; Guisan and Zimmermann 2000). Within each bioregion, *regional ecosystems* (REs) are defined by certain government conservation agencies as native vegetation communities consistently associated with particular combinations of land zone and soil. Notably, some variation in species composition of the vegetation community can be accommodated by a single RE, and mixing of REs may be recognized (Neldner et al. 2012), thereby accommodating some flexibility in land planning and design. The scale at which REs are mapped is influenced by the activities under consideration whereby high-intensity activities such as mine-site rehabilitation may require a resolution of 1:20,000 or 1:25,000 (mapping units of ~2-4 acres). At these scales, relatively fine details of landscape formed together with the lithology and pedology of a reconstructed

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Source: Doley et al. 2012; Doley and Audet 2013.

Figure 21.5 Hierarchies of site information for analysis of functional landscapes

site can be determined accurately (Tongway and Ludwig 2011). Meanwhile, land surveys can discriminate more subtle differences in landform so that assessment of a target vegetation community could be tempered by local variations in land capability. With this information, a critical first step for mine-site rehabilitation is to consider the extent to which the predisturbance landform and soil conditions have been retained or can be reinstated, and the consequent management objectives and actions (cf. Figure 21.4). This may include but is not limited to the following questions:

- Is the predisturbance landform reinstated?
- Does the new or rehabilitated landscape meet the predisturbance criteria?
- Are soil integrity and fertility intact?

Based on these criteria, the historical REs could be used as targets for rehabilitation only if the postdisturbance landscape units are judged by the environmental

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regulator to bear a reasonable physical resemblance to these environments. Such conditions may occur when a relatively thin layer of material is removed (e.g., bauxite mining; Koch 2007a, 2007b) or the bulk of the material can be returned without drastic physical or chemical alteration (e.g., sand mining; Smith and Nichols 2011).

Reports on the progress and success of mine rehabilitation in Australia are relatively sparse and unevenly distributed (Cristescu et al. 2012). However, successful mine lease extinguishment has followed the attainment of completion criteria in a bauxite mine in Western Australia (Gardner and Bell 2007; Grant and Koch 2007), and progress toward this goal has been recorded in Australia for other bauxite mines (Gould 2011, 2012) and sand mines (Audet et al. 2013b; Herath et al. 2009; Gravina et al. 2011; Smith and Nichols 2011). When discerning the likelihood of natural or novel rehabilitation outcomes, this RE approach assumes that geomorphological processes will have resulted in a land surface with a relatively predictable pattern of variation in soil characteristics resulting in a predictable vegetation community (Burgess 2003). If quantitative comparison of the abiotic characteristics of the disturbed landscape (cf. Figure 21.5) and that of the known historical REs (predicted or extant) do not correspond within defined limits (Burgess 2003; Tongway and Ludwig 2011), it may be necessary to consider an alternative or hybrid vegetation association for establishment on that land unit. This alternative would preferably be one that aligns with multiple components from the historical landscape while also accommodating potentially novel or nonnatural elements (e.g., waste rock heaps and open pits) based on landform components found within the RE. Ideally, pre-mine planning (Warhurst and Noromba 2010) would predict the range of landforms and lithologies that could be assembled in the final landscape to ensure that the rehabilitation outcome aligns as closely as possible with the essential function and attributes found nearby or more broadly within the RE (Worrall et al. 2009).

It is important to accept that, where the integrity of the abiotic system is compromised, novel landforms (not referring to novel ecosystems, per se) should be considered as acceptable management outcomes provided they meet the safety, stability, and nonpolluting criteria. For example, in some environments, flat-topped hills with steep slopes maximize waste-rock storage over the smallest possible footprint. Concave hill slopes minimize erosion (Hancock et al. 2003), so it is preferable to construct the upper slope from competent rock without a uniform cover of fine material or topsoil, and to limit soil application to the lower slopes where erosion losses can be limited by contoured structures, variation in surface texture, and vegetation. An additional benefit is that the area of topsoil application is reduced and a scarce resource can be used more effectively. Examination of steep and often rocky natural hill slopes in lower-rainfall regions commonly reveals them to be sparsely vegetated but stable. Therefore, it may be reasonable to construct postmining landscapes that include steep slopes, provided appropriate material

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can be obtained and that the resulting landform is stable, safe, and nonpolluting. Nevertheless, a common requirement for rapid and successful rehabilitation is the elimination of topsoil storage that is associated with the loss of microbiological condition and plant propagules. Dispersive or sodic soils are almost always naturally associated with flat surfaces or slopes of less than ~3 degrees (Burgess 2003), and they are susceptible to erosion if placed on steeper slopes (Hancock et al. 2003). If the original topsoils are highly erodible, the landform design must be modified so that slopes do not have to be soil covered and flat areas are constructed to minimize surface runoff and erosion. The resulting landform and soil combinations might be novel, requiring appropriate planning, design, and construction, and they are likely to support different vegetation associations. In short, an understanding of the properties of soils applied to the reconstructed landscapes must become part of the mine planning and engineering processes.

Biotic Management: Influence of Soil

Once essential landform elements are reconstructed, typical rehabilitation schemes assume that the physical requirements for the development of a desired vegetation type could be assembled almost immediately after the disturbance has ceased (Australia DRET 2011). The replacement of retained bioactive topsoil (containing indigenous seed and beneficial microbes) on reconstructed landscapes has been shown to facilitate the reestablishment of native and/or keystone vegetation and the reinstatement of preexisting REs (Bell 2001; Queensland DEHP 2012). As mentioned previously, such rehabilitation has been successful following mineral sand mining on the southeastern coast of Queensland, Australia (Smith and Nichols 2011), and bauxite mining in Western Australia (Gardner and Bell 2007; Koch 2007a, 2007b; Grant 2009; Tongway and Ludwig 2011) in which the biogeochemical composition of the postdisturbance landform and substrates are not significantly different from the predisturbance conditions.

Outside of these examples, the reshaping of the landscape and disturbance of topsoil is likely to have different ecological consequences depending on the underlying landform and lithology due to obvious and subtle losses of matrix structure and reductions in nutrient status and microbial viability (Cooke and Johnson 2002; Bradshaw 2004; Bens and Hüttl 2005; Banning et al. 2012; Huang et al. 2012; Zipper et al. 2013). Therefore, commensurate changes may be required in the identification of target vegetation associations where there is a fundamental change in the physical and chemical attributes of a land unit. These circumstances give rise to the following questions:

- Are beneficial soil components of the rehabilitated environment intact?
- Do rehabilitated soils support a distinct vegetation type(s) conforming to predisturbance land zone criteria?

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- Do these soils support rare, endemic, or vulnerable flora?
- Does climate/seasonality (e.g., flood erosion or drought) represent a significant obstacle for revegetation?

The following critical abiotic properties have significant impacts on the biotic system being rehabilitated: the propensity of the site for erosion, the amount of plant-available water in the rooting zone, soil pH, fertility, and salinity (Schmidt et al. 1999; Schneider et al. 2010; Zipper et al. 2013)—all of which, in principle, can be predicted well in advance along with potential strategies to mitigate their effects within the postdisturbance landscapes. However, if the soil characteristics of the reconstructed site cannot be specified closely, which is often the case, the specification of the vegetation association cannot be very precise. The difficulty of such prediction can be demonstrated by considering a very detailed soil and vegetation analysis carried out over 700,000 acres in central Queensland (Burgess 2003): the setting for intensive mining of coal (and coal seam gas), gold, silver, limestone, magnesite, and gemstones. Sixty-nine soil profile types were identified on landscapes ranging from steep slopes to flat clay pans and flood plains derived from igneous, metamorphic, and sedimentary rock types. In the central Queensland environment, where evaporation exceeded rainfall, one of the major limitations to plant survival was salinity, and many of the soils were dispersive because of high sodium contents, so they were prone to erosion. In addition, in many parts of Australia, total rainfall is highly variable from year to year, and also within the nominally wet seasons (Audet et al. 2013a). As a result, revegetation may fail for several years in succession because of a lack of rainfall that is followed by a season of intense rain, preventing access to the site until the soil is firm enough to carry vehicles and by which time it may be too dry for seed germination and plant establishment. In these situations, a fundamental decision must be made as to the extent and development time of vegetation cover to achieve a satisfactory rehabilitation outcome.

The first requirements for postmining sites is that they be safe, stable, and nonpolluting (Queensland DEHP 2012). In many mining situations (e.g., see Zipper et al.'s (2013) review of rebuilding soils on mined land in native Appalachian forests), the resulting landform properties may entail predictable surface and soil characteristics that may be associated with vegetation associations that are different from the historical and are potentially novel. In the extreme, it may be preferable to not rely on vegetation to stabilize the soil against wind and water erosion, and to accept vegetation as an opportunistic benefit of the infrequent wet seasons. Accordingly, reconstructed coal-mine spoils may be as productive as the original forest soils, even though they may contain up to 60% by volume of rock (Zipper et al. 2013), provided the requirements for water, aeration, nutrients, and pH are satisfied. However, if the rehabilitated environment is required to support a particular historical vegetation type, then appropriate actions (such as modifying

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fertility and moisture parameters) must be taken to bridge the gap between the characteristics of the post- and predisturbance environments.

These actions may require decades and extensive management inputs for completion (Majer et al. 2013), so identification of realistic and achievable end points is necessary to account for changes in rehabilitation planning. For example, in the nutrient-limited soils common in Australia, the addition of fertilizer to soils is a common part of land rehabilitation. Most domesticated plant species require relatively high soil nutrient concentrations compared to the majority of Australian native species, especially in parts of the country with very old, weathered landscapes (Lambers et al. 2010). On many mine sites, the addition of nutrients results in weed infestations, so if the objective is to return native species, very limited fertilizer application may be required. The need for supplementation of soil microbiota has been recognized more recently as a critical component of soil health on rehabilitated mine sites (Harris 2009; Huang et al. 2012). Although the species assemblages of soil microbiota vary substantially over space and time, it is possible to greatly enhance vegetation establishment by the application of organic materials containing broad-spectrum microbial supplements (Larney and Angers 2012).

Though replaced and redistributed topsoil may contain seeds and other material that may introduce species to the new site, the amount and proportions of species in seed spread on the soil may need to be managed carefully to obtain an acceptable final species mixture (Koch 2007b; Gravina et al. 2011; Smith and Nichols 2011). Where an exotic or weed species is well established in a locality, it may eliminate slower-growing native species (Friedel et al. 2011). As in the case of planning for ecological uncertainty associated with shifting climate boundaries and/or effects of climate vulnerability, all of these scenarios require a commitment to accounting for different potential outcomes at the earliest stages of planning along with a capability (or flexibility) to refine interventionist rehabilitation approaches in relation to ecological outcomes based on ongoing monitoring outcomes.

Biotic Management: Influence of Vegetation

Another matter for consideration is the manner in which vegetation types coexist on multiple soil types. In central Queensland, Burgess (2003) described 42 vegetation associations according to the procedures described by Neldner et al. (2012) covering sufficiently large areas to be analyzed. For all of the 69 soil profile types in the study area, there was no unique association with a given vegetation type, but between two and six vegetation associations could be found on any soil profile type.

Where one soil type was examined at more than one location, the dominant vegetation association sometimes differed among locations. This variation could indicate that there is a stochastic component to the occurrence of vegetation on soil types or, alternatively, that subtle changes in vegetation associations are the result of the separation of localized niches for different species (Austin et al. 2009)

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that are not related to the variables assessed by Burgess (2003). In either case, this underlines the practicality of mixed RE categories at broad mapping scales for setting rehabilitation goals (Neldner et al. 2012) compared to the common strategy of targeting a particular soil–vegetation assembly and perhaps relatively narrow rehabilitation outcomes. If specific vegetation associations are identified for replacement in particular landform elements, it must be assumed that the necessary physical conditions can be provided. Where these assumptions cannot be met, different vegetation associations might be expected to occur regardless of the nature of the topsoil that is spread over the substrate. In view of the sometimes pronounced differences in vegetation associations that occur with relatively small differences in soil profile type (Gravina et al. 2011; Audet et al. 2013b), rehabilitation contract conditions that require the establishment of only local ecotypes of preexisting species on a reconstructed landscape may not be fulfilled.

This issue has recently been debated more widely across the field of ecological restoration (Nichols and Williams 2006; Lindenmayer et al. 2011, 2012) but still remains a fundamental pitfall of monitoring approaches that evaluate the development of vegetation assemblies strictly in relation to reference ecosystems and without extensive consideration of potentially insurmountable barriers to restoration, including novelty and novel ecosystems (Lindenmayer et al. 2008). Within the context of mine closure, this may result in very few ecological criteria being met that would permit relinquishment of mining leases despite the possibility that rehabilitation practitioners had responsibly applied sound practices resulting in safe, stable, and nonpolluting postmining landscapes that otherwise would meet high standards of ecological stewardship. Instead, species selection could be based on scenario modeling of landscape function analysis (Guisan and Zimmermann 2000; Tongway and Ludwig 2011) and the identification of functional groups that are most likely to survive in the new conditions (Grant et al. 2002; Bradshaw 2004; Wagner 2004), particularly to allow for climatic and seasonality obstacles to revegetation.

Somewhat contentiously, it may be necessary to compromise local biodiversity (i.e., via strict threshold interpretations of biodiversity metrics) to emphasize stable vegetation cover by early introduction of the major structural and functional components of vegetation associations that might be expected to survive in the postdisturbance abiotic environment (Koch 2007a, 2007b; Whalley et al. 2013). However, this would necessarily require very careful negotiation among all stakeholders on a case-by-case basis to eliminate the possibility of lowering rehabilitation standards. A consequence would be that a broad list of species from the bioregion could be tested for incorporation in rehabilitation procedures, including fast growers versus slow growers, or native versus nonnative species (Shackelford et al. 2013a). This would require a change in perceptions since the criteria for assessment of the success of species establishment might be based first on ecological function analysis

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(Tongway and Ludwig 2011), second on biodiversity criteria (Eyre et al. 2011), and third on a commitment to timely management intervention based on ecosystem developmental trajectories as well as final target outcomes (Grant 2006, 2009; Shackelford et al. 2013b). In this regard, a large-scale field trial (perhaps among others) focusing on the "novel" restoration of former agricultural lands in Western Australia (known as the Ridgefield Multiple Ecosystem Services Experiment) is being conducted to address these very issues (Perring et al. 2012), albeit in relation to less disruption than is involved in most mining operations. Meanwhile, the latest collective understanding of ecological resilience among recovering systems (as determined across various investigative contexts) now emphasizes species diversity as a significant component of valued ecosystem function (Erskine et al. 2006; Chazdon 2008; Gamfeldt et al. 2013; Isbell et al. 2011). Consequently, it should be reasonable that mined land rehabilitation planning places equal emphasis on ecological functionality (within the collective mosaic of REs) and on particular ecological reference states to account for the variability inherent in the reconstruction of such highly disturbed landscapes.

Holistic Assembly: Ecosystem Function and Habitat Development

The final component of our conceptual approach to determining the extent to which postmining landscapes may be considered natural or novel relates to the condition requirements for reinstating and maintaining natural ecological regimes. *Ecosystem stability* is defined as variation in structure and condition (Eyre et al. 2011) within the historical range of variability (Suding and Hobbs 2009), and a *manageable habitat* is defined as that which can be maintained in a stable condition by intervention that is practical and economical (Grant 2006). As such, it is necessary to inquire of the rehabilitated environment over time and throughout life-of-mine planning:

- Do rehabilitated ecosystems provide stable and manageable habitat?
- Are historical ecosystem functions achieved?

Of course, this questioning could also be extended to address whether the rehabilitated landscapes meet the needs and requirements of local landowners and traditional/native people. Nevertheless, the capacity to develop a suitable habitat for flora and fauna on a mine site depends on the physical attributes previously discussed as well as resolute action to ensure that the various biological components are established and maintained on the site. Unfortunately, there are no general or rapidly applied indicators of stability for highly disturbed and potentially novel ecosystems. This is not only attributable to the potentially complicated and site-specific requirements for ecosystem assembly (Koch 2007a, 2007b; Bullock et al. 2011; Tongway and Ludwig 2011), but also the fluid socioeconomic boundaries typically associated with postmining land rehabilitation (Gardner and Bell 2007; Worrall

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et al. 2009; Warhurst and Noromba 2010; Smith and Nichols 2011). Mined land rehabilitation is expensive, and resource limitations (e.g., lack of topsoil, toxicity, or salinity of substrate) often limit the extent to which the historical ecosystem conditions can be approached (Grant et al. 2002; Madsen and Mulligan 2006). In addition, expectations for highly disruptive (and lucrative) mining activities are that rehabilitated ecosystems should recover relatively soon after the disturbance and in proportion to investment of resources, often regardless of the size and severity of the disturbance (Australia DRET 2011). Paradoxically, because soil and subsurface properties may be changed radically, rehabilitation success can only be assessed effectively over longer timelines and preferably using multiple ecological indicators and end points (e.g., Block et al. 2001; Nichols and Nichols 2003; Craig et al. 2012; Williams et al. 2012; Cristescu et al. 2012; Evans et al. 2013; Majer et al. 2013).

Determination of the stability of novel or alternative ecosystems is one activity for which adaptive management may be most appropriate. Part of this management process would be the development and refinement of quantitative indicators of site and ecosystem condition, of which a multitude of suitable ecological metrics are already available and used widely among mine rehabilitation monitoring programs. Evidently, convergence of rehabilitated environments toward target ecosystems is most likely to occur where physicochemical alteration of the substrate has been limited, the climate has suitable temperatures and distribution of rainfall, and the soil-surface conditions are favorable or may improve over time (Norman et al. 2006; Koch 2007a, 2007b; Smith and Nichols 2011; Audet et al. 2013a).

Rehabilitation efforts can then be focused on facilitating conditions in support of stable habitat and manageable ecological regimes including, for example, the integration of seasonal fire (Grant et al. 2007) and/or low intensity grazing (Tongway and Ludwig 2011; Firn et al. 2013) to name just a few. Hence, the determination of the stability of hybrid or novel ecosystems is one activity for which adaptive management may be most appropriate, particularly since reference analogues cannot be used in the same manner as in traditional restoration approaches. However, where the postdisturbance environment has an altered nutritional status and/or contains seeds of less desirable species (e.g., exotic or selected pasture grasses), repeated attempts at introducing natural ecological regimes may fail and even cause further divergent outcomes (Hobbs et al. 2013). It then follows that restoration of natural ecological regimes and habitat would remain incomplete or in a state of arrested development if left unmanaged (Audet et al. 2013b; Grant 2006, 2009). Meanwhile, truly hybrid or novel site conditions may not have previously described ecosystem characteristics, other than those that can be predicted from the broader RE. For these reasons, it is suggested that rehabilitation goals for highly disturbed areas such as mine sites should be set by agreement between the industry, regulator, and relevant stakeholders at the highest feasible level (such as the predisturbance RE)—as envisaged in the New Zealand Resource Management

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Act (Pokhrel and Dubey 2012)—while also allowing for adjustment of the goal in the light of circumstance (Worrall et al. 2009; Evans et al. 2013). Each agreed change of goal should be preceded by a thorough and objective analysis of the physical environmental and socioeconomic conditions so that the highest attainable environmental outcomes are delivered.

Many studies have been carried out on the suitability of mine sites for the early establishment of vegetation (e.g., Bell and Bellairs 1992; Huxtable et al. 2005; Madsen and Mulligan 2006; Courtney and Mullen 2009) and the subsequent outcomes of rehabilitation (Mulligan 1996; Menzies and Mulligan 2000; Koch 2007a, 2007b; Gravina et al. 2011; Vickers et al. 2012; Evans et al. 2013). Therefore, determining the range of predictable outcomes for hybrid or novel ecosystems can be achieved based on properties found naturally in broader REs. However, apart from reports on fire and tree thinning (Koch 2007a, 2007b; Craig et al. 2010) and microhabitat management (Christie et al. 2013) in rehabilitated bauxite mines in Western Australia, there are fewer accounts of the longer-term ecological and associated site-management processes that may be involved.

CONCLUSIONS

Rehabilitation of highly disturbed landscapes such as mine sites may not provide realistic opportunities for the ecological processes normally associated with ecosystem recovery to occur. Consequently, the most appropriate test for a rehabilitated mined landscape may be that it provides a safe, stable, and nonpolluting environment in which the plant and animal communities meet agreed ecological, environmental, and social criteria that can be managed viably in the medium to long term. As such, the authors of this chapter believe that the definition of pragmatic closure criteria should be widened to include conditions leading to the development of natural, hybrid, and novel ecosystems. This would refine the requirements for veritable restoration versus alternative ecosystems and thereby avoid costly and undesirable outcomes. This definition will lead to clearer specifications for the design, construction, and operation of mine sites and possibly even greater overall efficiency for the mining industry. Nevertheless, it should be acknowledged that the target ecosystems may be quite different from those that occupied the site prior to disturbance, and they may be difficult to discern at the planning stage of a mining operation. This lack of a clear rehabilitation goal requires careful analysis of the available evidence at each stage of planning and operations, and a willingness and capacity to adjust goals according to the best practice that can be achieved with the expectation that it will be overtaken in the future by something better.

The fact that some mine leases have been relinquished indicates that successful rehabilitation is possible. Given that the number of abandoned, pending, dormant, or inactive leases exceeds the number that has been relinquished shows that the

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path to mine-site rehabilitation is not smooth or direct. The engineering aspects of landscape reconstruction are well known, and the principal challenges lie in site design and management, and in the recognition and avoidance of physical hazards. On the other hand, matching biological and physical attributes through engineering of a site is still a relatively poorly developed field of knowledge. In particular, there are no simple rules for the selection of ecosystems and constituent species for establishment on novel landforms. Therefore, it is necessary to gain a better understanding of the responses of a range of plant species to the limiting environmental conditions that may be associated with a particular mine site. It is the authors' view that the more completely these rehabilitation activities can be incorporated in initial mine planning, the more effective, in physical and commercial terms, these activities will be. In addition, transparent early decision making would assure regulators and community stakeholders that their concerns have been addressed, and they can contribute to the attainment of the most effective outcomes.

By definition, further rehabilitation inputs invested over time could facilitate the restoration of predisturbance landform criteria among hybrid ecosystems; however, this goal cannot be claimed for novel ecosystems, given the irreversible crossing of abiotic thresholds (Hobbs et al. 2013). Nevertheless, the approach would still be conducive to the development of rehabilitated ecosystems bearing features and capabilities similar to those found within the broader bioregional mosaic. Some may see this as a "lowering of the bar" since it implies a permanent loss of historical fidelity. On the other hand, it could be seen as the best that can now be achieved in some circumstances given environmental and socioeconomic changes, and the scale of degradation that has occurred (Perring et al. 2014).

ACKNOWLEDGMENTS

This chapter is an adaptation of works by Doley et al. (2012) and Doley and Audet (2013), incorporating relevant perspectives from Perring et al. (2013). Whereas these initial studies were targeted primarily to the academic community of ecologists and restoration scientists to reconcile latest ecological theory with land management policy, the present work has been formulated to address the community of engineers and restoration practitioners in hopes of optimizing achievable rehabilitation outcomes in a rapidly changing environment without compromising higher standards of biological conservation and ecosystem stewardship. Where possible, examples from the Australian context for mined land rehabilitation have been used to populate the unique challenges (and incongruity) of securing rapid rehabilitation against the biological reality that reestablishment of a functioning ecosystem takes time; similar examples can readily be drawn across the mining industry worldwide.

The authors thank M. Perring and R.J. Hobbs for providing early access to the compilation book *Novel Ecosystems: Intervening in the New Ecological World Order*,

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edited by R.J. Hobbs, E.S. Higgs, and C.M. Hall. This study was made possible by funding to P. Audet from the Centre for Mined Land Rehabilitation (CMLR) at The University of Queensland and the Natural Sciences and Engineering Research Council of Canada while he was then affiliated with the CMLR within the Sustainable Minerals Institute.

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CHAPTER 22

After the Gold Rush: Developing Closure Criteria for a Mined Landscape

Augustine Doronila, Marc Bellette, and Singarayer Florentine

INTRODUCTION

Determining successful mine rehabilitation depends on realistic, clearly defined objectives. This enables the development and use of practicable measures of success and an assessment of progress towards goal(s) achievement (Box 1996; Ruiz-Jaen and Aide 2005; Hobbs et al. 2009). Gold mining activities during the gold rush period of 1850–1900 in the State of Victoria, Australia, have left a legacy of heavy metal contamination of soils, surface water, and groundwater of residential areas of mining towns (DMID 1991). In that period, rehabilitation objectives for mine sites in Australia were absent, ill-defined, and/or poorly conceived. Early examples of mine-site rehabilitation and reestablishment efforts were focused on nonindigenous vegetative cover including grasses, shrubs, and trees. While this effort sought to return land stability, there is general recognition that the approach was poorly integrated and incompatible with surrounding natural ecosystems (Thompson and Thompson 2004). Although current law and policy for mine rehabilitation of native ecosystems disturbed by mining in Victoria are focused on indigenous revegetation as the primary objective, the methods for measuring success, especially in regard to species composition, and a return of vegetation structure and function are not well defined. Moreover, as one of the minor mineral-producing states, it has perhaps Australia's most stringent policy of any jurisdiction for native vegetation removal under its general planning controls, which would align the state with Australian best practice. This legislative framework can therefore enhance the environmental performance of local mineral industry, which is now undergoing resurgence.

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Rehabilitation goals may be difficult to define and measure. A desirable goal may be to restore a natural, functioning, self-regulating system that is integrated with the natural landscape in which it occurs, as well as incorporating social and cultural perspectives in restoration design (Higgs 1997; Thompson and Thompson 2004; Clewell and Aronson 2013). Many assessments of success use reference communities and ecological benchmarks as a means to define success against a goal, particularly in regard to a return to "natural" state. While such an approach may be sensible and logical, there are limitations that need to be considered. The comparison between a reference and mined (treatment) site(s) may be distant from each other in space and/or time, and ecological differences may be due to variation in disturbance history, land use and fragmentation, and biophysical factors such as climate and soils. Factors such as these increase the measured parameters of ecological difference between the reference and mined sites (White and Walker 1997). Variations in disturbance may result in patches with different compositional characteristics reflecting different successional states and time since disturbance (Pickett and Parker 1994). Therefore, care must be taken not to specify an unattainable goal based on a poorly selected reference site, but objectives may be based on a desired degree of similarity between the reference and mined sites (Hobbs and Norton 1996; Koch and Ward 2005).

Current standards for mine rehabilitation are broad measures of composition and structure, and though useful to determine the similarity of mined-out areas and surrounding native vegetation, there is a lack of measures that assist in understanding functioning and self-sustaining ecosystems. Several prominent authors have argued for the use of a range of objectives in measuring success, including targets for composition, structure, and function (Ludwig and Tongway 1995; Hobbs and Norton 1996; Tongway and Hindley 2003; Thompson and Thompson 2004; Temperton 2007; Benayas et al. 2009). There are few cited examples of ecosystem components other than vegetation being monitored in Victorian rehabilitation sites or elsewhere (Brooks and Lake 2007; Lindenmayer and Likens 2010). Furthermore, despite the obvious importance of fauna use in rehabilitated sites, the chapter authors are unaware of any systematic approach to evaluating fauna recolonization in Victoria, despite Australia having ample cited examples of invertebrate monitoring and the recognized importance of invertebrates in ecosystem functioning in mined landscapes (Majer 1983, 1989; Bisevac and Majer 1999; Anderson et al. 2002, 2004).

Victorian Legislation and Policy as It Relates to the Stawell Gold Mine

Most applications to remove, destroy, or lop native vegetation in Victoria operate under the Planning and Environment Act 1987 and supporting policies. This is not the case regarding mining. In Victoria, requirements for the mining industry when removing native vegetation are regulated through the state's Mining

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and Extractive Industry Work Approvals (MEIWA) process. This is administered through the Department of Environment and Primary Industries (DEPI 2004). A link between the requirement for offsets under the MEIWA process and the Planning and Environment Act 1987 native vegetation planning policy operates by way of a memorandum of understanding (MOU) at the work plan approval stage. This process is meant to ensure in-principle alignment of the MEIWA process with general planning policy. There is, however, one important policy difference. The notion of *temporary loss* applies to mined lands in Victoria where land is to be reinstated following mining to a similar landform. Under the Planning and Environment Act, vegetation is usually considered wholly (or partly) lost to a development where native vegetation is removed.

Stawell gold mine (SGM) conducts an underground mining operation located in Western Victoria, Australia, approximately 230 km northwest of Melbourne. The first recorded phase of mining on the site was from 1853 to 1920, and current mining operations recommenced in 1982. The mine site is located within 1 km of the main street of Stawell, and a continuing focus on community relationships is a key factor in the ability of the mine to operate. Sustainability has been a key driver for mine-site rehabilitation so that ongoing management of the site is in the interests of the long-term owners and is not a liability (Osborne and Doronila 2005).

This chapter presents the authors' understanding of rehabilitation success following a 10-year field trial aimed to assist SGM in proposing a revegetation objective on the different areas affected by the mine. Under the Victorian Mineral Resources Development Act 1995 (MRDA) and the Extractive Industries Development Act 1995 (EIDA), degraded land must be rehabilitated in accordance with a rehabilitation plan. To ensure that rehabilitation is carried out to an acceptable standard, a rehabilitation bond is set by the government to the approximate value of the anticipated works required.

The government guideline (Extractive Industries Development Act 1995) set a success objective stating that at completion of mining, the aim is to provide a rehabilitation plan that takes into account any special characteristics of the land, the surrounding environment, and the need to stabilize the land, as well as the necessity to protect or conserve native vegetation and protected flora and fauna. This type of statement offers little guidance to measure success. Therefore, this study attempts to investigate a strategy to create a safe and sustainable system that replicates a Box Ironbark woodland as closely as possible to provide an approximate structure of representative indigenous community, with approximately 70% of tree and understory species to be returned. To ensure a safe and sustainable land unit, species from adjoining vegetation communities may be used.

There is an assumption that 70% of tree and understory species will provide a sufficient target for the approximate return of the Box Ironbark Forest after 5 years, which to the chapter authors' knowledge has not been previously tested. Therefore,

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several other objectives have been specified to help define this aim in comparison to some existing "across the fence" remnant native vegetation:

1. Similarity of species presence and abundance
2. Projective foliage cover of understory and overstory species

Monitoring began in the southern spring/summer of 2002–2003 following several rehabilitation treatments involving ripping and dressing with indigenous forest topsoil taken from a nearby site and stockpile. This report examines the variation in response to the trial rehabilitation treatments, using floristic diversity and vegetation cover as measures of change in ecosystem structure compared to a reference site Box Ironbark Forest community.

Study Area—Stawell Gold Mine

The study area (S37°48'08.6", E142°55'43.3") is located approximately 2 km from the township of Stawell, Victoria (Figure 22.1a). The mine is within the Victorian Goldfields bioregion, and vegetation in the locality includes dry eucalypt-dominated forests and woodlands, called bushland (DSE 2004a).

The area has a temperate climate. Summer months are typically warm and dry, with a mean daily maximum temperature ranging between 26.4°C and 29.0°C. Winter months are cool and wet, with a mean daily maximum temperature ranging between 12.6°C and 14.2°C. Average annual rainfall at Stawell is 480 mm, the months of highest rainfall occurring between June and September (BOM 2009).

The study site is a highly disturbed bare earth pad, positioned between a site previously revegetated in 1988 and a small area of bushland. The remnant bushland used as a reference area for the study is illustrated in Figure 22.1b. Vegetation on the reference area is geographically defined as Box Ironbark Forest Ecological Vegetation Class EVC 61 (DSE 2004a), consisting of "a variety of eucalypts, often including one of the Ironbark species, often with a dense to open small tree or shrub layer over an open ground layer ranging from a sparse to well-developed suite of herbs and grasses" (DSE 2004b). The reference area at the site shares some of the characteristics described for Heathy Woodland (Western Goldfields) in Muir et al. (1995). The dominant canopy species is *Eucalyptus goniocalyx* (Bundy), occurring over understory shrub species from the families Myrtaceae, Mimosaceae, Epacridaceae, and Fabaceae, and monocotyledon species from the Poaceae family and subfamilies Lomandroideae and Anthericaceae. *Eucalyptus tricarpa* (Red Ironbark) is the dominant overstory tree on-site in lower slope areas.

METHODS

Field Methods

Species composition and community structure in 2003 were studied using three sets of 25-m transects (25 1×1-m quadrats; Mueller-Dombois and Ellenberg 1974). The

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reference sites were the Davies bushland and Mulvaney bushland in close proximity to the Wonga waste-rock stockpile. Sampling was carried out at each of the treatment sites to assess differences in species composition and community structure. In 2007, the line-intercept method (Mueller-Dombois and Ellenberg 1974) was used over a 25-m line. Four 25-m lines were placed in each of the treatment areas: the reference site and A, B, and C. Starting points for the lines were randomly located within each treatment, and lines were laid out across the fall line of the site. These surveys were conducted in a different manner than the 2009 survey, which is not strictly comparable. The 2009 assessment of the treatments was done once again using the same method as in 2003. A further set of analogue sites (Wonga bushland [WB] around the SGM tailings storage facilities where the topsoil for treatment A was obtained) were incorporated in the study; however, because of the patchy distribution of the vegetation, it was decided to sample these sites with four 100-m^2 circular plots. Starting points for the lines were randomly located within each treatment, and lines were laid out across the fall line of the site.

Treatments at the rehabilitation site were contour rip-lines in basement oxidized clays and bedrock (Figure 22.2), with variations in topsoil additions as specified in Table 22.1. No other plantings or seeding were undertaken.

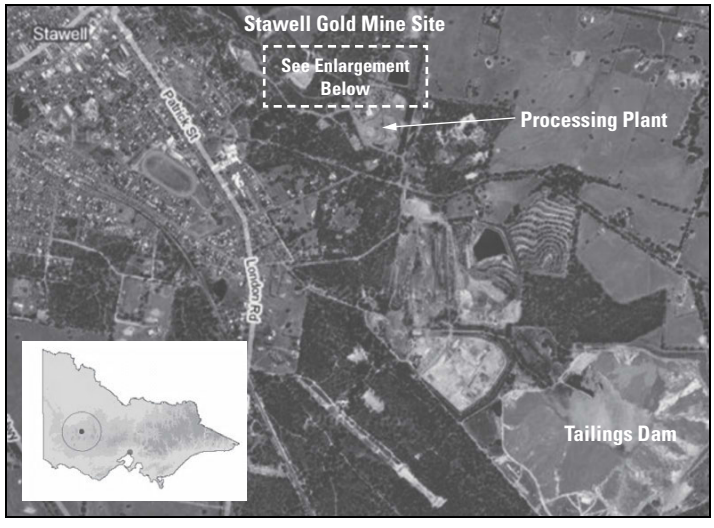
All plant species present and visually evident in the transects or circular plots were identified. A visual estimate of the projective foliar cover for each species was estimated according to the Braun-Blanquet 6 cover-abundance scale: +, <1%, 1%–5%, 6%–25%, 26%–50%, 51%–75%, and 76%–100%.

Data Analysis

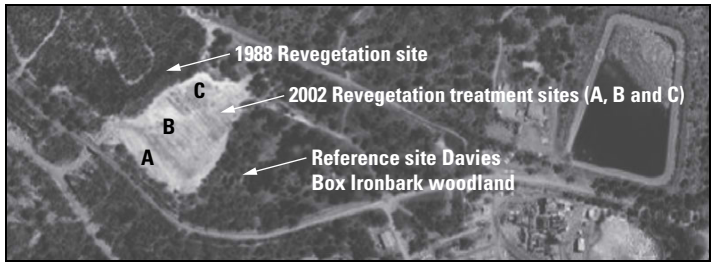
Descriptive statistical calculations were performed in Microsoft Excel. Floristic data were entered into the multivariate statistical software PC-ORD V4 for calculation of species richness (S), Simpson's diversity index (D), Shannon–Weiner diversity index (H' $\log^e$), and Pielou's evenness index (J'). Species richness was calculated simply as the number of species present. Simpson's diversity index is also a measure of the number of species present, making some allowance for the number of individuals. The Shannon–Weiner (or Shannon's) index combines species richness with relative abundance as a proportion of total cover (Kent and Coker 1992). Pielou's evenness index is a measure of equitability or how evenly the individuals are distributed among the different species (Clarke and Warwick 1994). Each set of S, D, H' $\log^e$, and J' scores for each intercept line were then averaged to provide scores for each site.

Ordination was performed as a nonmetric multidimensional scaling (MDS) based on a Bray–Curtis distance/similarity matrix. This ordination arranges sites in a reduced set of dimensions based on the rank order of the Bray–Curtis similarity matrix. A two-dimensional (2-D) ordination plot was produced to show relative similarity from the relative positions of the points to one another. The goodness of the fit of the ordination plot is indicated by a stress value <0.20 (Clarke 1993). All

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A. Location of the Stawell gold mine



B. Site locations in the Stawell gold mine operational area

Figure 22.1 Study area



Figure 22.2 Ripping treatment at 2002 revegetation site, looking from treatment A, northwest, to treatment C, Stawell gold mine

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Table 22.1 Summary of treatments (A, B, and C) and projected 10-year rehabilitation targets

Site Name	Reference (Davies and Mulvaney bushlands)	A	B	C
Treatment	None. Small intact area of Box Ironbark Forest vegetation with high species diversity.	Deep ripped. Sandy loam topsoil (top 2–5 cm) spread into the rip lines. Topsoil freshly removed from intact heathy woodland (harvest site 1).	Topsoil spread over area. Ripping followed by topsoil application. Topsoil freshly removed from intact heathy woodland (harvest site 2).	Deep ripped. White schist and soil applied generously. Material from Davis open cut semi-native vegetation site, stockpiled for 15 years and received "seed rain" from adjoining 1988 revegetation site.
Rehabilitation Bond Target	EVC 61 Box Ironbark Forest	70% of tree and understory species returned		
Species Diversity		75% shared similarity in both species present and abundance (n) to reference site		
Presence of Life-Form Classes		All life forms present at the site to 50% of EVC benchmark cover (for each class)		
Projective Foliage Cover		Projective cover for understory species and overstory species is not less than 65% of EVC benchmark		
Organic Litter Cover and Logs		Organic litter cover and logs (m/ha) are not less than 50% of reference site		
Photos: Source of Soils Used in Each Treatment				

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species occurring at the sites were ascribed to a life-form class to be able to compare cover abundance and species numbers for each life form between the treatment sites and the rehabilitation targets based on the benchmark values.

RESULTS

Species Diversity and Composition Under Different Rehabilitation Treatments

Previous diversity measures are included in the results from surveys performed in September 2003 after the first year of the trial. The relevant ecological parameters are summarized in Table 22.2. The cover values from plants that have emerged from the heathland-obtained fresh topsoil (A and B) show much greater emergence than the schist and old rehabilitation topsoil resource (C). Treatments A and B had a higher species richness than the disturbed Mulvaney bushland (MB) area. However, both topsoil treatments had approximately two-thirds of the species found in the Davies bushland (DB), which had approximately 1.6× more species. This is not surprising because various species such as geophytes and vegetatively reproducing resprouter species are not readily identifiable at early stages of recolonization.

The second survey in September 2007 followed the same line transect-protocol used in 2003. A total of 116 species were recorded from the 12 sample plots. The summary ecological parameters is presented in Table 22.3. At 5 years from topsoil spreading, species richness (S) values ranged from 35 at the reference area to 10 in treatment A. The mean evenness index (J') ranged from 0.56 in treatment A to 0.44 in treatment B. Mean diversity indices (H') ranged from 1.82 in the reference area to 1.29 in treatment B. The trends observed were similar to those 1 year after topsoil spreading.

In October 2009, 100 species were recorded from the 20 sample plots. Area A had 87% of the total species richness of the analogue sites while areas B and C had 54% and 59%, respectively (Table 22.4).

Mean species richness (S) for the reference areas ranged from 39.0 at the Davies woodland sites to 37.8 in the Wonga woodlands surrounding the tailings storage facility (WB), 2 km away from the trial site (Table 22.4). The selective topsoil placement (treatment A) was comparable to the analogue sites with 34.5 mean species richness. Topsoil spread over the site (treatment B) had 20.5 mean species richness, and treatment C (schist containing the seed rain and old topsoil) had 22.5 mean species richness. Mean richness indices (D) ranged from 0.91 in treatment A and declined to 0.76 in treatment C. Mean diversity indices (H') ranged from 3.35 in the Davies bushland (DB) and 2.86 in the Wonga reference area (WB) to 2.16 and 2.25 in treatments B and C, respectively. The selective topsoil treatment (A) was comparable to the analogue sites with a diversity index of 2.94 (Table 22.4). Statistically significant decreases in species richness and diversity occurred from the reference area and treatment A to treatment C. Evenness index (J') values for

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Table 22.2 Ecological diversity parameters of the topsoil-handling treatments and analogue woodland sites in September 2003*

Plot ID†	Species Richness S	Pielou's Evenness Index J'	Shannon–Weiner Diversity Index H'	Simpson's Diversity Index D
A1	16.00	0.61	1.70	0.74
A2	24.00	0.54	1.72	0.76
A3	18.00	0.61	1.75	0.78
Mean	*19.33*	*0.59*	*1.72*	*0.76*
s.e.‡	*2.40*	*0.02*	*0.01*	*0.01*
B1	21.00	0.58	1.78	0.73
B2	22.00	0.35	1.09	0.57
B3	21.00	0.33	1.01	0.37
Mean	*21.33*	*0.42*	*1.29*	*0.56*
s.e.	*0.33*	*0.08*	*0.24*	*0.10*
C1	12.00	0.53	1.31	0.63
C2	16.00	1.00	2.77	0.94
C3	10.00	0.68	1.57	0.64
Mean	*12.67*	*0.74*	*1.88*	*0.74*
s.e.	*1.76*	*0.14*	*0.45*	*0.10*
DB1	30.00	0.63	2.15	0.82
DB2	31.00	0.53	1.82	0.75
DB3	36.00	0.60	2.15	0.77
Mean	*32.33*	*0.59*	*2.04*	*0.78*
s.e.	*1.86*	*0.03*	*0.11*	*0.02*
MB1	13.00	0.41	1.04	0.53
MB2	11.00	0.73	1.75	0.79
MB3	21.00	0.32	0.97	0.44
Mean	*15.00*	*0.49*	*1.25*	*0.59*
s.e.	*3.06*	*0.13*	*0.25*	*0.11*

*Summary of 15 sites. Total number of species = 111.
†Treatments as specified in Table 22.1.
‡s.e. $= \sqrt{p(1-p)/n}$.

each of the analogue sites were greatest in the Davies (DB) plots with a mean of 0.91, while the Wonga (WB) plots were lower at 0.79. Once again, treatment A had greater evenness of 0.83 while treatments B and C had lower evenness of 0.72 (Table 22.4), indicating the greater cover and biomass of ephemeral Acacia species.

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Table 22.3 Ecological diversity parameters of the topsoil-handling treatments and analogue woodland sites in September 2007*

Plot ID	Species Richness S	Pielou's Evenness Index J'	Shannon–Weiner Diversity Index H'	Simpson's Diversity Index D
A1	10.0	0.740	1.705	0.672
A2	19.0	0.327	0.964	0.339
A3	26.0	0.603	1.965	0.354
A4	21.0	0.566	1.722	0.385
Mean	*19.0*	*0.559*	*1.589*	*0.437*
s.e.	*3.3*	*0.086*	*0.217*	*0.079*
B1	13.0	0.465	1.191	0.560
B2	22.0	0.461	1.424	0.219
B3	21.0	0.267	0.814	0.245
B4	19.0	0.582	1.713	0.137
Mean	*18.8*	*0.444*	*1.285*	*0.290*
s.e.	*2.0*	*0.065*	*0.190*	*0.093*
C1	17.0	0.449	1.273	0.221
C2	26.0	0.482	1.570	0.695
C3	16.0	0.454	1.259	0.301
C4	18.0	0.551	1.592	0.185
Mean	*19.3*	*0.484*	*1.424*	*0.350*
s.e.	*2.3*	*0.023*	*0.091*	*0.117*
DB1	35.0	0.654	2.324	0.257
DB2	25.0	0.405	1.302	0.374
DB3	19.0	0.713	2.100	0.314
DB4	25.0	0.481	1.548	0.395
Mean	*26.0*	*0.563*	*1.819*	*0.335*
s.e.	*3.3*	*0.072*	*0.237*	*0.031*

*Summary of 16 sites. Total number of species = 116.

Chronosequence of Parameters Measured

A comparison was made of the species richness for the three topsoil sources over three time intervals (Table 22.5). Treatment A (fresh topsoil applied to rip lines) showed the greatest species richness after 7 years, with mean numbers approaching values on the analogue sites. In comparison, the other two treatments had similar species abundance as the Mulvaney disturbed bushland, which was relatively devoid of understory species because of the previous disturbance history from animal grazing and also clearing.

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Table 22.4 Ecological diversity parameters of the topsoil-handling treatments and analogue woodland sites in October 2009*

No.	Plot ID	Species Richness S	Pielou's Evenness Index J'	Shannon–Weiner Diversity Index H'	Simpson's Diversity Index D
1	DB1	40	0.928	3.422	0.9421
2	DB2	40	0.928	3.422	0.9421
3	DB3	36	0.875	3.136	0.9198
4	DB4	40	0.928	3.422	0.9421
	Mean	*39.09*	*0.9146*	*3.351*	*0.9365*
	s.e.	*1.00*	*0.013*	*0.071*	*0.006*
5	WB1	37	0.801	2.891	0.9198
6	WB2	42	0.771	2.881	0.8933
7	WB3	32	0.779	2.698	0.8679
8	WB4	40	0.804	2.968	0.8926
	Mean	*37.75*	*0.789*	*2.8560*	*0.8934*
	s.e.	*2.18*	*0.008*	*0.057*	*0.0110*
9	A1	38	0.881	3.203	0.9247
10	A2	37	0.839	3.029	0.9187
11	A3	37	0.795	2.869	0.9017
12	A4	26	0.811	2.641	0.8966
	Mean	*34.5*	*0.832*	*2.936*	*0.9104*
	s.e.	*2.84*	*0.019*	*0.120*	*0.0070*
13	B1	16	0.685	1.899	0.7345
14	B2	25	0.751	2.418	0.8382
15	B3	21	0.720	2.191	0.7375
16	B4	20	0.715	2.143	0.7752
	Mean	*20.5*	*0.718*	*2.1628*	*0.7714*
	s.e.	*1.85*	*0.014*	*0.106*	*0.0240*
17	C1	24	0.745	2.368	0.7712
18	C2	28	0.763	2.544	0.8521
19	C3	15	0.651	1.764	0.6419
20	C4	23	0.737	2.311	0.7608
	Mean	*22.5*	*0.724*	*2.247*	*0.7565*
	s.e.	*2.72*	*0.025*	*0.168*	*0.0430*

*Summary of 20 sites. Total number of species = 100.

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Table 22.5 Gross comparison of mean species richness among the sampling periods

Code	Treatment	2003 Year 1	2007 Year 5	2009 Year 7
A	Fresh topsoil in deep rips	19	20	35
B	Fresh topsoil spread over area	21	14	21
C	White schist and soil spread with rehab seedbank	12	8	23
DB	Davies bushland analogue	32	23	39
MB	Mulvaney disturbed bushland	15	—	—
WB	Undisturbed woodland analogue at Wonga	—	—	38

Table 22.6 Gross comparison of mean Pielou's evenness index among the sampling periods

Code	Treatment	2003 Year 1	2007 Year 5	2009 Year 7
A	Fresh topsoil in deep rips	0.59	0.56	0.83
B	Fresh topsoil spread over area	0.42	0.44	0.72
C	White schist and soil spread with rehab seedbank	0.84	0.48	0.72
DB	Davies bushland analogue	0.59	0.56	0.91
MB	Mulvaney disturbed bushland	0.49	—	—
WB	Undisturbed woodland analogue at Wonga	—	—	0.79

Table 22.7 Gross comparison of mean Shannon's H' index among the sampling periods

Code	Treatment	2003 Year 1	2007 Year 5	2009 Year 7
A	Fresh topsoil in deep rips	1.72	1.59	2.94
B	Fresh topsoil spread over area	1.29	1.29	2.16
C	White schist and soil spread with rehab seedbank	2.10	1.42	2.31
DB	Davies bushland analogue	2.04	1.82	3.25
MB	Mulvaney disturbed bushland	1.25	—	—
WB	Undisturbed woodland analogue at Wonga	—	—	2.86

Trends in evenness index (Table 22.6) showed that there was no major shift in the relative contribution of the species present in the sites. The slower-growing understory species proliferated in the selective topsoil treatment (A) along with the decline of the faster-growing pioneer *Acacia* species. The relative contribution of these later successional species increased the evenness index, but once again, treatment A had greater evenness after 7 years (0.83) than treatments B and C (0.72).

Changes in alpha diversity or biodiversity, represented by Shannon's H' index, over the three sampling intervals are summarized in Table 22.7. As the understory assemblages matured over time, biodiversity increased. However, as with the

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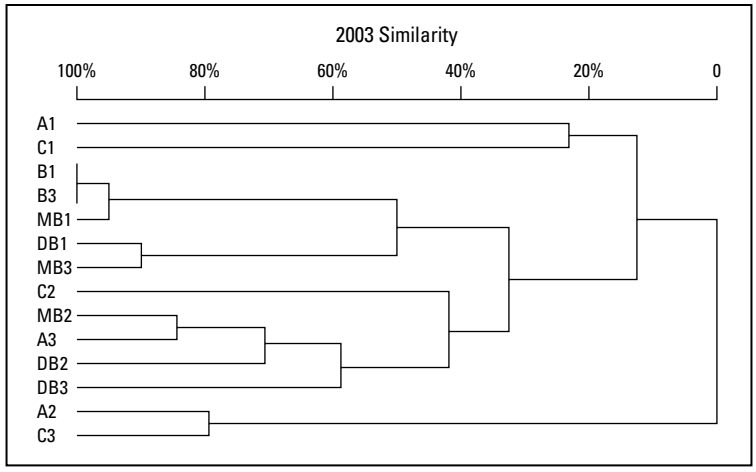


Figure 22.3 Hierarchical cluster analyses of the vegetation compositional data of topsoil treatments and woodland analogue sites in 2003

previous two ecological parameters, Shannon's index for treatment A 7 years after rehabilitation was the most similar to the Wonga analogue site (WB), which was the source of topsoil for treatment A.

Hierarchical clustering (Figure 22.3) of the community data was performed to identify the relative similarity of each site according to the species assemblages in each of the sampling areas. After 1 year (2003), the most similar groups at similarity of >90% were the MB1 and the spread topsoil sites B1 and B3. The least similar to the majority of sites were A1 and C1 at about 24%, and A2 and C3 at about 5% similarity to all the other sample sites.

Applying the same cluster analysis to the community matrix on the 5-year-old data set showed well-defined segregation of the different sites (Figure 22.4). Line intercepts within treatments A, B, and C and the reference area (DB) are all clustered together, although sites in treatment A and the reference area have relatively low average similarities.

An analysis was performed in 2009 using a hierarchical cluster analyses on two sets of analogue sites—once again, the DB and a WB in the proximity of the tailings storage facility. The dendrogram (Figure 22.5) strongly segregated the Wonga analogue sites and the selective topsoil treatment A at approximately 50% similarity level, then both at a 25% level from the Davies plots. The other topsoil treatments (B and C) were only 1% similar to the treatment A and the analogue sites.

This strong affinity between the treatment A and the WB sites is highly indicative that the provenance of the topsoil used in the trial was the Wonga cleared bushland. The lack of convergence between the Davies bushland and the WB sites is also indicative of the importance of comparing the appropriate analogue sites. The high species richness in treatment A is similar to the bushland locality where the topsoil was stripped rather than the Davies bushland control analogue site.

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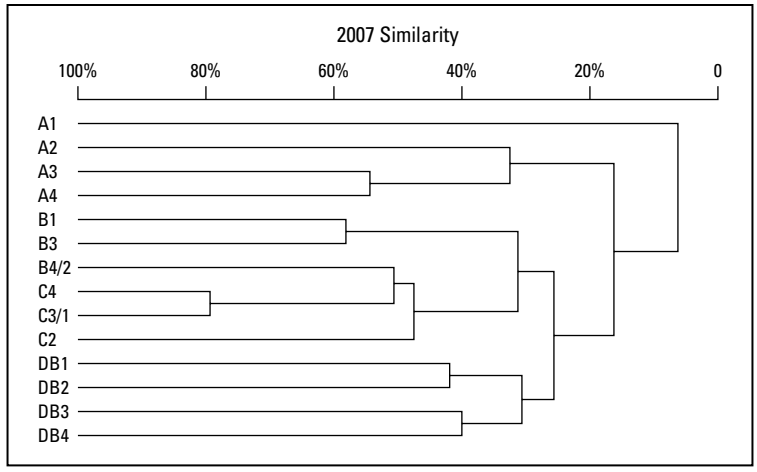


Figure 22.4 Dendrogram of floristic similarity within and between reference and rehabilitation treatment sites in 2007, Stawell gold mine

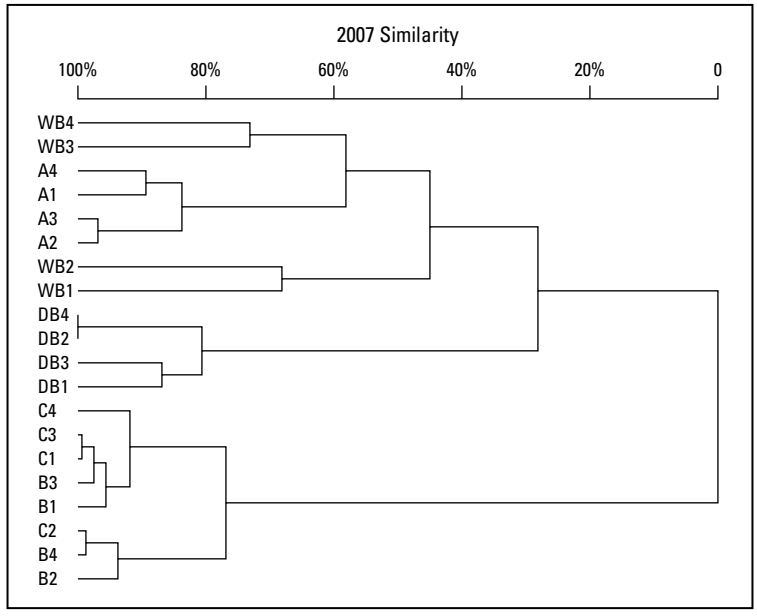


Figure 22.5 Hierarchical cluster analyses of the vegetation compositional data of topsoil treatments and woodland analogue sites in 2009

The multivariate analysis was also taken further on the species compositional data for the three sampling periods. The most informative plots are the 2-D ordinations using the Bray–Curtis index to first generate the similarity matrix between the different sample sites followed by a nonmetric MDS and the vectors plotted

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in ordination plots. Using two and three dimensions, MDS ordinations of species and cover abundances in each plot were performed with 20 iterations. The minimum stress value attained for two and three dimensions was 0.19 and 0.14, respectively. The 2-D representation (Figure 22.6) was chosen in preference to aid visual interpretation. While the 2-D stress value is acceptable, over-interpretation of the ordination details could be misleading (Clarke 1993). Sampling sites that are most similar are closer to each other in the 2-D space. In the first year, the treatment C plot and one of the treatment A plots were clearly segregated from the analogue sites (Figure 22.7). The sampling in 2007 was also analyzed, and 2-D and 3-D MDS ordinations of species and cover abundances in each plot were performed with 20 iterations. The minimum stress value attained for two and three dimensions was 0.15 and 0.09, respectively. Some of the sites are clearly grouped, such as treatment A. The reference area sites are also clearly differentiated from the other treatments, but one site is relatively distant from the other reference area sites. This is most likely due to data error, the cover abundance values not having been converted from distance to percentage cover values. Treatments B and C are grouped relatively close to each other, with only one treatment C site differentiated from the others.

For the 2009 data, 2-D and 3-D MDS ordinations of species and cover abundances in each plot were performed, with 999 iterations. The minimum stress value attained for two and three dimensions was 0.18 and 0.14, respectively. The 2-D representation (Figure 22.8) was chosen in preference to aid visual interpretation. Some sites are clearly grouped, such as treatment A; but according to the cluster analyses, these sites are closer to the reference area sites that are more dispersed in the multivariate space. Treatments B and C are grouped relatively close to each other.

Weed Invasion

Fifteen exotic species were recorded at all sites and were distributed across the treatment areas. The greatest abundance was observed in the reference area with 11 species, the species contributing most to weediness being *Gladiolus* spp. (gladiolus), *Arctotheca calendula* (capeweed), and *Ehrharta calycina* (perennial veldtgrass). Treatments A, B, and C had 6, 4, and 7 weed species, respectively. Weed cover was <0.1% in all the areas. The only woody weed species present, *Chrysanthemoides monilifera* (Boneseed), a declared noxious weed species (<0.1% cover), was observed in treatment C. Most of the weedy species are common pasture species.

DISCUSSION

The choice of a reference area adjacent to the treatment sites, and simultaneously measuring differences in attributes between that site and the treatment sites, would

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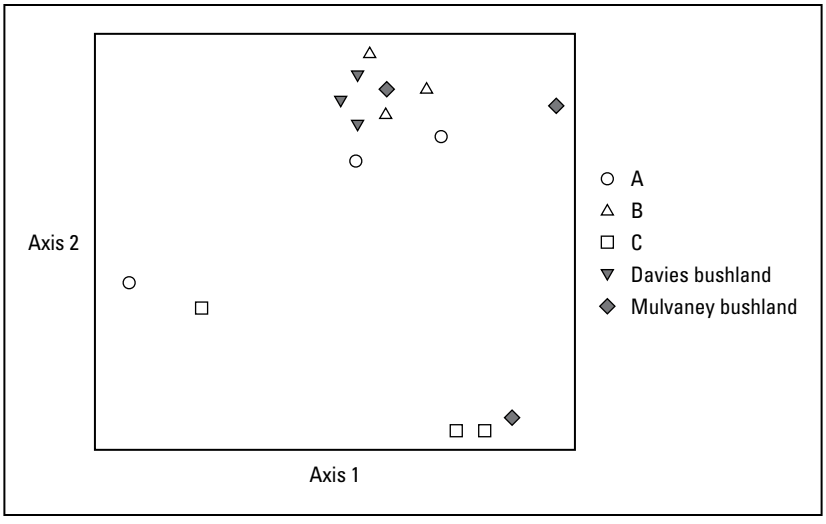


Figure 22.6 2-D MDS ordination of species and cover abundance of reference and topsoil treatment sites in 2003 (stress value = 0.19)

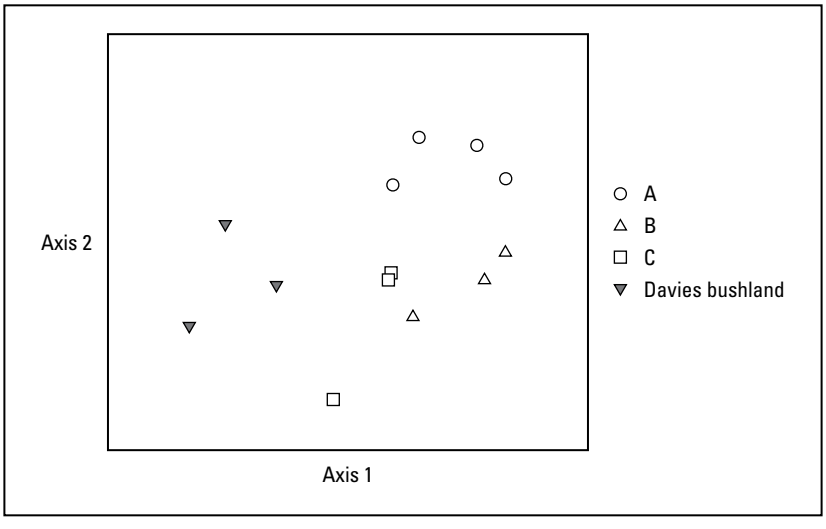


Figure 22.7 2-D MDS ordination of species and cover abundance of reference and topsoil treatment sites in 2007 (stress value = 0.18)

seem to be optimal in minimizing the differences due to spatial and temporal variation. However, as a small remnant, fragmented by roads and in close proximity to industrial, agricultural, and urban land uses, the reference condition may be compromised representing only a sample of the original vegetation community (White and Walker 1997). This effect has been compensated through subjective

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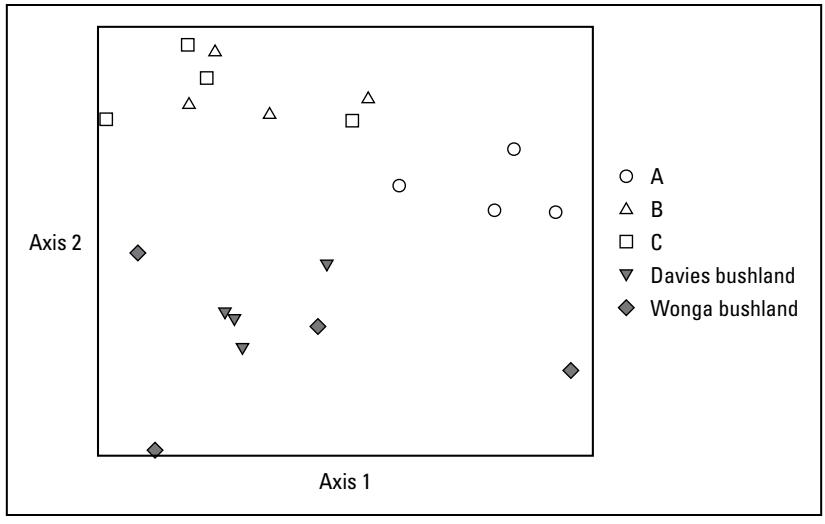


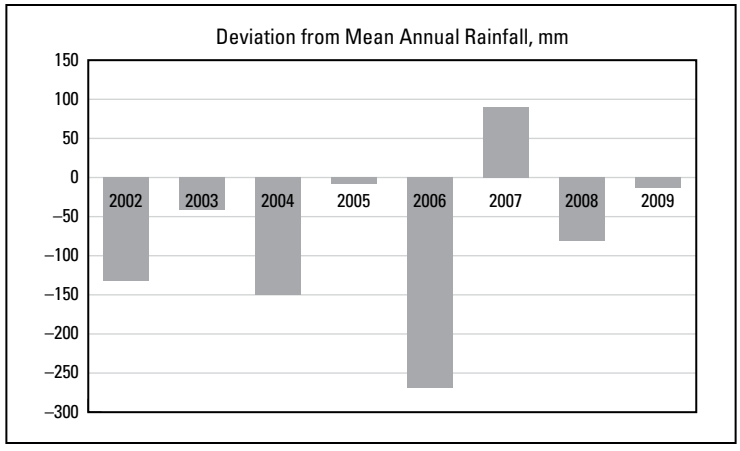
Figure 22.8 2-D MDS ordination of species and cover abundance of reference and topsoil treatment sites in 2009 (stress value = 0.18)

selection of the remnant, chosen to represent the "average characteristics of a mature and apparently long-undisturbed stand of the same vegetation community" (Parkes et al. 2003).

Cover abundance values in treatment sites could not be expected to have recovered to an extent comparable with the reference area after only 5 years. However, depending on the variety and quantity of seed present in soil sources, and the survivorship of seedlings, given adequate time, it is theoretically possible that species richness and diversity values could be similar to remnant area values. Koch et al. (1996) found that the density of germinable seed was reduced to 53% of source densities in an unstockpiled soil application to a restoration site. In this study, the measures of species richness and diversity were relatively consistent between treatment A and the reference sites. Diversity and richness were variable across the treatment A site, but this was reflected in the high variability of the reference area also.

Although large woody shrubs and canopy trees may take much longer than 5 years to form the canopy structure observed in the remnant area (impacted by mining in the 1850s), it is concerning that only one of the four species of eucalypts observed in the remnant occurred in treatment A. This indicates that supplementary hand planting of select canopy species may be appropriate for reintroducing canopy species into reclaimed surfaces when using topsoils. Measures of diversity (H' $\log^e$) and richness (S) for treatment B were lower than the remnant area. Species numbers and cover abundances for most life-form classes were considerably less than for the benchmarks in the remnant area, except for the numbers of medium shrub species.

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Source: BOM 2009.

Figure 22.9 Deviation from average annual rainfall calculated for 1971–2009, Stawell

All measures of diversity and richness were clearly less in treatment C than in the reference area. Species numbers for all life-form classes were less than in benchmarks, except for large graminoids. However, the cover abundance of medium shrubs was dominated by *Acacia pycnantha*, *Acacia paradoxa*, and *Austrostipa mollis* and was almost double that of the benchmark.

Although drought and low rainfall after planting as well as grazing by the native and introduced mammals may influence juvenile mortality (Cowling and Lamont 1987; Koch et al. 2004), lower richness or diversity in treatments B and C cannot be explained by other factors such as grazing, since diversity in the treatment A site was reasonably consistent with remnant-area and benchmark values. However, consistently low rainfall conditions from 2002–2006 (Figure 22.9) may slow growth rates and increase the time required to develop benchmark cover-abundance values.

Differences in diversity and richness are likely to be a result of differences in site treatment. Soils containing seeds were taken from three areas, and different treatments were applied to each. The variety and abundance of seed stores present in each soil source are expected to have varied, and the treatments may have variably reduced the soil seed store (Koch et al. 1996). Stockpiling, as in the case of treatment C, will result in seed loss, because high levels of organic matter and anaerobic conditions in the stockpiles will damage seed (Koch et al 1996; Rokich et al. 2000). Koch et al. (1996) found that the most persistent seeds were large and hard, such as seed from leguminous species such as the genus *Acacia*, therefore explaining the dominance of *Acacia* species in treatment C. "Seed rain" from the adjacent revegetation area may also have contributed to this dominance.

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Germination of seeds from many species may be prevented by their dormancy mechanisms, which may be overcome by burning, heat, and/or scarification (Bell et al. 1995). Scarification may occur as soil is spread or the profile is ripped. Most seed occurs in the top several centimeters of soil (Grant et al. 1996). If soil is applied too thickly, seed buried too deep may be unable to germinate (Grant et al. 1996; Rokich et al. 2000). However, Koch et al. (1996) and Rokich et al. (2000) found no decrease in recruitment from ripping after spreading, allaying concerns that this process may bury seed too deeply. Once germinated, seedlings are subject to more harsh conditions in the restoration environment than on the forest floor, such as greater diurnal temperature fluctuations, more severe drying, and grazing (McChesney et al. 1995). Seedling mortality from inadequate water, due to the restriction of the root system to the subsurface moisture (Enright and Lamont 1992), may be mitigated by ripping (Rokich et al. 2001). Appropriate seasonal timing of soil stripping and spreading is necessary to prevent interruption of germination events; treatments in winter or spring may not allow sufficient time for seedling germination and establishment prior to the summer dry season (Ward et al. 1996; Rokich et al. 2000).

Rip lines appeared to be critical for the recruitment of plant species. Although the spatial pattern of recruitment was not measured, most recruitment appeared to have occurred in the rip lines, particularly in treatments A and B. In treatment A, this may be explained by the topsoil (and seed) having been spread into rip lines. In treatment B, where topsoil was spread over the entire area, the explanation must include various effects of the ripping, including increasing infiltration capacity and root development potential in the rip line, interruption of water flows across the surface, and deposition of soil sediments and seed against furrows.

Environmental legislation and policy requirements are obviously an important part of defining ecological success. In Victoria, the notion of temporary loss is usually applied to bond conditions regarding the return of prior land use, and broadly environmental conditions and functions. It is troublesome that the notion relates poorly to the return of native ecosystems on-site given that Victoria has done little to develop its own capability in the restoration of postmined ecosystems.

Indeed, the MOU that binds the mining industry to the general planning controls often mandates that off-site native vegetation be "secured" in return for lost ecosystems as a result of the mining activity. Although this is a sophisticated system of trading losses to secure native vegetation off-site, it should also be acknowledged that it acts as a disincentive to capability development in mine-site restoration. It is imperative that the Victorian government develops policy instruments to better promote a strategic investment in postmine environmental planning and ecological restoration.

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CONCLUSIONS

The following conclusions have been drawn from the study:

- The treatments combined a number of variables. It is therefore difficult to assess whether variation in results are due to differences in the source of soil-stored seed (harvest site 1 and 2) or differences in ripping treatment (before or after spreading soil). However, the similarity of the freshest topsoil treatment A to the analogue tailings storage facility sites strongly indicated the affinity of the floristic composition of the treatment to the topsoil resource.
- Stockpiled soil is likely to store only large, hard seeds such as *Acacia* species, which are able to withstand the pressure of being buried at depth. Soil should be applied as soon as possible after stripping to maximize recruitment and diversity.
- Species richness for some life forms was acceptable under some treatments. However, canopy species were under-represented in all treatments, and the number of individuals present means that cover abundance for this life form is not likely to reach target levels without further intervention.
- Criteria have to be defined for appropriate closure of the mining-affected areas, and in particular, of the tailings storage facilities with the aim of returning these to a self-sustaining ecosystem similar to the adjoining Box Ironbark communities. The current challenge of these areas in the Victorian goldfields is restoration is made more difficult because these vegetation communities have been severely impacted from historic mining operations from the 1800s. This study contributes information regarding the possible trajectories of a reconstructed vegetation community based on three topsoil-handling regimes.
- Possible criteria by which bond relinquishment can be negotiated should address the time required for establishment of many species. It appears appropriate to measure revegetation success after at least 6 years or alternatively three successive yearly assessments. The minimum time required would enable tracking of the reproductive states of most of the species. Most of the species would be at a stage in which reproductive fitness can be quantified, therefore indicating their self-sustainability. Most studies on restoration of terrestrial ecosystems include at least one measure in each of three general categories of the ecosystem attributes: diversity, vegetation structure, and ecological processes. Most of the reviewed literature uses multiple measures to evaluate restoration success. It is encouraged that future projects include (1) at least two variables (e.g., indices of biodiversity as presented in this report within each of the three ecosystem attributes that clearly related to ecosystem functioning) and (2) at least two reference sites to capture the variation that exists in ecosystems. The Stawell gold mine is unique as having the first and longest-running tailings storage facility in Victoria; therefore, any

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prescriptions for determining appropriate closure criteria are not currently available. Sensible criteria have been proposed in this study, and current topsoil trials will only be verified by further research. Determining the necessary values to define satisfactory benchmarks will assist the regulators as well as the mining operation.

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CHAPTER 23

Best Practices for Forest Restoration When Reclaiming Surface Coal Mines

Carl E. Zipper, Christopher D. Barton, Jennifer A. Franklin, Jeffrey G. Skousen, Patrick N. Angel, and James A. Burger

INTRODUCTION

Surface coal mining in the eastern United States' Appalachian region often disturbs large areas occupied by forest ecosystems. These forests contain rich and diverse flora and fauna, generate marketable wood products for landowners, and provide a wide range of ecosystem services. Traditional mine reclamation practices, however, have often established postmining land covers that do not restore the vegetation and wildlife, biological productivity, ecosystem services, and economic value provided by the premined landscapes. In response, reclamation scientists have developed a Forestry Reclamation Approach (FRA) that can be used by coal mining firms to reestablish productive forest vegetation and landscapes during reclamation, reducing the overall long-term environmental impacts of a mining activity. With the support of mine regulatory agencies, this reclamation method is implemented by some mining firms within the region today. More widespread and effective application of the FRA will aid the Appalachian coal industry's efforts to operate responsibly in the context of sustainable mining. The FRA may be considered as "best practice" by Appalachian mining operations seeking to restore forested land uses through reclamation. With modification to accommodate local conditions, it may provide a model for development of forest restoration practices by mining firms operating in other forested regions of the world.

This chapter describes the FRA and its application on Appalachian mined sites, from the state of Tennessee northward. It reviews specific reclamation procedures that are essential to the FRA and their scientific rationale. It concludes

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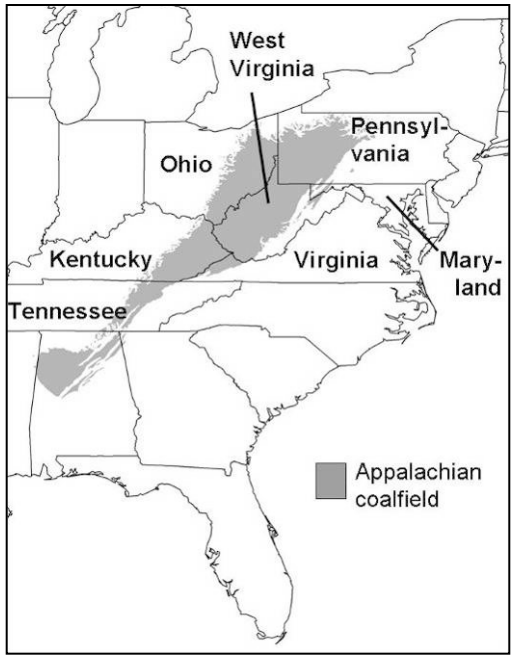


Figure 23.1 The Appalachian coalfield of the eastern United States

by describing three case studies of mining operations where the FRA has been successfully employed.

MINING AND ENVIRONMENTAL SUSTAINABILITY IN THE EASTERN UNITED STATES

The Appalachian region of the eastern United States is extensively forested. The region also contains coal reserves that have been significantly mined in the past and continue to be mined today (Figure 23.1). Much of Appalachia's current mining activity is surface coal production. As a result, large areas of forest are being converted to other land covers by coal surface mining. In Appalachia, more than 600,000 ha (1.5 million acres) have been mined for coal since 1980 under the Surface Mining Control and Reclamation Act (SMCRA), with new mining creating additional surface disturbances of ~10,000 ha/yr, or ~25,000 acres/yr (Zipper et al. 2011b).

Appalachian forests are a globally significant ecological resource (Riitters et al. 2000), and they provide economic and environmental benefits for area residents. These forested ecosystems are diverse, with more than 40 commercially valued tree species and more than 500 native woody species (USDA 2013). They provide ecosystem services, including carbon storage, watershed and water quality protection, and habitat for a diversity of plants and fauna that are highly valued

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and essential to life quality in this mountainous region. Appalachia's forests supply timber to local users and to the world economy. Like the mining industry, Appalachia's forest industry is a major employer. Surface mining, however, has caused forest fragmentation and a net loss of productive forestland (Wickam et al. 2007; Sayler 2008; Townsend et al. 2009). The loss of forested areas has obvious environmental impacts, but it also has associated social impacts in the form of lost jobs and economic revenue to the region. This progressive loss of forest vegetation is of concern to area citizens, to mining and environmental agencies, and to some within the coal industry.

Appalachian forest loss has occurred under the regulatory structure established by U.S. federal law—the SMCRA—despite the fact that the vast majority of those lands were reclaimed in compliance with legal requirements as interpreted by industry and agencies. During the SMCRA's early implementation in the late 1970s and early 1980s, special efforts were made to address problems caused by uncontrolled mine-spoil placement prior to the law such as land stability hazards, soil erosion, and stream sedimentation. Hence, agencies implementing the SMCRA emphasized reclamation practices to stabilize land surfaces and to hold surface soils in place, such as intensive grading and soil compaction by mining equipment and establishing vigorous herbaceous vegetation (Angel et al. 2005). As an unintended consequence, soil conditions and vegetation on reclaimed sites prevented colonization by forest vegetation but often allowed nonnative plants from older mining areas to invade and become established. Compacted soil surfaces hinder planted trees' root growth and access to water, air, and nutrients, and they limit soil aeration. Vigorous herbaceous ground covers, heavily fertilized to stimulate rapid growth, had the unintended effect of impairing survival and growth of planted trees. As a result, trees were not planted on many SMCRA mine sites, while those mines that did plant trees often selected species not characteristic of the region's mature forests but able to withstand the difficult conditions created by conventional SMCRA reclamation. A survey of Appalachian mined lands conducted in the mid-2000s found that most were occupied by herbaceous vegetation and shrubs, that common shrub and herbaceous species were nonnative, and that few native trees of the types found in mature forests were present (Zipper et al. 2011a).

Scientific research, however, has demonstrated that forested vegetation can be established on Appalachian coal surface mines, and that such restored vegetation can be productive and diverse. When properly prepared for forest vegetation, mine soils provide a deeper rooting medium than many native soils in steep mountain landscapes, and they are also rich in some geologically derived nutrients—calcium, magnesium, and potassium—that are essential to productive tree growth. Tree productivity on Appalachian mine sites reclaimed to be compatible with growing trees has been documented as equivalent to or better than that of forests growing on unmined soils in adjacent areas (Zipper et al. 2013).

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Researchers have also found that vegetation on coal mined lands can be diverse when appropriate reclamation procedures are employed. For example, Holl (2002) observed that 102 nonplanted native species, most of which are characteristic of native forests, had colonized southwestern Virginia mine sites, while Wade (1989) found that mined-land research plots reclaimed with topsoils from the premining forested areas gave rise to 84 plant species. Wade and Thompson (1993) found more than 270 plant species occurring on five older Appalachian mine sites, including one on which only three tree species had been planted during reclamation. In contrast to these findings, plant communities on mine sites reclaimed using conventional SMCRA reclamation practices are often limited and dominated by nonnative invasive plants.

Research also clearly demonstrates that the potential for forest reestablishment on surface coal mines is influenced by reclamation practices. For example, Holl (2002) found that the influence of reclamation method on vegetation community structure remained evident 15 to 30 years later. Burger et al. (2007) observed that the rock types used to construct mine soils greatly influenced growth of planted trees more than 20 years later. Skousen et al. (2006) found that revegetation practices strongly influenced community composition 20 years after reclamation had taken place. Based on these insights and other studies, researchers developed a mined land reforestation prescription for use by the Appalachian coal industry (Burger et al. 2005). That prescription, the FRA, is being used in Appalachia by some mining firms today.

The Appalachian mountains are predominantly forested landscapes. The geology is sedimentary, and most of the rocks are sandstones, siltstones, and shales, with interbedded coal seams. The strata are generally flat-lying, with most sedimentary beds oriented within a few degrees of horizontal (Figure 23.2). The region's highlands occur as remnants of an ancient plateau that has been heavily dissected, causing steep side slopes to become the predominant landforms. Soils on those side slopes are generally thin (<1 m, or <3 ft), but soils can occur with greater depth on the remaining ridgetops and near waterways. Beneath the soil is a zone of "weathered" rocks, meaning near-surface geologic materials that have been affected by surface environmental processes such as oxidation and leaching of some mineral-origin salts. Weathered rock zones range widely in thickness, often extending from 5 to 20 m (16 to 66 ft) below the surface, and are typically brownish in color and easy to identify visually within the mine. The weathered rocks, like the overlying soil, are typically mildly acidic, with pH values in the upper 4s and 5s for those lying directly beneath the soils. The unweathered rocks below are typically grayish in color and minimally affected by surface processes. The unweathered rocks can have chemical properties that are often alkaline, but can be strongly acidic if they contain reduced sulfur minerals, and are typically more saline than the near-surface materials. By law, highly acidic rocks must be managed to prevent surface exposures and water contamination.

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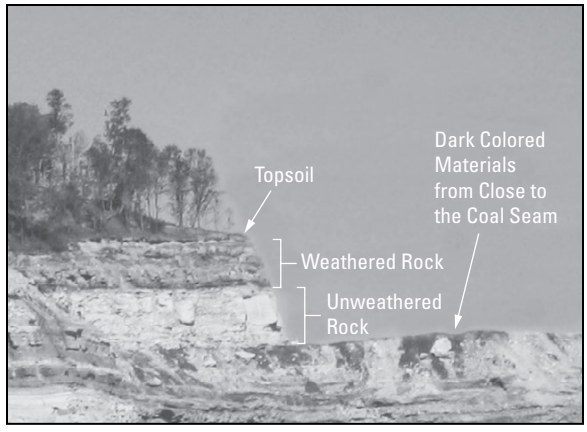


Figure 23.2 Overburden rock and soil at an Appalachian coal surface mine

THE FORESTRY RECLAMATION APPROACH

The FRA is intended to produce site conditions that are favorable to forest vegetation and to establish an initial suite of commercially valuable forest trees. Native Appalachian forests host numerous plant species, and it would be costly to attempt reestablishment of the full forest plant community on mine sites by seeding and planting alone. In fact, full community replacement by seeding and planting immediately after mining is likely impossible, given that many forest species are unable to tolerate the full-sun conditions that exist prior to plant community reestablishment. Hence, the FRA establishes site conditions that enable colonization by native vegetation whose seeds are carried by wildlife and wind. Planted trees and shrubs are selected to reestablish tree species with large seeds that are important to the native forest but slow to move into the landscape, and to attract seed-carrying wildlife. These practices of soil construction and revegetation are also intended to create site conditions suitable for establishment of nonplanted species that may enter the site carried by wildlife and wind.

The FRA is presented as a series of five steps, each of which is essential to successful mine reforestation. All five steps are critical to achieving the intended outcome of rapid forest reestablishment. Those five steps are briefly described here while noting that more complete descriptions are available as "Forest Reclamation Advisory" publications that are cited by the text that follows.

FRA Step 1: Create a suitable rooting medium for good tree growth that is no less than 1.2 m (4 ft) deep and composed of topsoil, weathered sandstone, and/or the best available material.

The first step in reestablishing forest vegetation is to select the "best available" growth medium for use in soil construction. The properties of materials used to create a mine soil will influence the survival and growth of planted trees and the

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"natural succession" of native vegetation that is essential to forest development (Groninger et al. 2007).

Fundamental to selection of soil reconstruction materials is the nature of rock spoils (Figure 23.2). Native soil is generally considered to be the best available material for reforestation (Skousen et al. 2011; Zipper et al. 2013). Native soil has physical and chemical properties that are favorable to native trees. Native soils contain a full suite of essential nutrients, especially nitrogen and phosphorus that are present in limited quantities (if at all) in rock materials but are essential to trees' growth as well as organic matter that is essential to soil life and hydrologic processes. They contain live seeds and other forest soil organisms that remain alive and viable if moved from excavation to reclamation areas directly (Hall et al. 2010). Native soils have chemical properties, including low salinity and moderately acidic pH, that are conducive to plant growth and soil nutrient availability.

Native soil may be applied alone or it may be mixed with the upper portion of the weathered rock spoil if soil and weathered spoil can be removed together easily (Table 23.1). When native soil is available from areas where nonnative invasive vegetation is not prevalent, woody debris such as stumps of cleared trees, roots, dead limbs and branches, and leaves from the forest floor should be excavated and spread with the soil materials because these organic materials will be valuable resources that can aid restoration. Excavation of the soil surface materials (forest litter, roots, stumps, and woody debris) along with the soil and then spreading that material on the reclamation area will create favorable soil properties, establish plant materials from the native soil seed bank, allow release of nitrogen and phosphorus as organic materials decompose, and aid reintroduction of soil fauna and other wildlife to the reclaimed mine area.

Weathered spoils are usually superior to unweathered spoils for forest restoration. If native soils and weathered spoils are not available in adequate quantities to construct the tree-growth medium, they can be mixed with unweathered overburden materials with suitable properties for soil construction. Unweathered spoils can vary widely in their suitability for native trees, so properties such as pH (should be nonpyritic but moderately acidic, in the range of 5.0–6.5 when possible) and soluble salts (as measured by electrical conductivity—should be low) are important indicators of mine spoil suitability for reforestation. For further details, see Skousen et al. (2011) and Zipper et al. (2013).

FRA Step 2: Loosely grade the topsoil or topsoil substitutes established in step 1 to create a noncompacted soil growth medium.

Minimizing soil compaction is essential for effective mine reforestation. Operation of mining equipment on reclamation areas will compact soils, causing them to become dense and thereby hindering survival and growth of planted trees (Torbert and Burger 1994; Burger and Evans 2010) and recruitment of nonplanted forest

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Table 23.1 Summary of material types and guidelines for constructing forestry mine soils on Appalachian coal surface mines

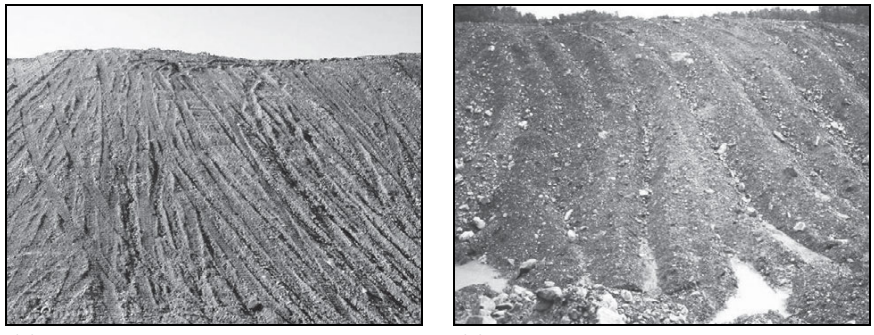
Type	Description	Use
1. Soil	Premining forest soil; includes mineral horizons, rocks, stumps, roots, and seed pool as well as soil-dwelling animals and microorganisms	Use if available; usually the best available material.
2. Weathered rock	Brown rocks that lie beneath the soil prior to mining	Mix with type 1 if necessary to achieve adequate quantity for ≥1.2 m (4 ft) depth; sandstones are best.
3. Selected unweathered rock	Rock below weathered strata, usually gray, that weathers within a few years to pH 4.5–7.0, has relatively low soluble salts, and breaks down to form soil-like material	If types 1 and 2 are not available in adequate quantities to produce a mine soil of ≥1.2 m (4 ft) depth, type 3 may be mixed at up to a 2:1 ratio with types 1 and/or 2.
4. Unweathered rock to avoid	Have pyritic minerals, high pH, and/or high soluble salts; or is durable rock or black shale	Avoid use for forestry mine soils, either alone or in significant quantities within mixes.

Source: Skousen et al. 2011.

species (Angel et al. 2008). This also reduces the economic value of timber that eventually grows on the mine site.

A loose mine soil with a rough surface is best for forest reestablishment. A loose soil suitable for reforestation can be achieved by limiting reshaping and grading of surface materials to the minimum needed to form the desired land configuration (Sweigard et al. 2007b). If materials such as rocks and woody debris remain on the land surface, those materials will not hinder forest restoration. In fact, they may even help it by shielding the soil surface from the sun, which helps to conserve soil moisture during warm weather. Placing soils to create loose, rough, uneven surfaces will actually reduce erosion on many mine sites, compared to conventional smooth grading, because this condition allows more water infiltration, leaving less water runoff to erode and carry soil. The increased water infiltration aids tree growth, and the loose soil aids rooting of planted trees. The rough soil surface also aids plant recruitment by providing "nooks and crannies" to hold and germinate seeds carried to the mine site by wind, birds, and other wildlife. Leaving the soil loose and with woody debris and rocks on the surface will aid reintroduction of wildlife to the reclaimed mine area (Wood et al. 2013). The reduced grading practices that produce soil surfaces suitable for reforestation are also less costly than conventional smooth grading (Figure 23.3).

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(A) (B)

Source: Burger and Zipper 2011.

Figure 23.3 (a) A mine spoil slope that has been graded smoothly and covered with dozer tracks, and is not a favorable site for planting trees; and (b) a loose-graded slope that is more favorable for survival and growth of planted trees

If soils do become compacted by equipment, they can be loosened prior to revegetation and tree planting through the use of a soil ripper (Sweigard et al. 2007a). Loosening of soil prior to tree planting is advised on areas such as roads and equipment storage pads. If land stability requires compaction, subsurface spoils can be compacted prior to covering the site with 1.2–1.8 m (4–6 ft) of additional media that remain uncompacted and suitable for planting trees (Sweigard et al. 2007b).

FRA Step 3: Use less competitive ground covers that are compatible with growing trees.

Ground-cover vegetation used in reforestation requires a balance between the benefits that herbaceous vegetation provides and the competition for the light, water, and space required by trees. Some level of herbaceous ground cover is beneficial to the reclamation process and to tree growth on reclaimed mines (Franklin et al. 2012). Herbaceous ground-cover stabilizes and protects the soil surface, aids in preventing soil erosion, maintains rooting channels from surface to subsurface for soil aeration and water infiltration, adds organic matter to the soil, and aids the development of microbial communities. When the ground-cover vegetation contains a legume component (as recommended), those legumes convert atmospheric nitrogen to plant-available forms in the soil that can aid tree growth. However, the fast-growing grasses and legumes that have been used traditionally in coal mine reclamation, such as fescue, sericea lespedeza, and certain clovers, are too aggressive and competitive for use with trees. These ground-cover species overtop the young planted trees, depriving them of sunlight, and form dense rooting that hinders the planted trees' from accessing essential soil water and nutrients. Alternatively, short-statured, bunch-forming grasses such as timothy and native grasses are less competitive and can be easily established on mine sites. Low-growing legumes convert atmospheric nitrogen (an essential plant nutrient) to plant-available forms, and

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(A) (B)

Source: Burger et al. 2009.

Figure 23.4 Ground-cover vegetation on coal mine sites. (a) A tree-compatible ground cover in mid-summer of a dry year, about 3 months after seeding. (b) A tree-compatible ground cover 3 years after planting. At least half the cover is made up of native plants, and young planted trees are able to survive and grow. Growing tree seedlings are visible in both photos.

legume species such as birdsfoot trefoil are less competitive than those traditionally used in reclamation. These slower-growing, less competitive ground covers can be used without causing excessive erosion because the loosely placed mine soils established by FRA step 2 allow greater rates of water infiltration than conventionally smoothed and compacted soils. To further discourage heavy ground-cover growth, applied fertilizers are low in nitrogen, but they include sufficient phosphorus and potassium to support forest trees' needs over longer terms (Burger et al. 2009).

The tree-compatible ground cover is typically sparse in its first growing season, which minimizes competition with the planted seedlings and allows recruitment of nonseeded plants that will promote natural succession. If the mine soils have been prepared in accordance with FRA steps 1 and 2, seeded and volunteer (established by natural means) herbaceous vegetation will commonly approach 100% cover by the third growing season (Figure 23.4).

Scientific research clearly demonstrates that conventional ground-cover vegetation, comprised of fast-growing grasses and legumes, will hinder the survival and growth of planted trees (Burger et al. 2008) and the establishment of volunteer native vegetation (Fields-Johnson et al. 2012). Seeding of tree-compatible herbaceous ground covers (Tables 23.2 and 23.3) will aid survival and growth of planted trees, and will allow plant species carried into the reclamation area by wind and wildlife as live seeds to become established.

FRA Step 4: Plant two types of trees—early successional species for wildlife and soil stability, and commercially valuable crop trees.

Crop trees are long-lived species that offer value to landowners as saleable forest products. Native hardwood species are commonly planted as crop trees on mining operations that are reclaimed using the FRA (Figure 23.5). Tree species with

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Table 23.2 Example of a seeding and fertilizer application for FRA reclamation on mine sites where soil conditions are favorable for forest vegetation (pH between 5.0 and 6.5)*

	Rate	
Species/Fertilizers	**kg/ha**	**lb/acre**
Perennial grasses:		
Perennial ryegrass (*Lolium perenne*)	11.2	10
Orchard grass (*Dactylis glomerata*) (steep slopes only)	5.6	5
Timothy (*Phleum pratense*)	5.6	5
Annual grasses:		
Annual ryegrass (*Lolium multiflorum*), or	5.6	5
Foxtail millet (*Setaria italica*)	11.2	10
Legumes (with inoculant):		
Birdsfoot trefoil (*Lotus corniculatus*) (steep slopes only)	5.6	5
Ladino or white clover (*Trifolium repens*)	3.4	3
Fertilizers:		
Nitrogen (N)	56–84	50–75
Phosphorus (as P)	90–112	80–100
Phosphorus (as P_2O_5)	202–258	180–230

Source: Burger et al. 2009.
*These rates are intended to achieve >80% ground cover after 2 years, although species and rates may differ based on local conditions.

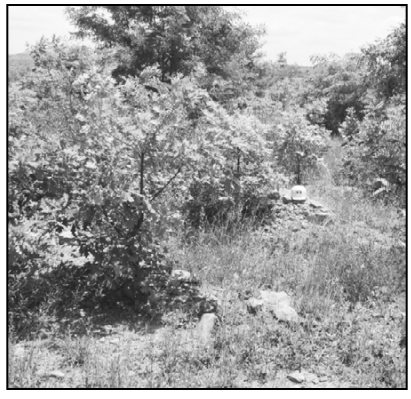
Table 23.3 Native warm-season grasses that can be seeded to aid reforestation in the southern Appalachians*

Common Name	**Botanical Name**
Broomsedge bluestem	*Andropogon virginicus*
Sideoats grama	*Bouteloua curtipendula*
Little bluestem	*Schizachyrium scoparium*
Indian grass	*Sorghastrum nutans*
Eastern gamagrass	*Tripsacum dactyloides*

Source: Burger et al. 2009.
*Typical seeding rates for total native warm-season grass seed: 9–11 kg/ha (8–10 lb/acre).

large seeds, common in eastern forests and including oaks and hickories, are often emphasized in FRA plantings. Early successional "nurse trees" are also planted to enhance the organic matter and nitrogen status of the soil, and to attract seed-carrying birds and other wildlife to the site. Common and effective nurse trees are eastern redbud, hawthorn, and dogwood. Leguminous nurse species, such as black locust and alder, convert atmospheric nitrogen to plant-available forms, which

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Source: Skousen et al. 2011.

Figure 23.5 An emerging hardwood forest established with researchers' involvement on an active mine site in West Virginia. Multiple species were planted and are present. The brown weathered sandstone used as a rough-graded soil medium is visible in the photo.

aids accumulation of this essential nutrient in the emerging forest system. Nurse tree species that produce edible fruits and seeds at a relatively young age, such as dogwood, are often selected to attract wildlife. Planting a mixture of crop trees and nurse trees, both nitrogen-fixers and species that attract wildlife, will accelerate development of a forest plant community on the reclaimed site.

Regulatory agencies throughout the Appalachian region require mining firms to achieve minimum densities of living trees of desirable species on reclamation areas. Although specific numbers vary by state, most states require approximately 988 living trees/ha (400 trees/acre). If the mining firm plants 1,730 trees/ha (700 trees/acre), a survival rate of 70% will leave 1,211 living trees/ha (490 trees/acre) and provide a comfortable margin over legal requirements. If FRA reclamation practices are used, additional living trees may become established as volunteers from live seeds or roots. A common planting practice is to emphasize heavy-seeded crop trees, since many nurse trees move across the landscape more easily. As an example, the planting mixes in Table 23.4 include 1,483 crop trees and 247 nurse trees/ha (600 crop and 100 nurse trees/acre).

Mine sites and natural forests contain a variety of landforms and associated soil conditions (Davis et al. 2012). Certain tree species prefer specific landscape and soil conditions. Hence, a best practice for mine reforestation is to vary the tree-planting mix that is applied to various areas of the site in response to landscape and soil conditions (Table 23.4). Professional tree-planting contractors are often aware of these differences and can provide landscape-oriented tree-planting prescriptions if asked. Targeting tree planting to the conditions that occur over the mine site will improve the survival and growth of planted trees.

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Table 23.4 Example tree-planting prescriptions (seedlings per acre)*

Dry Slopes (south, west)		**Flat Sites** (and rolling)		**Moist Slopes** (north, east)		**Wet Sites** (riparian)	
Crop trees		**Crop trees**		**Crop trees**		**Crop trees**	
White oak	200	White oak	100	White oak	100	Pin oak or river birch†	200
Scarlet or post oak	100	Northern red oak	100	Northern red oak	200	American sycamore	200
Black oak	100	Sugar maple	100	Sugar maple	100	Sweetgum	200
Chestnut oak	100	Yellow poplar	100	Yellow poplar	100		
Virginia pine	100	Black cherry	100	Black cherry	100		
		Black walnut	100				
Nitrogen fixing tree		**Nitrogen fixing tree**		**Nitrogen fixing tree**		**Nitrogen fixing tree**	
Black locust	25	Bristly locust	20	Bristly locust	25	Alder	25
Wildlife trees		**Wildlife trees**		**Wildlife trees**		**Wildlife trees**	
Common persimmon	25	Flowering dogwood	20	Eastern white pine	25	Black willow	25
Eastern redbud	25	Bitternut hickory	20	Shagbark hickory	25	Silky dogwood	25
Mockernut hickory	25	Eastern white pine	20	Green hawthorn or gray dogwood	25	Elderberry	25

Source: Davis et al. 2012.

*Use species native to the planting area and those that are suited to the landscape position of the mine site. If more than 450 surviving stems per acre are required by mining regulations, increased planting numbers are advised. 1 acre = 0.4 ha.

†Select either species, considering native range.

FRA Step 5: Use proper tree-planting techniques.

It is essential that tree seedlings be correctly cared for after being received from the nursery, and then planted properly (Davis et al. 2010). Mine sites are commonly planted by commercial contractors who maintain and manage large crews and equipment; they can properly care for seedlings while planting and get large mine sites planted quickly. Proper tree planting requires a planting hole that is deep enough to accommodate the seedling's root system. Use of FRA steps 1 and 2 to prepare the soil material will leave the soil loose, making it easier for tree planters to open an adequately sized hole.

The tree seedlings that are brought to the mine site for planting are living organisms. To retain their potential to survive and grow after planting, seedlings must be cared for prior to planting (Figure 23.6). Proper care of unplanted seedlings involves keeping them in a moist condition and shielding them from the sun.

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Source: Davis et al. 2010.

Figure 23.6 Commercial tree planters who specialize in planting large areas

In Appalachia, tree seedlings are best planted during the winter season, and most planting takes place in January, February, and March. Planting during these months allows the seedlings to become acclimated to their "new home" on the mine site and to begin extending their roots into the soil before the warm-weather growing season starts. The summer season, with its warm temperatures and occasional extended periods without rainfall, is a stressful time of year for young, newly planted trees, especially if soil conditions become dry. If a planted tree seedling is able to live through its first year, chances are good that it will continue to survive and grow.

ENCOURAGING FRA REFORESTATION

Reclamation scientists recognized that development of the FRA, although a significant step toward the ultimate goal of forest reestablishment on active coal mines, was not in itself sufficient to achieve that goal. To be an effective tool for forest reestablishment, it was necessary to communicate the FRA process to the mining industry and to change those aspects of the mine reclamation regulatory culture that were unfavorable to tree plantings. Many agency personnel remembered the poor survival and failures of earlier tree plantings into compacted soils and heavy ground cover. Agency cooperators also realized these needs. As a result, the U.S. Department of Interior's Office of Surface Mining Reclamation and Enforcement (OSMRE) and the seven state regulatory authorities in Appalachia created the

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Appalachian Regional Reforestation Initiative (ARRI) in 2004. ARRI encourages and supports industry efforts to reestablish healthy, productive forest habitat on active and abandoned mine lands in the eastern coalfields. The ARRI Core Team was formed to facilitate and coordinate the coal industry; landowners; university researchers; watershed, environmental and conservation groups; and state and federal government agencies that have an interest in creating productive forestland on reclaimed mined lands. The ARRI Science Team was established to ensure that the methods ARRI promotes are based on proven science and research, and to guarantee the continued scientific research into forestry reclamation.

ARRI's goals are to communicate and encourage mine reforestation practices that plant more high-value hardwood trees on reclaimed coal-mined lands in Appalachia; increase the survival rates and growth rates of planted trees; and expedite the establishment of forest habitat through natural succession. ARRI's primary activities concern active mining. The SMCRA requires that active coal mines "restore the land affected to a condition capable of supporting the uses which it was capable of supporting prior to any mining, or higher or better uses of which there is reasonable likelihood" (SMCRA 1977). Since most lands mined for coal in Appalachia are forested prior to mining and are not placed in managed uses after mining, restoration of forest vegetation with equal or greater productivity than the premining forest satisfies the letter and the spirit of that SMCRA requirement.

ARRI's initial work concerned identification and removal of "barriers" to effective reforestation by SMCRA-regulated mining operations (Angel et al. 2009):

- *Cultural Barriers* are perceptions by industry and regulatory personnel that reestablishing forest vegetation is difficult, expensive, or impossible. ARRI's actions to combat cultural barriers included communications to the full range of parties that control mine reclamation procedures—including mining operators and agency mine inspectors—that FRA is a recommended reclamation procedure on mine sites that are not being prepared for specific land uses such as agricultural land or community services. Those communications included field tours to mine sites, both active and experimental, where forest trees had been reestablished successfully.
- *Technical Barriers* are lack of knowledge by reclamation personnel regarding how to reestablish forest vegetation successfully on mine sites. ARRI's Core Team identifies technical barriers and communicates these to the Science Team, whose members address gaps in knowledge through research and publication. ARRI's actions included development of "Forest Reclamation Advisory" publications that describe the FRA and "best practices" for its application (Burger et al. 2005, etc.; see references).
- *Regulatory Barriers* are regulatory obstacles to FRA application. OSMRE, the federal agency that oversees coal mining, determined that FRA reclamation is consistent with SMCRA, and communicated that finding to agency

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inspectors and industry. State and federal regulatory programs were also examined in an effort to identify specific regulatory barriers to FRA application that could be eliminated. Several states found that their regulatory structures required minimum levels of herbaceous ground cover that had potential to hinder planted trees' survival and forest restoration. Hence, several states altered "minimum ground-cover" regulations for reforestation practices to state that herbaceous ground cover must be adequate to control erosion but without specifying a minimum required level of ground cover.

As a result of these activities, use of the FRA is spreading in Appalachia. The following three case studies document specific applications of the FRA.

CASE STUDY 1: REFORESTATION ON A CONTOUR SURFACE MINE IN TENNESSEE

In 2005–2006 the FRA was applied on a second-cut contour surface mine in Campbell County, Tennessee. This mining operation extracted additional coal from a previously mined area. As mining progressed along the topographical contour, the spoil produced was used to fill pits and eliminate highwall remaining from the original mining operation. In total, 27 ha (68 acres) were reclaimed, with the FRA applied to a 6-ha (15-acre) portion of the site, which is described here. All reclamation was part of regular, ongoing operations permitted for the site and visited annually by scientists from the University of Tennessee.

Reclamation Methods

The reclaimed site is comprised of steep slopes (30%–40%), with a road at the base and intact forest above. The narrow (50–75 m [164–246 ft]) linear site follows the topographic contour, with aspects being primarily eastern and southern. The slopes were constructed using the contour haulback method (Jeldes et al. 2013), with a loose surface layer 1.2–1.5 m (3.9–4.9 ft) in depth applied as a rooting medium over a compacted base. Because much of the weathered overburden had been removed by previous mining operations, spoil types were primarily unweathered sandstones, siltstones, and shales. Any available weathered sandstone was mixed with unweathered material to construct the surface layer of rooting media. Soil pH on adjacent research plots ranged from 6.6 to 7.5. Reclamation grading was minimized, and surface material was left in a loose condition as recommended by the FRA.

A seed mix that included native warm-season grasses (Table 23.5) was applied with fertilizer (45 kg/ha nitrogen, 90 kg/ha phosphorus, and 90 kg/ha potassium) and hydromulch (1,680 kg/ha) by a hydroseeding contractor in early spring 2006. Trees were planted by a commercial contractor at a density of 1,050 stems/ha in spring of 2006, with tree species selected by the contractor from a list of species recommended for FRA plantings.

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Table 23.5 Reclamation seed mix applied at the Tennessee case-study mine site as a means of establishing tree-compatible herbaceous vegetation

Common Name	Botanical Name	Seeding Rate, kg/ha
Big bluestem	*Andropogon gerardii*	3.4
Korean lespedeza	*Kummerowia striata*	2.2
Annual ryegrass	*Lolium multiflorum*	6.7
Switchgrass	*Panicum virgatum*	0.2
Little bluestem	*Schizachyrium scoparium*	7.8
Indian grass	*Sorghastrum nutans*	3.4

Assessment Methods

In July of 2013, 18 circular measurement plots (3.6-m [11.8-ft] radius) were evenly spaced along the length of the site. The distance up the slope to plot center was located in an alternating pattern to place half of the plots within the upper one-third of the slope and half within the bottom one-third. Trees and shrubs were measured in fall 2013. Within each measurement plot, all trees were identified by species. Diameter at breast height (DBH) was measured on all individuals taller than 1.5 m (4.9 ft). Trees shorter than 1.5 m were placed into height classes. Northern red oak (*Quercus rubra*), chestnut oak (*Quercus prinus*), white oak (*Quercus alba*), black cherry (*Prunus serotina*), and white ash (*Fraxinus americana*) were found to be in regular rows, and the spacing was measured to verify the original planting density. Stocking metrics were estimated by extrapolating from measurement plot totals.

Results

Based on spacing measured in 2013, the original planting density was 1,425 stems/ha (577 stems/acre), which is slightly higher than the 1,050 stems/ha (425 stems/acre) specified in the permit. Total stem density was estimated at 1,845 living trees/ha (738 trees/acre) over the entire site from the measurement plot data (Table 23.6). Loblolly pine shows the greatest diameter growth, and highest stocking rate of stems greater than 1.5 m (4.9 ft) in height. Northern red oak, which was planted, had the highest overall stocking rate, but only one-third of these had reached a height of 1.5 m after 8 years of growth. In contrast, 72% of the white ash had reached a height of 1.5 m, and these had the largest diameters among the planted hardwoods. American sycamore and black locust, which had volunteered onto the site, also showed good diameter growth. Very few nonnative trees were found to have established on the site despite their abundance in the surrounding area. A few ailanthus and autumn olive were found, but all of these were in the larger size classes, and the absence of seedlings suggests that these are not actively invading the site. The high number of woody volunteer species may be the result of the intact forest above, which acts as a seed source.

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Table 23.6 Trees tallied at the case study mine site in 2013, 8 years after reclamation, by average density over the site*

Common Name	Botanical Name	Total Stems/ha	Stems/ha <1.5 m (>4.9 ft)	Stems/ha >1.5 m (>4.9 ft)	DBH, cm
Red maple	*Acer rubrum*	27	27	0	—
Ailanthus†	*Ailanthus altissima*	14	0	14	7.9
Yellow birch	*Betula alleghaniensis*	41	27	14	0.3
Eastern redbud‡	*Cercis canadensis*	137	82	55	0.8
Dogwood‡	*Cornus florida*	178	123	55	0.5
Autumn olive†	*Elaeagnus umbellata*	27	0	27	1.6
White ash‡	*Fraxinus americana*	192	55	137	2.8
Tulip poplar	*Liriodendron tulipifera*	151	82	68	1.0
Sourwood	*Oxydendrum arboreum*	27	27	0	—
Loblolly pine‡	*Pinus taeda*	219	0	219	10.4
American sycamore	*Platanus occidentalis*	137	41	96	4.4
Black cherry‡	*Prunus serotina*	82	0	82	1.9
White oak‡	*Quercus alba*	164	68	96	2.0
Scarlet oak‡	*Quercus coccinia*	14	14	0	—
Chestnut oak‡	*Quercus prinus*	82	55	27	0.6
Northern red oak‡	*Quercus rubrum*	233	164	68	0.6
Black locust‡	*Robinia pseudoacacia*	68	41	27	8.9
Winged elm	*Ulmus alata*	14	14	0	—

*Stem density is shown for stems less than 1.5 m (4.9 ft) in height, stems greater than 1.5 m in height, and total stems. Average diameter at breast height is shown for stems greater than 1.5 m tall.
†Nonnative (exotic) species, not planted but volunteering on the site.
‡Species known to have been planted on-site, and species likely to have been planted due to specification in the mine permit.

Herbaceous ground cover developed slowly on the site but eventually with high density (Figure 23.7). Annual ryegrass provided a relatively dense initial cover, which had died by mid-summer of the first growing season. Virtually no living ground cover was observed in the second growing season, although litter from the annual ryegrass was evident. Native warm-season grasses, along with native annuals and perennials, had begun to establish by the end of the third growing season and provided a fairly continuous ground cover by the spring of 2008. All planted warm-season grasses have been observed on the site. The relative lack of ground cover over the first year allowed trees to establish without heavy herbaceous competition.

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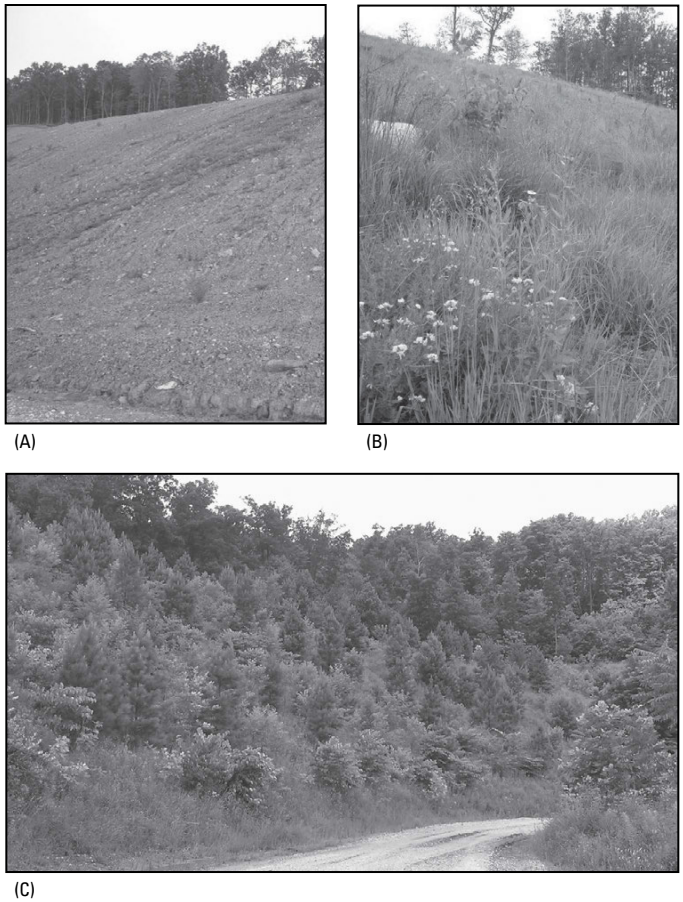


Figure 23.7 A Tennessee contour mine reclaimed using the FRA in 2006, shown (a) 1 year, (b) 3 years, and (c) 8 years after planting

Summary

At the case-study site, FRA reclamation produced tree densities of 1,845 trees/ha (738 trees/acre) after 8 years, with planted and volunteer trees contributing to create a diverse, primarily native stand of young trees on the reclaimed mine site. Native warm-season grasses developed slowly, but a nearly continuous ground cover was present by the third year of growth and appears to be highly diverse with numerous native forbs present. The FRA reclamation on this area appears to have been highly successful at promoting the development of a diverse, mixed pine and hardwood forest.

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CASE STUDY 2: REFORESTATION ON A MOUNTAIN-TOP REMOVAL MINE

The 17 West surface mining complex is located in Martin County, Kentucky, and encompasses an area of approximately 4,800 ha (11,860 acres). Two permits on the site comprising more than 800 ha (1,977 acres) were originally permitted for a postmining land use (PMLU) of hayland/pasture. With the issuance of Kentucky Reclamation Advisory Memorandum No. 124, or RAM 124 (KDSMRE 1997) in 1997, which highlighted methods for establishing forests on surface-mined lands, the mining company opted to change their PMLU on portions of the permits to evaluate the feasibility of this new reclamation approach. In cooperation with the University of Kentucky, the company developed a large-scale reforestation demonstration project at the site. A permit revision for 588 ha (1,453 acres) of the site was approved with 188 ha (465 acres) of commercial forestland and 400 ha (988 acres) of fish and wildlife habitat, of which at least 30% would be forested. A commercial forestland PMLU must contain at least 70% forest cover, and at least 75% of the species planted must be of good to excellent commercial value. Between 2000 and 2004, more than 675,000 trees were planted on 403 ha (996 acres) at 17 West. A majority of the reforestation area (257 ha [635 acres]) had been reclaimed as hayland/pasture and was dozer ripped with a D-10 bulldozer to reduce compaction and prepare the spoil for seedling planting (Sweigard et al. 2007a). The remaining area was reclaimed to its approximate original contour following methods outlined in RAM 124 (KDSMRE 1997) using low-compaction techniques with a spoil depth between 1.5 and 2 m (4.9 and 6.5 ft), in a manner similar to that later described as the FRA (Sweigard et al. 2007b). In addition, an experimental practice was deployed on 13 ha (32 acres) of uncompacted dragline spoils that were irregularly placed on the landscape with slopes between 45 and 75 m (148 and 246 ft) in length and angles greater than 2:1, which are steeper than suggested in RAM 124. A topsoil variance was approved for the site, and all spoils were of a mixed geologic composition.

Early and late successional native tree species that are suited for growth in the region, provide habitat for wildlife, and represent a gradient of tree growth and litter quality were planted on the site. Tree species included white oak (*Quercus alba*), red oak (*Quercus rubra*), white ash (*Fraxinus americana*), and other available species (Table 23.7). Seedlings of each species were planted randomly in mixed species cells at a rate of 680 stems/acre (275 stems/ha). Sample plots were established in mixed species planting cells at the reforestation site. Plots were designed in a manner to adequately sample each species planted and to account for differences with respect to site preparation activities and micro-topographic variability among planting units. As such, eight 50 × 50 m (164 × 164 ft) plots were set within each cell (nine cells across the mine). Survival and seedling height were measured within the monitoring plots on an annual basis until 2006.

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Table 23.7 General planting species distribution for the 17 West surface mine

Common Name*	Botanical Name	% of Total
Northern red oak	*Quercus rubra*	22
White oak	*Quercus alba*	18
White ash	*Fraxinus americana*	15
Yellow poplar	*Liriodendron tulipifera*	9
Black locust	*Robinia pseudoacacia*	9
Chestnut oak	*Quercus prinus*	7
White pine	*Pinus strobus*	5
Sugar maple	*Acer saccharum*	3
Redbud	*Cercis canadensis*	3
Dogwood	*Cornus florida*	3
Sycamore	*Platanus occidentalis*	3
Black cherry†	*Prunus serotina*	3

*Generalized planting composition for the entire site, although species planted varied in response to topographic variability and soil wetness.
†Often substituted with wild plum (*Prunus americana*).

Results and Discussion

For seedlings planted in 2003 (93 ha [230 acres]), average survival was greater than 70% for all species after 3 years of growth except white pine, 62%, and black cherry, 50% (Table 23.8). Initial seedling height at 17 West was between 30 and 50 cm (12 and 20 in.) for all species planted except for black locust. By 2006, all species exhibited increased height growth. Black locust demonstrated the greatest height growth (>100 cm [39 in.]) over the 3-year period, while red oak exhibited the least height growth (<4 cm [1.6 in.]) (Table 23.8). Survival for trees in the experimental practice area that were planted in 2002 had an average survival of 91% in 2006 and showed similar growth rates as those described here.

Soil samples were collected on an annual basis, and analyses revealed that total carbon and nitrogen levels fell from 2003 to 2005 at 17 West. Carbon content fell from 8.8 Mg/ha to 6.97 Mg/ha. Given the limited growth rates for most planted species (black locust being the exception), soil carbon increases during this time were not anticipated. Several factors may be responsible for the reduced levels of soil carbon, such as the oxidation of previously accumulated soil organic matter in the pasture spoils due to the ripping or weathering losses of carbonate materials in the spoil as described by Maharaj et al. (2007). Similarly, extractable (KCl extraction) nitrate (NO_3) and ammonium (NH_4) showed reduced levels in 2005 compared to 2003. Nitrate fell from 0.51 to 0.17 mg/kg, while ammonium fell from 0.32 to 0.09 mg/kg. The reduction in both total N and soil-extractable N suggests that the seedlings were using available nutrients for growth while returning little to

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Table 23.8 Height (± standard deviation) and height growth during their fourth growing season (2006), and survival (as determined in 2006 since planting in 2003) at the 17 West surface mine

Common Name	Height, cm (± Standard Deviation)	Height Growth, cm	Survival, %
Black locust	311.4 (±163.0)	104.0	97
White ash	92.3 (±40.8)	29.5	96
Dogwood	50.6 (±14.2)	9.3	91
Redbud	69.1 (±32.1)	21.5	88
Sugar maple	45.9 (±18.6)	4.4	85
Sycamore	69.4 (±45.8)	32.6	83
White oak*	47.0 (±24.9)	5.8	81
Yellow poplar	58.3 (±16.1)	17.0	77
Northern red oak	43.8 (±8.9)	3.7	70
White pine	59.0 (±55.6)	24.4	62
Black cherry	76.1 (±59.6)	15.0	50

*White oak and chestnut oak have been combined in this analysis.

the forest floor. Litter-fall collectors placed in the reforestation areas yielded no measurable catch during the 2003–2006 study period, and the development of a litter layer was not observed during that time period.

To evaluate the effectiveness of compaction mitigation by dozer ripping, bulk densities were measured on the site using a nuclear density probe. A general increase in bulk density with depth was exhibited at the 17 West mine site (Table 23.9). Although the averages are higher than what one may observe in a general agricultural soil (Brady and Weil 2002), they fall within the range of those reported for ripped mine spoils in Kentucky (Conrad 2002). In addition, the bulk density values at 5- and 15-cm (2- and 6-in.) are similar to or slightly lower than values observed at the Starfire mine in Perry County, Kentucky, on uncompacted spoil (Angel et al. 2006).

Based on the initial heights, seedling survival rates, and seemingly good soil physical properties, the early results were encouraging. However, many obstacles may present themselves that could influence the trajectory of the newly established forest, including herbaceous competition, nutrient deficiency, fire, insects, plant pathogens, and invasive species. As such, the site was revisited in 2013 to evaluate conditions after approximately 10 years of growth. Prior to the visit, digital ortho-photographic images of the site acquired from the Farm Service Agency's National Agriculture Imagery Program were examined to evaluate forest establishment. Images collected from various years since planting in an area that was ripped in 2002 and planted in 2003 (cell 7; 15 ha [37 acres]) were compared. From a photograph taken in 2004 (Figure 23.8a), the path of the dozer rips is visible

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Table 23.9 Bulk density in ripped spoil at the 17 West mine

	Bulk Density, g cm^{-3}		
Year	5-cm (2-in.) Depth	15-cm (6-in.) Depth	30.5-cm (12-in.) Depth
2003	1.41	1.61	1.74
2004	1.35	1.58	1.69
2005	1.28	1.54	1.68

(inside large circle) and a few seedlings appear to be emerging from a predominate herbaceous ground cover. By 2006 (Figure 23.8b) and 2008 (Figure 23.8c), the images clearly show a developing forest cover in the ripped areas. In 2010 (Figure 23.8d), canopy closure appears to have begun in some of the ripped area. For comparison, the area within the smaller circle was not ripped and has developed into a pasture over the same time period.

During the 2013 site visit, the forest canopy in cell 7 was nearly closed and the herbaceous ground cover had diminished substantially (Figure 23.9). Seedling survival in 2006 was 94%, and rates appeared to have remained high 7 years later. Unfortunately, tree tags that were used for determining survival were missing, so a direct comparison of survival to the early measurements was not possible. Height and diameter of the trees was measured using a systematic random sampling procedure in the approximate location of the original plots at cell 7 (Table 23.10). Although yellow poplar and white oak heights were lower than those reported for 10-year old regenerating trees (nonmined) of the same species in eastern Kentucky (11.2 and 5.5 m [36.7 and 18.0 ft] for yellow poplar and white oak, respectively), diameters of the trees on the mine were within the reference range for the regenerating trees (Cotton et al. 2013). Similar height-to-diameter relationships have been described elsewhere and are attributed to the open growing conditions found on the surface mine as compared to that of a regenerating forest (i.e., less competition for light due to fewer trees per hectare or acre on the mined land; Cotton 2006). Interestingly, both height and diameter of these two species exceeded that of 9-year-old trees growing on uncompacted spoil at the Starfire site in Kentucky (Cotton et al. 2013). White ash and red oak at cell 7 also exhibited increased height and diameters over those reported for 8-year-old trees growing on uncompacted spoil at Starfire (Angel et al. 2006).

Summary

The large reforestation effort at the 17 West mine continues to show progress but still remains a young forest; hence, continued observations are warranted. Many areas that were not ripped or reclaimed using FRA are now heavily occupied with the invasive shrub autumn olive (*Elaeagnus umbellata*) and very little "pasture" is

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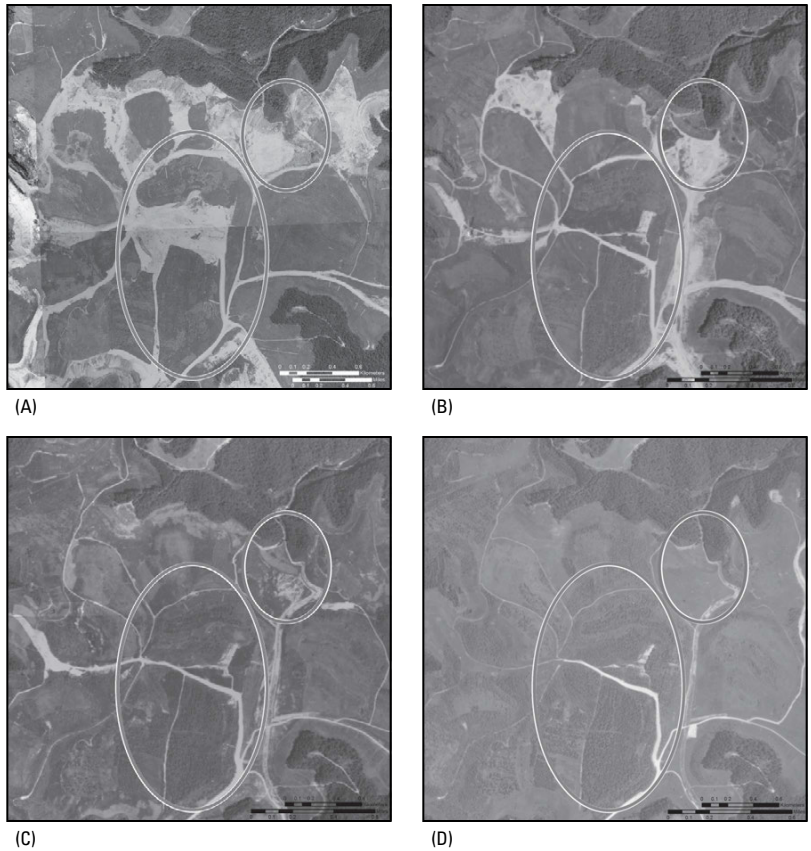


Figure 23.8 Images of cell 7 and vicinity taken by the Farm Service Agency's National Agriculture Imagery Program in (a) 2004, (b) 2006, (c) 2008, and (d) 2010 at the 17 West mine



Figure 23.9 Cell 7 reforestation plot in ripped spoil at the 17 West mine

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Table 23.10 Average height and diameter of four planted species after 10 years of growth at the 17 West mine

Species	Height, m (± Standard Deviation)	Diameter, mm (± Standard Deviation)
Yellow poplar	5.0 (±1.4)	47.9 (±23.0)
White ash	4.9 (±1.3)	42.4 (±17.5)
White oak	3.7 (±1.3)	38.9 (±25.6)
Northern red oak	3.0 (±1.0)	21.4 (±11.6)

visible on the landscape. In most of the reforestation areas, autumn olive seems to exist on the road edges and has either been shaded out or outcompeted by the native trees in the forested stands. Concern over this and other invasive species is growing, and efforts to stop or suppress their spread, especially on disturbed lands, are needed. In contrast to other areas of the mine site, those portions of the mine site that were reclaimed using the FRA are occupied by young native trees that appear to be developing into a productive and diverse forest.

CASE STUDY 3: REFORESTATION ON A VIRGINIA CONTOUR SURFACE MINE

In 2001–2002, a prototype version of the FRA was applied on a second-cut contour surface mine in Buchanan County, Virginia. The mining extracted additional coal by taking deeper cuts than a former mining operation, generating spoils as needed to reclaim older mining areas and to cover coal refuse that had been disposed of on the valley floor below the elevation of the mined coal seams. In total, 28 ha (68 acres) were reclaimed, including the mining disturbance and cover for the refuse disposal fill. Company personnel worked with scientists to apply reclamation methods intended to restore forested vegetation during winter 2001–2002. In summer and fall of 2010, reclamation scientists returned to the site and assessed reforestation success after nine growing seasons.

Reclamation Methods

Most of the reclaimed site is comprised of steep slopes that drain into a gently sloping area that runs from north to south through the mining disturbance. The site's southeastern area is a ridgeline that also includes some relatively flat areas created by reclamation grading. The site's far eastern edge drains from that ridgeline to the east (Zipper et al. 2012).

Spoil types used to construct mine soils varied over the site. Most areas were reclaimed with weathered sandstones, often mixed with unweathered sandstones, siltstones, and/or shales. Although the mining firm endeavored to construct mine soils with weathered sandstones over the entire mine site, weathered sandstone quantities generated by the second-cut mining were not adequate. Hence, unweathered

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siltstones and shales were used on the surface in some areas. Reclamation grading of slopes was minimized, and most sloped areas were left in a loose condition as recommended by the FRA, but some flatter areas were compacted by equipment. A seed mix comprised of annual ryegrass (*Lolium multiflorum*, 27 kg/ha), redtop (*Agrostis gigantean*, 2 kg/ha), weeping lovegrass (*Eragrostis curvula*, 2 kg/ha), perennial ryegrass (*Lolium perenne*, 4 kg/ha), orchard grass (*Dactylis glomerata*, 13 kg/ha), and birdsfoot trefoil (*Lotus corniculatus*, 4 kg/ha) was applied with fertilizer (34 kg/ha nitrogen, 29 kg/ha phosphorus, and 56 kg/ha potassium) over the site by a hydroseeding contractor in early spring 2002. The seed mix was recommended as tree compatible by reclamation scientists.

After reclamation grading but prior to revegetation, the site was assessed for reforestation potential. Using field observations, the area was segmented into different site types for prescribing trees for planting (Table 23.11). Areas with mine spoils comprised predominantly of uncompacted sandstones were classified as either "Sandstone Dry" (south- and west-facing aspects) or "Sandstone Moist" (east- and north-facing aspects). Weathered sandstones were prominent in most of these areas. Since the Sandstone Dry and Sandstone Moist site types were also loose graded, planted with tree-compatible herbaceous vegetation, and planted with native hardwoods, these areas are described as reclaimed using the FRA in the text that follows. Areas with mine spoils comprised predominantly of uncompacted siltstones and shales ("SiS"), and relatively flat areas with compacted spoils, comprised the other two site types. The SiS areas were loose graded, as per FRA recommendations, but the siltstone and shale rocks used to construct soils in these areas were saline and otherwise unfavorable to reforestation. Hence, both the SiS and compacted areas are described as non-FRA in the text that follows.

Tree planting mixes were prescribed for each site type by specifying species considered suitable for soil and site conditions in each area (Table 23.11). For the uncompacted sandstone site types, planting prescriptions emphasized commercially valued native hardwoods suited for dry and moist growing conditions, respectively; while species known for the ability to survive and grow in less favorable spoil conditions were prescribed for the siltstone/shale site type. Four species (white oak, *Quercus alba*; white ash, *Fraxinus americana*; eastern white pine, *Pinus strobus*; and the nitrogen-fixing shrub bristly locust, *Robinia hispida*) were prescribed for all site types. The site was planted in spring 2002 by a commercial contractor.

Assessment Methods

Sixty-eight circular measurement plots (5.64-m [18.5-ft] radius) were laid out over the entire reclamation area on a gridded pattern. Soils were sampled from each measurement plot in June 2010. Trees and shrubs were measured in fall 2010. On each measurement plot, all trees within the 0.01-ha (0.25-acre) area and taller than breast height (~1.5 m [4.9 ft]) were identified by species and measured for height (h)

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Table 23.11 Tree planting prescriptions by site type (seedlings/ha)

Site Type	Moist, Sandstone*	Dry, Sandstone*	Siltstone/ Shale*	Compacted	Average density
Tree Planting Mix	**1**	**2**	**3**	**4**	
FRA Status	**FRA**	**FRA**	**non-FRA**	**non-FRA**	
Trees					
Red maple (*Acer rubrum*)	—	—	297	†	65
Sugar maple (*Acer saccharum*)	371	—	—	†	168
Dogwood (*Cornus* sp.)	62	62	62	†	62
White ash (*Fraxinus americana*)	371	494	297	†	395
Eastern white pine (*Pinus strobus*)	124	124	124	†	124
American sycamore (*Platanus occidentalis*)	—	—	297	†	65
White oak (*Quercus alba*)	371	494	297	†	395
Burr oak (*Quercus macrocarpa*)	—	—	297	†	65
Chestnut oak (*Quercus prinus*)	—	494	—	†	162
Northern red oak (*Quercus rubrum*)	371	—	—	†	168
Total trees	1,668	1,668	1,668	1,668‡	1,668
Shrubs					
Bristly locust (*Robinia hispida*)	124	124	124	†	124
Total trees and shrubs§	1,792	1,792	1,792	1,792‡	1,792

*Most sandstone spoils on surface included weathered rocks, as per FRA recommendations when soils are not available. Siltstones and shales were predominantly unweathered.
†Planting mix 4 was prescribed as "Plant mixture of all remaining trees and shrubs."
‡Assumed planting densities based on full-site planting prescription.
§Some totals do not add up correctly due to independent rounding. Original prescription was per-acre.

using an extendable height pole and for DBH. All trees were classified as either "planted" or "volunteer" based on the planting prescriptions: If a living tree was found in an area where it had been prescribed, it was tallied as planted; otherwise, living trees of species known to be growing in the local area were tallied as volunteers. All burr oaks (*Quercus macrocarpa*) were tallied as planted since that species is not known to be growing in the local area. White ash was planted at all sites, but green ash (*Fraxinus pennsylvanica*) and white ash could not be discriminated during site survey; therefore, all *Fraxinus* species were tallied as planted and are listed here as ash.

A volume index was calculated for each living tree as $h*DBH^2$. Living trees were summed to estimate species density, and per-tree volume indices within

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Table 23.12 Site-average reforestation success metrics, by reclamation area FRA status

	FRA			Non-FRA			FRA and non-FRA
	Planted	Volunteered	All	Planted	Volunteered	All	
Survival, %	34			32			33
Tree species richness*	8	19	24	9	8	15	24
Tree density, trees/ha	565	993	1,558	528	364	892	1,313
Trees' average height, m	3.45	3.68	3.60	3.80	3.36	3.62	3.60
Trees' total volume index, m^3/ha	3.3	11.1	14.4	6.4	2.4	8.8	12.9

*Trees were classified to the lowest practical taxonomic level except for dogwood and ash.

measurement plots were summed to calculate measurement plot totals. Survival and stocking metrics were estimated for FRA and non-FRA reclamation areas by extrapolating from measurement plot totals.

Results

Tree Densities and Survival

An average of 1,313 living trees/ha (531 trees/acre) over the entire site were estimated from the measurement plot data (Table 23.12). This is in excess of the 990 trees/ha (400 trees/acre) established as a reforestation goal in response to regulatory requirements. However, tree density was highly variable over the site. For the 68 measurement plots, densities ranged from 100 to 5,800 trees/ha. Thirty-seven of the 68 measurement plots had tree densities of >990 trees/ha (400 trees/acre), the reforestation goal, but the remaining 31 did not. Most of the measurement plots in FRA reclamation areas (63%) had tree densities exceeding the reforestation goal, in contrast to non-FRA reclamation areas (40%). Only trees taller than breast height (~1.5 m [4.9 ft]) were tallied, but visual observation indicated numerous living trees of smaller stature in the FRA reclamation areas and few in the non-FRA areas. However, because of competition with taller trees and the self-thinning that occurs naturally in emerging forests as dominant trees grow to increase their size, most of these smaller trees are unlikely to survive.

Calculated survival rates for planted trees differed little between the FRA (34%) and non-FRA (32%) reclamation areas. However, factors affecting calculated survival rates appeared to have differed. Planted trees in most of the FRA reclamation areas had been subjected to vigorous competition by trees that established by natural means (volunteers), likely by seed blown by winds or carried by wildlife into

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the area. In contrast, planted trees in most non-FRA reclaimed areas had not been subjected to such competition, suggesting that soil properties had limited survival.

Total tree densities (a metric that combines planted species and volunteers) in FRA reclamation areas (1,558 trees/ha) exceeded densities in other areas (892 trees/ha) by a considerable margin. There was little difference in planted tree densities between the two areas (565 vs. 528 trees/ha). However, volunteer trees in FRA reclaimed areas (993 trees/ha) exceeded volunteers in non-FRA areas (364 trees/ha).

Although planted tree densities did not differ greatly among FRA vs. non-FRA reclaimed areas, species composition of planted trees did differ. Ash was tallied as the most common planted species in both areas, constituting 37% and 45% of planted trees in the FRA and non-FRA reclamation areas, respectively. However, green ash (unplanted) and white ash (planted) were not discriminated during the reforestation assessment, and both species volunteer readily. Hence, it is likely that some of the ash trees tallied as planted actually became established as volunteers. In FRA reclamation areas, the second and third most common planted species were dogwood and white oak. Both are common forest trees in the local area, with dogwoods typically found in the local forest understory and white oak often achieving dominance within mature forests on upland landscapes. In contrast, the second and third most common planted species for non-FRA areas were burr oak, which is not native to the local forests, and American sycamore, which is tolerant of wet and compacted soils but is not found commonly in upland forest areas.

Species Richness and Diversity

Species richness is a common metric for evaluating ecosystem structure and is calculated by tallying the number of species present within a given system or area (Table 23.13). Species richness for the FRA reclamation areas (24) exceeded richness for the non-FRA reclamation areas (15) by a considerable margin (Table 23.12). Considering only tree species that occur in local forests (i.e., excluding exotic species, eastern cottonwood, and burr oak), FRA richness (20) exceeded the non-FRA richness (14). Twelve unplanted native species were found growing in FRA reclamation areas, while only 5 unplanted native species were found in non-FRA areas.

In the FRA and non-FRA areas, black locust was a common and prolific volunteer, constituting 39% of FRA volunteers and 63% of non-FRA volunteers. Black locust is nitrogen-fixing legume and proliferates on eastern U.S. coal surface mines (Zipper et al. 2011a) but often attains a bushy form. Black locust does, however, have the potential to grow tall and become part of the tree canopy. Many of the observed black locust trees in FRA reclamation areas were growing straight and tall, likely because of competition due to growth by other trees. Sourwood was another prominent volunteer in the FRA reclamation areas. Sourwood is an appropriate site occupant at this successional stage and is a slow-growing, small tree that does not occur as a dominant component of mature forest canopies.

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Table 23.13 Trees tallied at the case study mine site, by average density over the site*

Common Name	Botanical Name	Species Type	Trees/ha
Red maple	*Acer rubrum*	Native	25
Sugar maple	*Acer saccharum*	Native	21
Dogwood	*Cornus sp.*	Native	53
Ash	*Fraxinus spp.*	Native	222
Eastern white pine	*Pinus strobus*	Native	22
American sycamore	*Platanus occidentalis*	Native (off-site)†	46
White oak	*Quercus alba*	Native	104
Burr oak	*Quercus macrocarpa*	Native (not local)‡	44
Chestnut oak	*Quercus prinus*	Native	26
Northern red oak	*Quercus rubrum*	Native	71
Black locust	*Robinia pseudoacacia*	Native	326
Sourwood	*Oxydendrum arboreum*	Native	231
Sweet birch	*Betula lenta*	Native	51
Tulip poplar	*Liriodendron tulipifera*	Native	25
Pitch pine	*Pínus rígida*	Native	15
Black cherry	*Prunus serotina*	Native	15
Eastern redbud	*Cercis canadensis*	Native	4
Ailanthus	*Ailanthus altissima*	Exotic	3
Serviceberry	*Amelanchier sp.*	Native§	1
Paulownia	*Paulownia tomentosa*	Exotic	1
Virginia pine	*Pinus virginiana*	Native	1
Eastern cottonwood	*Populus deltoides*	Native (not local)‡	1
Scarlet oak	*Quercus coccinea*	Native	1
Sassafras	*Sassafras albidum*	Native	1

*Planted species are above; nonplanted species below. Some trees observed for some planted species are believed to have volunteered.
†American sycamore is described as "off-site" because it commonly grows in riparian areas with moist soils, but most observations were on upland areas where it would not typically be found in nature.
‡Burr oak and eastern cottonwood are natives to the eastern United States but do not grow naturally in forests of the local area.
§Serviceberry is sometimes classified as a shrub.

Height and Volume

For most species found on FRA and non-FRA areas, average heights did not differ greatly (Figure 23.10). However, the total tree volume index was very different. Total volume index for FRA reclamation areas (14.4 m^3/ha) exceeded that

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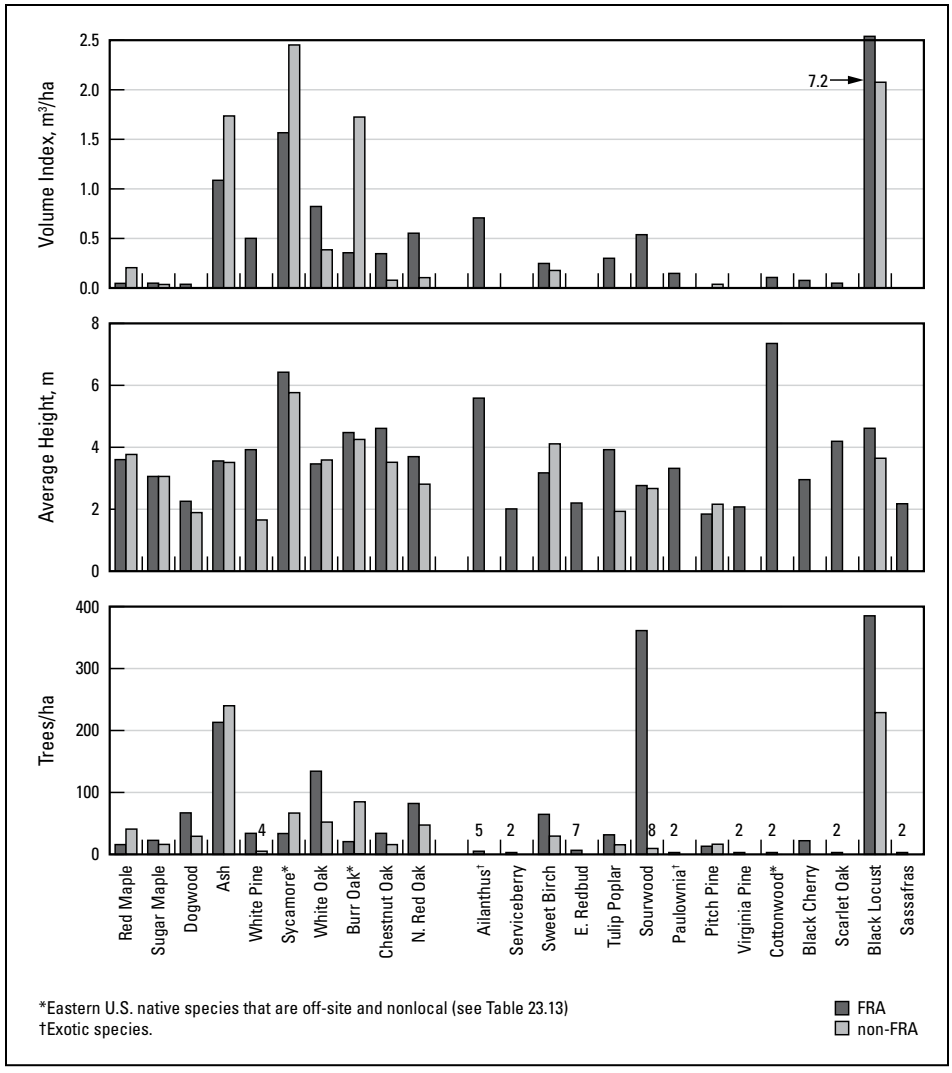


Figure 23.10 Total volume index, average height, and average densities for all tree taxa tallied at the case-study mine site, by reclamation area FRA status. On upper plot, the bar height for black locust total volume index on FRA sites is truncated. On lower plot, numbers designate average trees ha^{-1} by species when >0 and <10.

calculated for non-FRA reclamation areas (8.8 m^3/ha). On non-FRA reclamation areas, 90% of the total tree volume was primarily composed of four species: ash, burr oak, American sycamore, and black locust. On FRA sites, three of the top four species (ash, black locust, American sycamore) were the same, and the top four species (including white oak) constituted a lesser percentage (74%) of total tree biomass. Three locally common timber-producing species (chestnut oak, northern

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red oak, and chestnut oak) occurred in FRA and non-FRA areas but produced far more volume on FRA sites.

Discussion

Reclamation procedures were intended to encourage establishment of planted and volunteer forest trees and to develop a forest with similar composition and productivity of a premining forest. These data indicate that those efforts were effective over most areas reclaimed using FRA procedures, including loosely graded mine soils constructed of weathered rock materials and seeded with tree-compatible herbaceous vegetation. Older mine sites reclaimed using conventional methods are often dominated by nonnative herbaceous species, and invasive or early-successional woody species (Simmons et al. 2008; Zipper et al. 2011a). Over most of this site's FRA-reclaimed areas, native woody species with potential to form a mature forest were dominant vegetative components.

Volunteer and planted species were major contributors to reforestation success on the strongly and moderately acidic soils that were established intentionally over most of this mine site, but more than half of total density (59%) was composed of volunteers. Other studies have found prolific volunteering of native trees on older Appalachian mine sites with soils similar to those of native forests (Brenner et al. 1984; Holl and Cairns 1994; Skousen et al. 1994, 2006).

On this reclaimed mine, survival of planted trees (~33%) was lower than has been documented in other studies of Appalachian mines reclaimed using methods intended to stimulate forest reestablishment (i.e., Angel et al. 2008; Emerson et al. 2009; Miller et al. 2012), where planted trees' survival ranged from 59% to >90% on favorable soil areas. Those studies, however, took place on controlled experimental areas and over shorter time frames. Also, planted trees on those sites were not subjected to the vigorous competition from volunteers as occurred here. This case-study site was older and directly adjacent to and often downslope from forested areas, allowing gravity and wind to carry live seeds into the reclamation area. This combination of close proximate factors is generally not present on Appalachian mines, which are often larger and with reclamation areas upslope from the nearest forest seed sources. Studies have shown, however, that the soil conditions associated with high rates of volunteer establishment on this site (e.g., uncompacted and moderately acidic) are also conducive to survival by planted native trees (e.g., Angel et al. 2008; Emerson et al. 2009).

Summary

At the case-study site, FRA reclamation produced tree densities that exceeded the presumed regulatory goal of 990 trees/ha (400 trees/acre), while non-FRA reclamation did not. The total tree volume index on FRA reclamation sites exceeded that occurring on non-FRA reclamation areas by nearly 2×, while FRA tree species

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richness exceeded that found on non-FRA areas by a considerable margin. The mining operation applied the FRA successfully over a large segment of the mine site. Those areas of the mine reclaimed using FRA procedures appear to be on a growth and development path that will restore a biologically productive and diverse Appalachian forest plant community to the mined area.

FOREST RESTORATION IN A BROADER CONTEXT

Restoration of preexisting plant communities after mining is a means of mitigating environmental impacts. The term *restoration*, when applied in a mining context, is often interpreted to mean restoring the land to its former condition or state. Given the dramatic disturbances of land that occur through mining, it is doubtful that complete restoration of mined landscapes can be achieved. However, the authors' Appalachian experience demonstrates that restoration can be approached by establishing land conditions and young plant communities with potential to develop into forested ecosystems resembling those on natural landscapes.

Reforestation Methods Apply Scientific Principles

The FRA reforestation prescription is uniquely Appalachian, but it applies basic principles of soil science, plant science, forestry, and ecology that have potential for application in other regions.

Soils are the foundation for plant community development, and forest restoration begins with restoration of soils. Native plants in any locale have evolved in association with the natural soils. Hence, it is logical to expect that mine soils with physical, chemical, and biological properties similar to those of natural soils will be well suited to the native forest trees. Such mine soils can be best constructed by reusing the natural soils themselves. This approach has also been applied successfully in mining locales as widespread as Australia (Tacey and Glossup 1980; Grant et al. 2007; Koch 2007), Brazil (Parotta and Knowles 1999; Parotta 2001), Germany (Topp et al. 2010), and South Africa (Cooke and Johnson 2002). Premining soils supporting the plant types that the mining operation intends to restore, salvaged with the surface layer intact, contain live roots and seeds, organic materials, and nutrients that can aid restoration, especially if the soils are spread promptly after salvage.

Soil physical properties, including density, must be suitable for native plants if those plant communities are to be restored. Soil compaction caused by mining equipment can be a significant revegetation problem (Bradshaw and Chadwick 1980), especially if the postmining goal is to restore native vegetation. As in Appalachia, avoidance of soil compaction is recognized as essential to plant community restoration on mines in India (Ghose 2001), Brazil (Parotta 2001), England (Haigh and Sansom 1999), South Africa (Rethman 2006), and other world regions (Cooke and

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Johnson 2002). Loose soils, not compacted by mining equipment, enable rooting, water and air exchange, and other functions that are essential to most plant species. In Germany, researchers observed that loose mine soils with rough surfaces—not smoothed as per conventional reclamation practices that cause compaction—were more conducive to restoration of soil biology on reforested mine sites than are smoothed soils (Topp et al. 2010). Some mining firms use deep rippers to loosen mine soils after placement as part of their efforts to ensure the loose soils that are needed by forest plant communities (Koch 2007; Krümmelbein et al. 2012; and see case study 2).

Natural succession can aid plant community restoration on mine sites. The term *natural succession* refers to the change in a young ecosystem's species composition that occurs naturally as it ages and matures. The FRA relies on natural succession processes to aid plant community restoration; its intent is to establish conditions that allow plant species, not purposefully established by the mining firm, to enter the site and thrive. Processes resembling natural succession have enabled unplanted forest trees to become established on mine sites in Brazil (Parrotta et al. 1997), eastern Europe (Pensa et al. 2004; Mudrák et al. 2010), and Australia (Norman et al. 2006), and in other world regions as well as in Appalachia.

The plant species established during reclamation influence community development for years to come. When natural succession is intended to aid plant community restoration, it is essential to establish an initial plant community that will yield to natural succession processes. Establishing species that will occupy and persist on large ground areas is not advised. Working on a bauxite mine in Australia, Norman et al. (2006) demonstrated that the plant species initially established during reclamation influenced plant community development for more than a decade afterward.

Seeded herbaceous species influence survival and growth by trees. Because fast-growing herbaceous vegetation can hinder planted trees' survival and growth on mined landscapes, the FRA uses "tree compatible" herbaceous vegetation to provide soil cover. Studies on mines in Canada (e.g., Sloan and Jacobs 2013) and in nonmining environments (Holl et al. 2000; Davis et al. 2005; Hooper et al. 2005) demonstrate the potential for fast-growing grasses to hinder natural succession and forest tree establishment. As an alternative to seeding of nonnative grasses, Australian mining firms often seed native herbaceous species on mine sites being prepared for reforestation (Bell 2001; Koch 2007). While Appalachian reforestation continues to use nonnative species for seeding even with the FRA, these seeding practices are not always successful, and efforts to develop alternative seeding mixes of native species are underway (Rizza et al. 2007).

Planted trees and shrubs, if they survive, influence plant community development. The use of planted trees to attract seed-carrying wildlife is a well-established forest restoration practice in nonmining areas worldwide (Corbin and Holl 2012) and is

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used by the FRA. As planted trees grow and produce canopy, they can also encourage natural succession through mechanisms such as the production of organic litter as leaf-fall, and the casting of shade that reduces herbaceous plant cover and, as a result, enable certain plants entering the sites as seed to establish (Holl et al. 2000).

Establishing forest tree species selectively can aid forest restoration. Although tree species with light seeds, easily dispersed by birds and wind, can move easily across mined landscapes, other tree species—typically those with large, heavy seeds—do not move so easily by natural processes (Bradshaw 2000). Hence, when such species are considered as desirable in locations far from native seed sources, they can be established by seeding or planting (Koch 2007). This practice is recommended by the FRA and is used in other mining areas. For example, working on bauxite mines in Amazonia, Parotta et al. (1997) demonstrated that volunteer plant species' establishment was influenced both by the initial species planted, as they influenced seed-carrying wildlife, and by distances from native seed sources. The researchers used these observations to aid decisions concerning which tree species should be established purposefully by a cooperating mining firm (Parotta 2001).

Fertilization practices will influence plant community development. Fertilization of the reclamation site with essential nutrients is generally desirable and is often essential for immediate revegetation. However, fertilization practices must be tailored to the plant community's restoration. Soil nutrients that are essential for planted trees' growth will also stimulate excessive growth by competing vegetation if applied in a manner that benefits the competition (Evans et al. 2013). In a study conducted on a northern Canada oil sands' reclamation site, Sloan and Jacobs (2013) made a similar finding. In Australia, Norman et al. (2006) observed that excessive nitrogen fertilization stimulated exotic species invasions that hindered natural succession.

Monitoring, management, and (when necessary) control of nonnative (exotic) species is essential to forest restoration on mine sites. Biological invasions by nonnative species ("exotics") are a worldwide concern (Ricciardi 2007). As significant landscape disturbances, surface mines can be favorable locales for exotic species invasions (Lemke et al. 2013). Once nonnative species become established, they can significantly alter plant community development, delaying and, in some cases, even preventing the form of natural succession that can restore the native plant community (Hobbs et al. 2006). Exotic species management, although not prescribed by the FRA, is a growing concern on Appalachian mines.

ARRI as an Organizational Model

Although the scientific concepts that underlie restoration efforts have potential for broad application, appropriate procedures and practices must be developed at the local or regional level to be compatible with climate, soils, and other local conditions. This often requires experimental trials to compare the effects of various mine

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soil construction methods; species selections; fertilization, seeding, and planting methods; and other reclamation procedures. For such trials to generate information that can be used by mining operations to restore plant communities successfully, the field trials must be documented and monitored, and will be most informative if maintained and observed for extended time periods.

The Appalachian experience demonstrates that collaboration and information sharing among mining firms, researchers, and agencies can aid development of improved reclamation procedures. ARRI has fostered such collaboration and information sharing. The FRA represents the outcome of numerous trials and studies throughout the Appalachian region, with cooperation and support by numerous mining firms. Individual mining firms can apply resources to develop improved reclamation practices within a given locale; but the authors' experience demonstrates that partnerships, collaboration, and information sharing can produce those advances more effectively.

Business Case for Forest Restoration and Sustainable Mining

The plant community established in the aftermath of mining remains as the mine site's most visible feature and will be viewed by the public as mining's legacy. Even when not adjacent to public roadways, mine sites remain visible today via aerial imagery that can be easily accessed on the Internet.

The public's view of mining and the mining industry is influenced by the quality of land and water resources left by mining to future generations. The public will be more accepting of mining if it views mining disturbances as temporary.

When the public acquires a negative view of mining and the mining industry, results may include regulatory scrutiny and restrictions. This is currently occurring in Appalachia. Although most Appalachian mining sites have been "reclaimed" as required by law, few non-FRA Appalachian mine sites resemble the forested lands on natural landscapes. In Appalachia today, new regulatory policies are restricting the industry's ability to obtain new mining permits. While factors such as water resource impacts have influenced agency decisions (USEPA 2011), negative public views of mining are also apparent.

The mining business requires a "social license to operate." Opening new mines, as needed to sustain a mining business, requires government approvals as new permits. Throughout the world but especially in democratic nations, government approvals are influenced by public perceptions. Hence, when operating in forested regions, it is in the industry's interest to apply reclamation methods that restore plant communities similar to those on nonmined landscapes. The authors' Appalachian experience demonstrates that the additional cost of doing so can be modest to nonexistent, once the basic scientific knowledge is in place and has been applied to develop effective reforestation techniques.

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Forest Restoration for Sustainable Mining

Implementation of the FRA during reclamation reestablishes conditions suitable for the development of diverse and productive forest vegetation, with a land-use capability that approaches, equals, or exceeds that present in forested areas prior to mining. When the FRA is fully and correctly implemented, mining can be a temporary disturbance of the land surface that is followed by restoration of the land's native forest vegetation and biological productivity, an outcome that is consistent with sustainable mining principles (see Chapter 1). This outcome satisfies the Brundtland sustainability principle as mining that provides materials and employment for current society followed by a rapid return of the land to a condition that can meet the economic and environmental needs of future generations through sustainable forest management. Stakeholder input during mine planning can help to ensure that reforestation plans, including tree species selection, address the needs of landholders and the community for production of wood and fiber, for wildlife, or for recreation. Successful forest restoration after mining also satisfies Elkington's triple bottom line (see Chapter 1). This occurs by minimizing the loss of economic value as it returns the land to productive use; providing social benefits by creating forested lands with a network of roads that can aid in future forest management; and restoring environmental quality by producing mined lands that support wildlife and plant community diversity, and protect water quality and watersheds.

CONCLUSIONS AND SUMMARY

Mining remains vital to sustainable development of modern society, given human needs for the materials and energy that the mining industry provides and for the technology that those mining-derived products make possible. *Sustainable development* is often described as "development that meets the needs of current generations without compromising the ability of future generations to meet their own needs" (WCED 1987). This ideal is approached when land resources disturbed by mining are restored to a biologically productive state and when ecosystem functions and services are returned to premining conditions in all of their complexity and scale. Given the increased visibility of mining and its impacts in an Internet-wired world, the industry's performance in restoring environmental resources affects its own sustainability. Mining requires a social license to operate, and in today's world, the public is demanding that the industry demonstrate improved environmental performance.

In the Appalachian region of the United States, extensive mining impacts to forested ecosystems have become visible to the public due to their increasing extent. However, new technologies are also becoming available for improved land resource restoration, and some industry segments are adopting them. The FRA, a reclamation method for restoring forest vegetation on land surfaces affected by Appalachian

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coal mines, are described in this chapter. Also described are case-study examples of mining operations that have applied the FRA operationally and successfully. Implementation of the FRA during reclamation reestablishes conditions suitable for the development of diverse and productive forest vegetation, with a land-use capability that approaches, equals, or exceeds that present in forested areas prior to mining. Three case studies of successful reforestation applied operationally by active mining firms were described, as were scientific concepts essential to the FRA in Appalachia that can be applied to enable forest restoration in other mining areas.

ACKNOWLEDGMENTS

Certain photos and tables have been published previously by the authors in publications prepared for the ARRI, OSMRE, and the Virginia Cooperative Extension, as cited in the chapter. The authors acknowledge and appreciate the funding and cooperation from numerous mining firms and from other entities, including the OSMRE, that were essential to development of the reforestation practices described in this chapter.

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CHAPTER 24

Responsible Land and Resource Management in Northeastern Minnesota

R.D. Learmont and Julie Varichak

INTRODUCTION

Northeastern Minnesota's mining industry is best known for its iron ore production. The region is the source of more than 70% of the iron ore produced in the United States and is the major supplier of new iron units to the United States steel industry. The mining industry is large, accounting for 30% of the regional economy, according to a 2012 study by the University of Minnesota Duluth's Labovitz School of Business and Economics (Skurla 2012). While economically very important, mining coexists with other activities and successfully operates within a larger context that includes national and state environmental laws and regulations; competition for or impacts on land, air, and water resources; social and cultural factors; and nonmining businesses such as tourism, health care, and timber production.

Responsible land and resource management includes both physical reclamation and restoration activities on each mine site that meet or exceed minimum requirements established by laws and regulations, and nonphysical activities. These best practices extend through the full mining cycle from exploration, to mine planning and development, to mine and plant operation, and to final closure, reclamation, and restoration. This chapter provides information and examples of responsible land and resource management, all of which are part of the current mining industry and are important in shaping the future of mining in northeastern Minnesota.

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THE NORTHEASTERN MINNESOTA MINING REGION

The history of mining in northeastern Minnesota dates back at least as far as 1850–1852 when outcrops of iron were reported on the far western part of the Mesabi Range near what is now Grand Rapids and on the shore of Gunflint Lake much farther east (Van Brunt 1922). In 1882, the first iron ore production began near Soudan on the Vermilion Iron Range. Since that time, iron ore has been produced from the Vermilion, Cuyuna, and Mesabi iron ranges in northeastern Minnesota. Historical records show that from 1888 through 2010, Minnesota produced and shipped approximately 5 billion tons of iron ore consisting of direct-shipping natural iron ores, processed natural iron ores, and iron ore pellets.

While examples of responsible mining practices in the iron ore industry are provided in this chapter, similar approaches to responsible mining are being used in mine planning of the region's major nonferrous resources. Figure 24.1 shows the location of major ferrous and nonferrous mining production and development activities in northeastern Minnesota.

Northeastern Minnesota's mining industry has developed land and resource management practices that meet or exceed legal requirements. Mining is planned and conducted in responsible ways that recognize and strive to attain various major stakeholder objectives. Responsible mining practices and programs involve technology development, collaborative and cooperative relationships and organizations, physical reclamation and restoration, legal and regulatory controls and requirements, and good management practices. Several examples are described in this chapter:

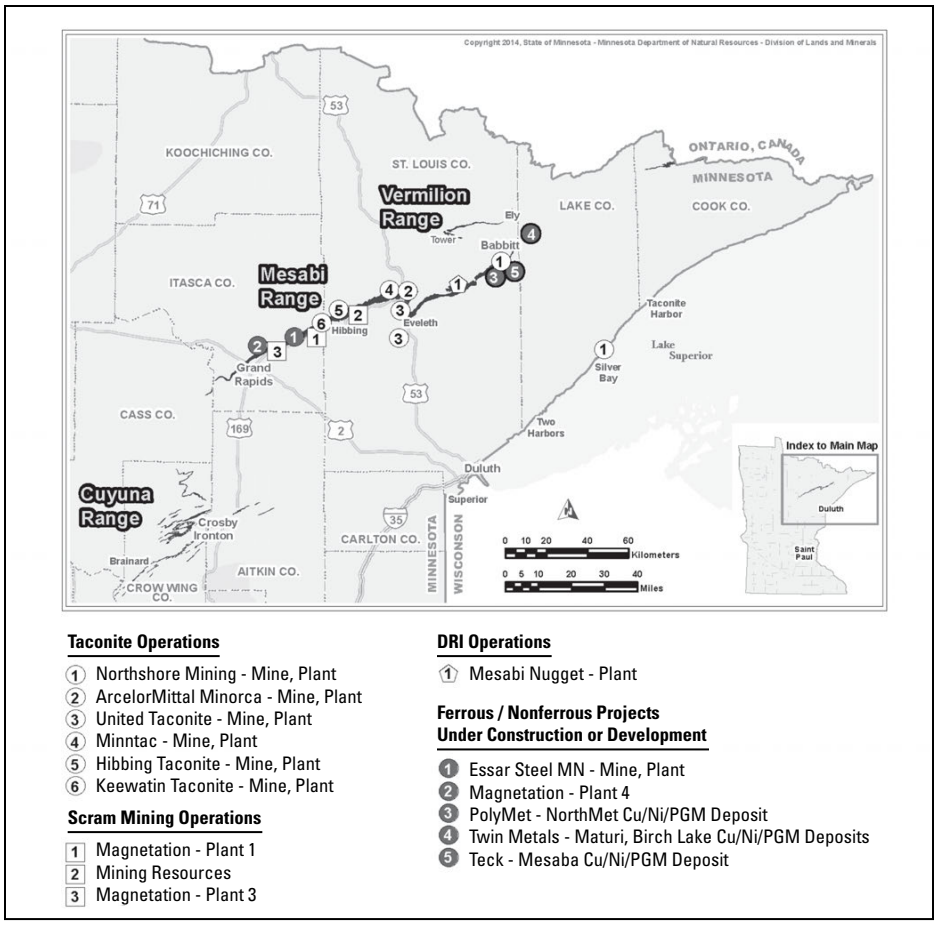
- Mining company mine planning, operations, and closure plans
- Resource conservation and protection, technology development, and reuse of resources
- Local government involvement
- The Laurentian Vision Partnership (LVP)

Together, these examples comprise a diverse and effective set of best practices and programs for responsible land and resource management.

MINING COMPANY MINE PLANNING, OPERATIONS, AND CLOSURE PLANS

The Minnesota Mineland Reclamation Act was passed in 1969. Rules were promulgated in 1981, including rules for issuance of a Permit to Mine for iron ore and taconite mining operations. In 1993, rules were issued for mining of nonferrous metallic minerals. Included in the Permit to Mine are formal postmining reclamation requirements for mining completed after 1981. The minimum standard for reclamation in taconite mining operations requires the postmining landscape to be safe and environmentally sound by sloping and seeding stockpiles and tailings

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Courtesy of Minnesota Department of Natural Resources, Division of Lands and Minerals.

Figure 24.1 Nine counties in the northeastern part of Minnesota showing the iron ranges, current iron ore mines, and several advanced metallic mining development projects

basins. The law also requires annual mine plans, including reclamation, to be submitted to maintain the Permit to Mine. The Mineland Reclamation division of the Iron Range Resources and Rehabilitation Board (IRRRB) reclaimed pre-1981 mine lands that had not been otherwise reclaimed.

The Minnesota Department of Natural Resources–Division of Lands and Minerals (DNR) is responsible for permitting new mining operations, including mine plans, construction, operation, and reclamation through closure. There is a close working relationship among DNR staff, mine engineers, and environmental personnel.

Currently, mine engineering departments develop plans that provide for continuous reclamation as part of the mining plan. Material movement is captured

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in the plan, including ore, waste rock, and surface overburden. Waste rock and surface overburden are stockpiled, sloped, and benched to specified standards, and are the primary areas for reclamation. Surface overburden material is used to sheath rock stockpiles to provide a medium for plant growth. After the stockpile has been sheathed, a seed mixture is sprayed to help with slope stability and limit dust lift-off. This practice of sloping and seeding is the minimum standard according to the law.

The DNR conducts periodic monitoring of reclamation sites to ensure the success of the sloping, seeding, and general design. Inspection criteria start with confirmation that vegetation establishment has been initiated. After 3–5 years, a 90% ground cover is required, depending on slope exposure. Within 10 years, reclamation sites can be deemed successful and the monitoring phase complete. At any time, the DNR can require repair or replanting if the site has been damaged.

The DNR also monitors the mining company's wetland replacement plans, which are prepared according to the Wetland Conservation Act and Minnesota Administrative Rules (MN ORS 2013). The DNR also coordinates with the U.S. Army Corps of Engineers before final approval of wetland replacement plans.

Each mining company is required to have mine closure plans, including the funding required to restore the landscape. This financial assurance is included in the Permit to Mine application and renewals. As mineland reclamation has progressed, there has been more discretionary effort from the mining companies. Partnerships have formed among local stakeholders and mining companies to look at future land-use planning. This has grown into more focused reclamation planning to better account for intended future use of the land. The financial support of an LVP Innovation Grant program (described later in this chapter) encourages the mining companies to go beyond minimum requirements in their reclamation efforts. The following two case studies describe successful reclamation efforts at the Minnesota Operations of Cliffs Natural Resources.

Case Study 1: United Taconite—Alfalfa Farming

United Taconite in Forbes, Minnesota, partnered with a local farmer and a wastewater treatment facility to grow alfalfa on the top of a retired tailings basin (Figure 24.2). According to Neil Tietz in *Hay and Forage Grower*, a farmer planted 180 acres of alfalfa crop on top of a 150-ft-high retired tailings basin to grow feed for his dairy farm (Tietz 2009). A municipal wastewater treatment facility provided biosolids as a soil amendment for taconite concentrator tailings to better support plant growth. The planting helps United Taconite with dust control on the retired tailings basin by providing cover crop to mitigate dust generation. This collaboration created a unique use for an otherwise unusable space.

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Courtesy of Cliffs Natural Resources.

Figure 24.2 Alfalfa hay grown on a retired United Taconite tailings basin

Case Study 2: Hibbing Taconite Company—Surface Stockpile Reclamation

Hibbing Taconite Company (HTC) in Hibbing, Minnesota, is currently reclaiming two surface stockpiles in partnership with the IRRRB/ LVP Innovation Grant program. Participation in this program provides funding for specialized seed mixes. It also allows HTC to collaborate with landscape architects to develop and implement a strategy for shaping stockpiles and mine pits to maximize aesthetic appeal and to promote landscape options for postmining uses.

HTC partners with a private landscape architecture consultant as well as the University of Minnesota to complete littoral zone development and stockpile reclamation design for the 5036 and 5012 stockpiles. The stockpiles are named with a numerical system that identifies the material type in the stockpile and the relative age. The 5036 stockpile, located between HTC's group 1 and group 2 pit areas, is a 120-acre surface hoosier dump at the bottom of an open pit where mining has been completed. HTC will be constructing a drainage feature, ridges, and lowlands, followed by seeding 80 acres of upland with a cover crop, native grasses, and wildflowers. The 5012 surface stockpile project located just west of the Kleffman road/tunnel area was started in the fall of 2012 and was completed in the summer of 2013 following a concept design that provides grouse habitat. This project includes the creation of open vistas on the surface as well as a shallow wetland. Vegetation plantings consist of a cover crop, native grasses, wildflowers, shrubs (red osier dogwood, cranberry, juneberry, crabapple) and white spruce and paper birch

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trees. This design provides surface relief and complements the topography of the 4090 stockpile and exceeds state reclamation standards.

RESOURCE CONSERVATION AND PROTECTION, TECHNOLOGY DEVELOPMENT, AND REUSE OF RESOURCES

Mining is commonly perceived as nonsustainable because it produces from what is generally considered a finite, depleting mineral resource. However, in the case of northeastern Minnesota, responsible mining practice demonstrates characteristics of long-term sustainable development through

- Resource protection,
- Resource conservation,
- Continued innovation and technology development, and
- Reuse of resources previously perceived as being materials of no value.

Resource protection in this context refers to practices that include defining the extent of the mineral resource through exploration drilling, sampling, and geologic mapping to determine the location, size, and characteristics of potentially economic mineral deposits. This work provides information needed to develop the mine plan as well as determining areas suitable for location of processing plants, stockpiles, tailings basins, and areas suitable for surface infrastructure so that mineral resources are protected from surface encumbrance and, from a sustainability standpoint, remain available for their future mineral value.

Resource conservation has historically been performed by mine planners and mineral owners who were careful to separate and segregate materials of similar characteristics and differing ownership in recognition of possible future value. They were especially vigilant with mine waste rock and lean or subeconomic mineral resources but also with processing plant tailings. An example of this practice is the stockpiling of non-iron-bearing waste rock either separate from or beneath low-grade or "lean ore." It was recognized that at some time in the future, lean ore would be more likely recovered for processing and shipment than would waste rock. This best-practice resource conservation prevented long-term loss of a resource that could be reasonably perceived as likely to have value in the long term while involving minimal short-term cost to perform the segregation.

Innovation and technology development refers to recognition that production from a mineral deposit depletes a defined resource, unless and until technology can be developed to allow converting initially noneconomic mineral resources into a mineral product economically. This recognition has long existed in northeastern Minnesota, given that many major production companies had major research and development facilities on the Mesabi Iron Range. These research facilities collected and analyzed technical information from producing iron ore mines and beneficiation operations to make incremental improvements in efficiency, iron recovery,

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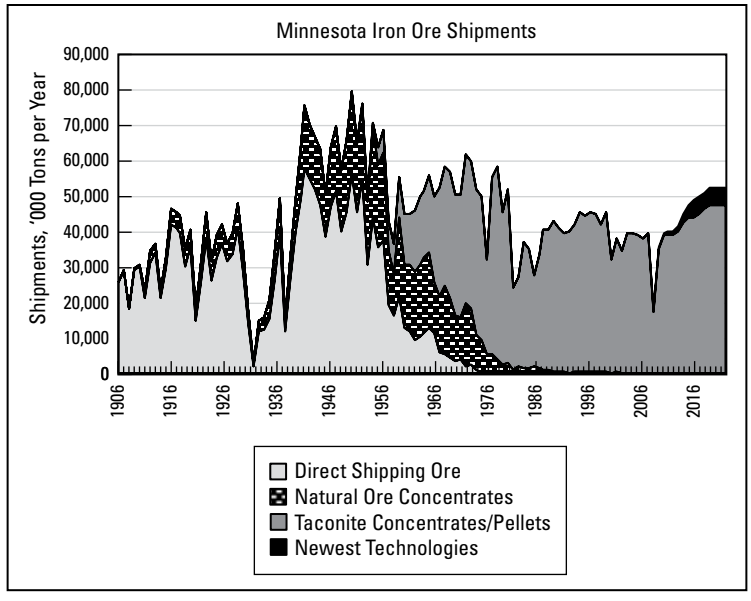


Figure 24.3 Resource protection, resource preservation, and technology development as elements of responsible mining best practice. Note the four periods as well as the shift in production technology and type of product shipped as technology has changed. Shipments beyond 2012 are authors' projections.

and ore grades. The research facilities also worked on new technology, identifying and developing the best practices that could be used to design new processing plants. These new facilities would produce commercial iron ore products from declining and more difficult mineral resources as natural iron ores were depleted. The research laboratories, two of which are still active (the independent Midland Research Center and the University of Minnesota's Coleraine Minerals Research Laboratory of the Natural Resources Research Institute), have been involved in testing and developing processes that could be applied to Minnesota's nonferrous mineral resources.

Reuse of resources previously perceived as "waste" of no value is also a form of responsible mining and results in sustainability of mining in northeastern Minnesota. Stockpiled low-grade or difficult-to-process iron ores and impounded tailings are now providing the feed material for a new generation of iron ore production, such as that produced by Magnetation LLC and Mining Resources LLC. This production may not have occurred had best-practice responsible resource protection, resource conservation, and technology development not taken place.

The resource protection, conservation, and technology development practices just described are examples that have lead to sustained mining in northeastern Minnesota for more than a century, with another century or more of expected

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operation. The success of historic responsible practices such as those mentioned is illustrated by historic data such as shown in Figure 24.3.

In Figure 24.3, three historic waves of iron ore production are clearly visible and a fourth wave is beginning to appear.

- **Wave 1:** Direct shipment of natural iron ore not involving beneficiation, primarily hematite iron ores, lasted from the start of iron ore mining in Minnesota in about 1882 well into the second half of the twentieth century.
- **Wave 2:** Invention and application of best-practice hematitic iron ore beneficiation techniques, while applied early in the twentieth century, began to have significant influence around 1940 as ore grades decreased yet continued to sustain total iron ore production while direct shipping iron ores were being depleted.
- **Wave 3:** University research in the 1920s lead to the first commercial taconite pellet production in the 1950s. Taconite pellet production using magnetite iron ore concentrates grew rapidly, and by 1980, when direct shipment of natural iron ore had stopped and beneficiated natural iron ores were nearing an end, production of pellets from magnetic iron ores became the major iron ore product.
- **Wave 4:** A number of technology developments, some of which had been under development for several decades, have resulted in what is now a new series of developments in Minnesota iron ore that use waste products (stockpiles or tails) of previous iron ore mining and newly developed technologies to produce iron ore concentrates and value-added products. While pellets made of magnetite ore are expected to continue at present levels and grow, production using new technology is expected to continue to add to the total annual production.

All of the northeastern Minnesota iron ore producers exhibit understanding of and involvement in best-practice resource management and technology development. Companies with direct ownership or ownership through subsidiaries in one or more current Minnesota taconite pellet production mines and plants include United States Steel Corporation, Cliffs Natural Resources, and ArcelorMittal. Essar Steel Minnesota has a permitted taconite pellet facility partially through construction with announced plans to advance beyond pellets into steel production. Non-pellet producers already operating using the newest technologies include Mesabi Nugget/Steel Dynamics, Magnetation, and Mining Resources. Much of the technology development and testing has been done using Minnesota minerals research facilities. While each of these iron unit producers has its own policies and approaches, all have shown indications of the recognition of best-practice resource management and long-term technology development that is part of responsible mining.

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LOCAL GOVERNMENT INVOLVEMENT

Beginning in the late 1980s, several local government units began to experience some shared issues as natural iron ore mines, which had provided the employment and economic backbone of the communities for 80 years, were rapidly being closed. Consequently in November 1993 many cities, townships, and Itasca County officially organized as a joint powers board under Minnesota statute. As part of this process, a map defining an area of common interest was developed and referred to as "the Western Mesabi Corridor," and the Western Mesabi Mine Planning Board (WMMPB) members developed a joint powers agreement to formalize their organization.

Consistent with the reasons for its establishment, which support mining while also recognizing that mining is part of a larger socioeconomic system, the 14 current WMMPB members recognize their role in responsible mining as formally stated in the board's statement of purpose:

> The purpose of the Western Mesabi Mine Planning Board shall be to formulate a management plan and develop strategies for environmental protection and orderly development of public and private lands; to protect said lands from uncontrolled and unplanned development, pollution or degradation through the preparation and adoption of comprehensive local ordinances; to provide for the recreational use of said lands; and to identify areas of high future mining potential and to preserve these lands for future mining opportunities. This management responsibility is shared by the county, cities and townships through the exercise of land use control and jurisdiction over certain public and private lands within this corridor as identified on attached Exhibit A [not included with this chapter].

WMMPB meetings are transparent and open to the public. Regular meetings are held monthly, with public notice being given in local newspapers. Recent examples of WMMPB activities include

- Providing educational and informational updates and participating in discussions about major development projects in the Western Mesabi area, including those involving Essar Steel Minnesota, the United States Steel Corporation Keewatin Taconite expansion, Magnetation, and additional iron mining projects in the Western Mesabi Corridor;
- Giving presentations regarding mining-based taxes and distribution of funds generated from them;
- Sharing information about mining-related concerns and priorities of community groups;
- Attending city, township, and county meetings and assisting in their mining-related planning activities;

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Figure 24.4 Participants in an August 2012 WMMPB field trip following an educational and informational session at the Twin Metals Minnesota field office in Ely, Minnesota

- Conducting informational field trips that are open to board members as well as the general public. Points of major interest on a recent tour included touring, presentations, and discussions at four stops: the Polymet project, the Mesabi Nugget operation, the Twin Metals Minnesota project (Figure 24.4), and the Pioneer mine;
- Representing itself regularly in the LVP, which has regional planning objectives that include developing information and planning tools related to the iron mining corridor; and
- Participating in a Mesabi Range–wide brownfields initiative to study and redevelop former mine lands.

WMMPB's appointed Advisory Committee members, many with technical backgrounds, actively support the board in developing and suggesting ideas, identifying issues, recommending actions, and pursuing board priorities. The board periodically reviews its activities and revises its priorities to achieve its responsible mining objectives. For example, while many things are addressed as they arise, 2013 priority goals were defined as follows:

- Encourage mining and re-mining, but develop and apply requirements to ensure that mining activities will not result in loss of iron units and will not leave environmental damage following closure.
- Improve ways for local government units to financially benefit from production or processing of iron ore tails, stockpiles, and surface materials, whether produced for their iron units or as aggregates.

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- Lead efforts to begin planning and design for the improvement of Highway 169, a thoroughfare along the mining corridor from Taconite to Pengilly.
- Provide assistance to and participate in efforts by WMMPB members in the development and revision of comprehensive plans and land-use ordinances, and other actions, especially those related to iron ore resources.
- Lead efforts to develop a workable plan to support and improve the future of Hill Annex Mine State Park.

Two recent examples of local government involvement in responsible mining activities involved an outflow issue at the Canisteo open pit mine and some comprehensive planning in the western Mesabi area.

Canisteo Outflow

In the mid-1980s, 75 years of mining of natural and direct shipping iron ore from the Canisteo area open pit mines north of Bovey, Minnesota, ceased. Collected water began to rise in the 5-mile-long sequence of connected open pits, which predated Minnesota's mineland reclamation rules. Pit water rose after pumping stopped, and it continued to rise to the point where significant public safety and environmental concerns were possible if action was not taken. Some physical damage had started to occur. The WMMPB led the efforts of its members over several years to gain the support of local legislators, its own members, and other interested sources for funding to conduct a series of engineering studies, public meetings, and other activities. These efforts were to make use of data collected and analysis done by the DNR to develop responsible, technically sound ways to control a threatening situation. The situation of concern was stabilized by some of the actions taken as a result of WMMPB's leadership, together with use of the excess water and pit water control measures that were part of the activities of a private mining company interested in beginning new mining activity in the area that had formerly been mined but idle for more than 20 years.

Comprehensive Planning

Responsible mining at a local government level involves qualified technical personnel, local government officials and planners, and public involvement. These individuals use available information about mineral and other resources, markets, and industry technology—plus good judgment, forecasting, public opinion, and input—to develop objectives, policy guidelines, and plans for zoning and land-use permitting purposes at the county and municipality level. The WMMPB is an active participant in this process at the county level for every 5-year review and update, and also periodically at the municipal level. The WMMPB also has a management plan that covers the joint powers area, which is periodically updated and used to guide its activities in the western Mesabi mining area.

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In addition to meetings, a coordinator is periodically called on to disseminate information to all members or particular ones. The WMMPB's executive committee or special task forces are also used to work on specific projects. The WMMPB also interacts with representatives from higher-level (state and federal) political offices. Elected officials from those higher bodies are included on regular WMMPB mailing lists. They participate at WMMPB meetings and serve as points of contact for gaining information about developments at a federal or state legislative level as well as for receiving information about preferences, priorities, and concerns of local government units and the local public.

The WMMPB establishes and maintains linkages with more regional groups through such mechanisms as the LVP, regional economic development groups, and interactions with state agencies. The WMMPB is also in contact with mining companies active in the Western Mesabi Corridor and can provide a discussion forum as well as coordinate communications when potential problem or conflicts arise.

LAURENTIAN VISION PARTNERSHIP

The LVP is a collaborative of mining, business, government, education, professional, and community interests representing all parts of the Mesabi Iron Range. The partnership promotes responsible mining and the reshaping of mining sites into productive future landscapes. The LVP serves as a convener and a conceptual land planner, arranging speakers and facilitating discussion and decision making among all interests, and helps identify lands for economic, recreation, and resource uses that meet mining and community goals. Playing both roles allows the LVP to encourage creative solutions, help craft future goals for the region, and clarify the steps needed to transform those goals into realities on the ground (LVP 2012).

Before the formation of the LVP, no large-scale effort had focused on the planned reshaping of mine sites for common economic, aesthetic, recreational, and natural resource goals. The LVP was formed to tackle that challenge, and the first partnership meeting was held in Duluth, Minnesota, in 1999. United States Steel Corporation, the IRRRB, DNR, University of Minnesota, and other parties began exploring how active mining processes could reshape the mined landscape of the Mesabi Iron Range as an integral part of iron ore mining operations.

The LVP is open to all interested stakeholders, whether private property owners, mining company representatives, government entities, or business or community interests. Partners typically contribute in-kind services, funds, or other financial and human resources to sustain the partnership's mission.

The LVP has been a sustained activity since its beginning, normally meeting three or four times per year. The 58th meeting of the full partnership was held in October of 2014. In addition, the Coordinating Committee and various groups meet to continue working sessions outside of the full partnership meetings. Among other things, the LVP performs data collection, carries out mapping sessions, and

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conducts public design workshops that visualize future uses for exhausted or idle mines. This sets the stage for how active mining and community goals can help reshape the physical landscape of Northeastern Minnesota's future.

The LVP supports the Mesabi Iron Range as a healthy place to live and work, and recognizes the economic importance of mining. The partnership encourages planned design efforts by mining companies and communities throughout the Mesabi Iron Range, promotes new ideas for the long-term restoration and development of individual mine sites, and facilitates meaningful actions among stakeholders. The partnership has established the following vision and mission statements (adapted from LVP 2012).

- **Vision:** Transforming pits and piles into living lakes and landscapes…our legacy for the future.
- **Mission:** The Laurentian Vision Partnership is a regional coalition that promotes the development of productive postmining landscapes by cooperating in
  - Preserving lands necessary to sustain current and future mining,
  - Promoting landscape options for postmining uses,
  - Identifying and discussing new development opportunities, and
  - Providing the tools to achieve these goals.

To fulfill its mission, and as described in its literature, the LVP activities integrate five tools to achieve its goals, described in the following sections (adapted from LVP 2012).

Tool 1: Community and Regional Visioning

LVP promotes visioning to assist stakeholders in creating new possibilities and maximizing potential. By developing a clear sense of purpose, decisions are made and problems solved by relying on the vision of the future as a guide to help mining companies, communities, and regional interests identify goals that promote sustainable mining and community enhancement. Stakeholder priorities are developed through the visioning process for preserving necessary lands for current and future mining, enhanced postmining landscapes, and regional economic growth. Neutral meeting sites are used so that group goal setting and other exercises result in legitimate participation, focused discussion, and quality decision making.

Tool 2: Land Design Workshops

LVP has conducted public design workshops, referred to as *charrettes*, which have been voluntarily hosted by a mining company with an interest in the area being studied, property owners, neighboring communities, and state and local government entities. Charrettes are staffed by teams of local and national designers and planners. Each design workshop identifies goals, which help the design teams

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Courtesy of Iron Range Resources and Rehabilitation Board.

Figure 24.5 Participants at a design charrette developing planning concepts for postmining landscapes on the Mesabi Range

(Figure 24.5) devise realistic development scenarios for former minelands. The workshop sequence takes place, uninterrupted, over several days. Site tours, discussions, and the consequential drawings, diagrams, maps, and other illustrations capture the teams' ideas and are presented and discussed with the mining company and community. The resulting scenarios are then translated into planning actions and development strategies that stakeholders can implement in the short and long term. The charrette format is a way for stakeholders to participate in legitimate discussions about development ideas that may affect them and is an effective, affordable way to quickly visualize future uses for former minelands. Since 2001, LVP charrettes have generated conceptual long-term goals for potential mining developments in the Virginia, Hibbing/Chisholm, and Biwabik areas.

Tool 3: GIS Mapping

A Geographic Information System (GIS) is a computer system capable of capturing, storing, analyzing, and displaying geographically referenced information. The LVP has created several GIS-based maps and updates them as new mining and land-use data become available. GIS maps provide the interested stakeholders with current data and can be used as a tool to visualize features as they may be in the future. The LVP develops maps for land design charrettes, and these maps are available for mining-related development projects. A GIS is used in envisioning postmining land use by mapping important site information such as pit lakes, the shape and

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location of stockpiles of mined material, delineation of underground mines, and pit-wall slopes.

The LVP identifies and maps the resources and land needed to sustain future mining. Mining resources are delineated according to the time frame in which development would most likely begin: 0–20 years, 20–50 years, and more than 50 years. Auxiliary lands needed to develop these resources, such as stockpile areas, tailings basins and their expansion areas, blast buffers, environmental setbacks, and haul routes, are also mapped. This mapping process helps stakeholders understand the mining industry's future land use needs and locations, preserves areas for mining development, and reduces potential land-use conflicts by nonmining development. The DNR prepares and updates project maps periodically for use by Laurentian Vision partners to track the status of major mining projects (Figure 24.6).

Tool 4: Innovation Grants

The LVP oversees allocation of Innovation Grant funds, a funding program started in 2006 to encourage and assist operating taconite mining companies, local communities, and other organizations interested in

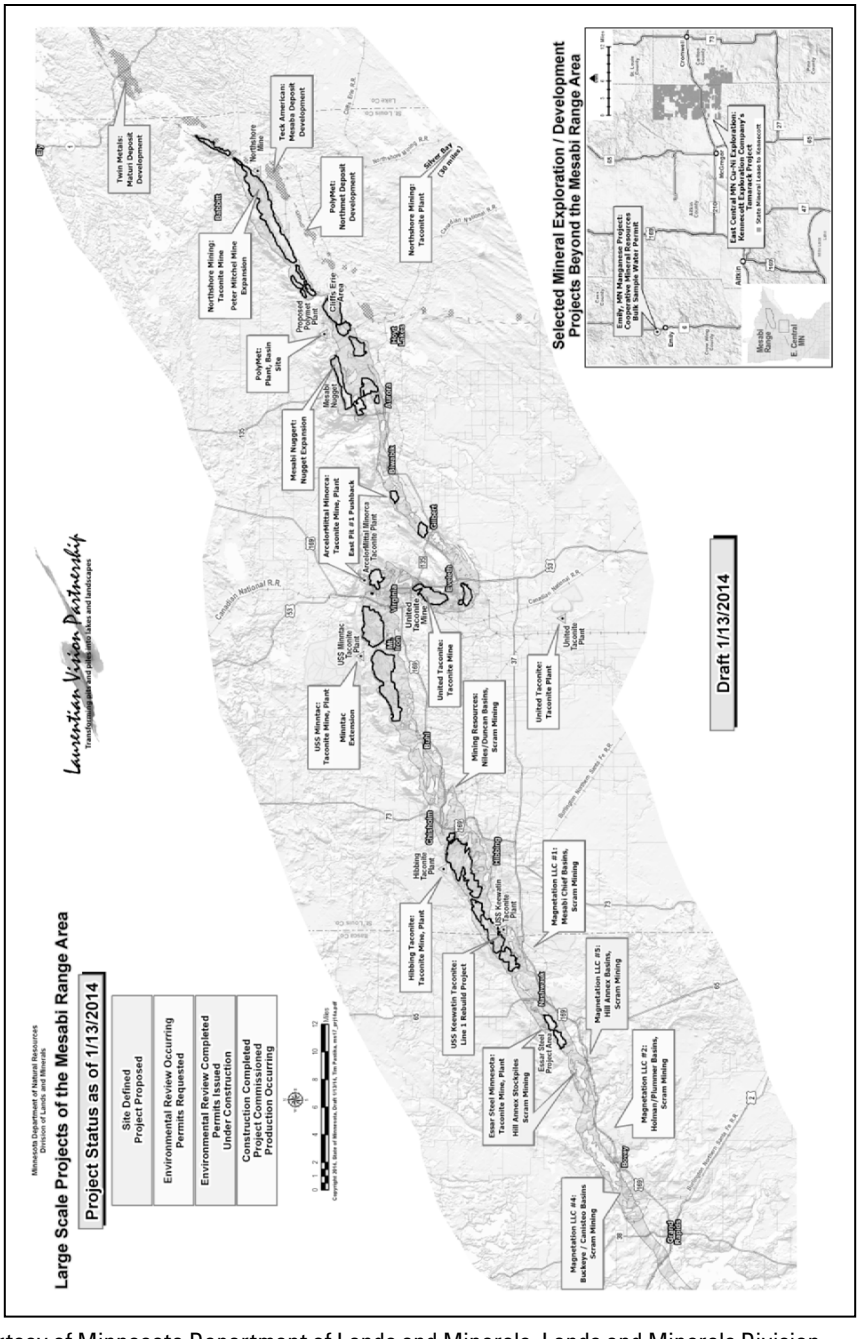
- Exploring future uses for lands disturbed by mining (e.g., commercial, residential, recreational, and/or environmental enhancement);
- Providing jobs or generating revenue from such ideas;
- Solving public safety issues associated with the public use of private minelands; and
- Active local community participation in the planning, design, and implementation of mineland projects.

Innovation grants provide an opportunity for mining companies and community interests to collaborate in deciding the best use of postmining lands to benefit Mesabi Iron Range businesses, communities, and the landscape. IRRRB provides funding for the innovation grants and expects that the approved applicants will provide a match, which may include in-kind services or other nonagency funds. Grant applications are reviewed by the LVP Coordinating Committee at its quarterly meetings along with IRRRB staff. Recommended applications are then reviewed and approved by the IRRRB Commissioner and board.

LVP Innovation Grant programs have included the following projects (LVP 2013):

- **Mesabi Mountain Wind Coalition.** A grant was given to the Mountain Iron Economic Development Authority to identify and develop renewable wind generation across the Mesabi Range at various mining sites. The total project amount was $389,000, toward which $139,000 of innovation grant funds were awarded.

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Courtesy of Minnesota Department of Lands and Minerals, Lands and Minerals Division.

Figure 24.6 DNR Mesabi Range large projects map used by Laurentian Vision partners to track major mining developments

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- **Biomass Fiber Production for Energy/Fuel on Mine Land Reclamation at United Taconite.** This project grew switchgrass on a tailings basin to provide an alternative source of biomass for the green energy industry. The total project cost was $158,099, of which $53,531 was Innovation Grant funding.
- **Underground Mine Mapping.** This DNR project graphically documented the extensive network of underground mines across a part of the Mesabi Range. The total project cost was $300,000, of which $150,000 was Innovation Grant funding.
- **United Taconite Stockpile No. 1406.** This United Taconite project innovatively shaped and vegetated a surface overburden stockpile adjacent to the heavily traveled Highway 53 corridor. The total project cost was $98,870, which included $72,150 of Innovation Grant funding.
- **Keetac Stockpile No. 43.** The Keewatin Taconite project involved shaping and vegetating a rock stockpile, which is more challenging to contour and vegetate than overburden stockpiles. The total project cost of $82,440 included $51,490 of Innovation Grant funds.
- **In-Pit Shoreland Development Project Phases I and II.** This City of Hibbing and HTC project designed and built a new mine pit lake shoreline, shallow pit lake areas suitable for aquatic life, fish spawning areas, islands, and usable upland areas. The total project cost was $272,120, which included $199,200 of Innovation Grant funding.
- **Hibbing Taconite Stockpiles Phases I and II.** The University of Minnesota School of Landscape Architecture, HTC, and the DNR cooperated in a two-stage project to build, reshape, and vegetate two rock stockpiles adjacent to a busy county road 3 miles east of Hibbing and 1 mile north of Kelly Lake. Follow-up involved monitoring, evaluating, and recording Phase I of the project and developing land-shaping templates for use by mining engineers. The total project cost was $682,420, which included $150,400 of Innovation Grant funding.
- **Northshore Mining—Peter Mitchell Pit Master Landscape Concept Plan.** This two-phase project involving the University of Minnesota School of Landscape Architecture, City of Babbitt, Cliffs Natural Resources, and the DNR involved developing a master concept for Northshore Mining's Peter Mitchell mine to provide a plan for future uses and multiple landscape opportunities for the mine once closed, including vegetation enhancement, littoral zones, islands, wetlands, and shoreland. This was to be followed by using concepts from the first phase to produce the working schematic plans for implementation by mine engineers. The total project cost was $432,600, which included $175,400 of Innovation Grant funding.
- **Sulfate Reducing Bioreactor.** This project included the East Range Joint Powers Board, Clearwater Layline LLC, Cliffs Natural Resources, PolyMet

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Mining, Natural Resources Research Institute, Lemna Technologies, Premier Plastics, and Apex Engineering to conduct an on-site field test to evaluate whether a biological sulfate reduction system could be designed and deployed to address the volume of sulfate reduction needed at an economically viable cost for a proposed base and precious metals mining operation. The total project cost was $369,500, of which $125,000 was Innovation Grant funding.

Tool 5: Cooperation

LVP members participate in work groups that engage in specific tasks and projects that support the LVP mission. Four regional groups represent their geographic areas of the Mesabi Iron Range. These four groups are the WMMPB, Central Iron Range Initiative, Quad Cities, and East Range Joint Powers Board. The regional groups

- Assist in the implementation of existing land design workshop plans;
- Help identify specific sites and projects that could benefit from more detailed LVP technical or monetary support;
- Provide information to the LVP on current activities in their respective areas;
- Facilitate communication and the flow of information among each other and with the LVP on behalf of local interests; and
- Operate as community liaisons from the LVP to their constituents, presenting new ideas, concepts and projects, providing region-wide information to their members, and receiving guidance from the partnership for their respective regions.

LVP is seen a significant part of responsible mining in the region. Being a collaborative partnership, it provides opportunities to communicate, express, and discuss needs and opportunities, and provides tools and access to resources that partners and stakeholders may find useful. Although it does not have legislative, administrative, or financial authority, LVP fills a region-wide niche among local and state-level entities that openly invites participation and discussion as it seeks to fulfill its vision of providing a legacy for the future.

CONCLUSION

Minnesota has produced, and continues to produce, a major portion of the iron ore that is the basis of iron and steel making in the United States. The state also holds world-class resources of base and precious metals, plus aggregates, peat, and some industrial minerals. Much of the state's mining industry is located in northeastern Minnesota.

Responsible land and resource management practices are integral to mining in northeastern Minnesota. Legal and regulatory requirements, best mining operational and reclamation practices, resource conservation and protection, technology

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development, and the cooperative and collaborative nature of formal or ad hoc actions and programs embody basic responsibility principles. These standards and practices simultaneously provide an environment in which elements of the physical and biological environment, financial integrity, and industrial technology coexist over an extended time period.

Examples of current practices related to mine land and resource management used in northeastern Minnesota have been provided, including their development and ways in which they are conducted and applied in northeastern Minnesota's mining industry. The variety of entities and activities, consisting of diverse stakeholders and their respective perspectives, result in strong and effective application of responsible land and resource management practices in northeastern Minnesota. The current structure has evolved over more than 100 years as production and environmental knowledge and technology, laws, and social interests and concerns have evolved. The structure is expected to continue to evolve as consensus is achieved to accommodate changes. Collaboration and cooperation at state, regional, and local levels among diverse stakeholders has been important to the overall success and attainment of sustainable, responsible mining in northeastern Minnesota.

ACKNOWLEDGMENTS

The chapter authors are responsible for the content of this chapter. In addition to their own experiences and direct knowledge, the authors have requested support from and relied on numerous sources for information that has been used in developing this chapter, including public documents and public entities such as the DNR, IRRRB, LVP, WMMPB, and Cliffs Natural Resources. Sincere appreciation is extended to these organizations for their efforts and contributions.

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CHAPTER 25

Adaptive Environmental Management Plans and Practices

Andrea Martin

INTRODUCTION

Adaptive management can be described as a structured, iterative process of robust decision making in the face of uncertainty, with a goal of reducing uncertainty over time through system monitoring. Adaptive management is a tool that can be applied to not only change a system, but learn about the system (Holling 1978). Adaptive management has been used in ecosystem management for years, and guidance is provided in a variety of handbooks and publications. Adaptive management can be applied to industrial facilities and mines through the use of an adaptive environmental management plan (AEMP) and associated practices. The goal of this chapter is to provide an explanation of how the plans and practices support regulatory agency approvals and permitting, span the life cycle of mines, manage uncertainty, and assist in addressing mining impact and legacy issues. AEMPs and associated practices are useful tools to address the uncertainties in identifying, evaluating, and managing impacts of proposed new and modified mining facilities undergoing environmental review. After a proposed project is approved, the AEMP continues as a living document, being informed, revised, and adapted by the operations. The AEMP can serve as an ongoing management tool for describing and evaluating environmental impacts, continuing in operations into post-reclamation.

If initiated during planning and environmental review of a project (the preparation of an environmental impact statement [EIS] in some locations such as the United States), the AEMP becomes a basis to identify, monitor, and manage potential project environmental impacts. Development of an AEMP for an operating

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mine is also beneficial because there are generally developing and ongoing environmental issues at those facilities as well. Over time, the AEMP is adapted to changing requirements and conditions, including those anticipated and unanticipated. Ever-increasing scrutiny of mining projects and the complexities of the EIS process highlight the uncertainties inherent in impact predictions. In making the momentous decision of initial project approval, these uncertainties can discourage the regulatory agencies' actions and create stakeholder anxiety and controversy about a project. A well-designed AEMP can support the decision to approve an EIS and enable a project to move forward. Additionally, an AEMP can inform financial assurance estimates and revisions over the life of a mine, providing all parties including the state tax payers and surrounding communities with greater confidence that potential environmental impacts and risks will be well managed.

MINING HISTORY AND OVERVIEW

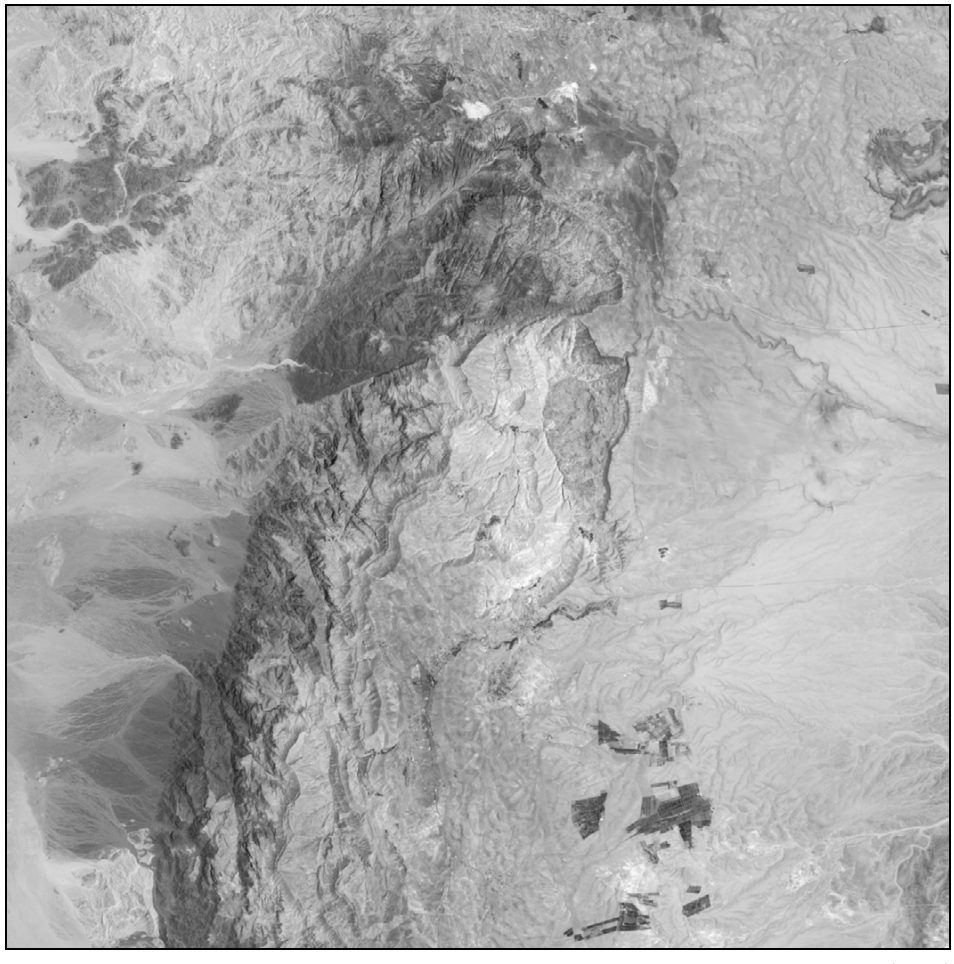
Mining is one of the more ancient human endeavors with evidence of mining dating back thousands of years (UCSD 2008). The Khirbat en-Nahas, located in Jordan, was built approximately 3,000 years ago and is one of the largest copper mining and smelting sites in the ancient world. The satellite image in Figure 25.1 shows large black piles of slag, indicating that waste disposal challenges and long-term environmental impacts from human endeavors are not just modern issues.

Mining affects the land and surrounding environment. It disturbs the soils and alters the mineralogy of the land, and thereby alters the naturally occurring geochemical reactions and weathering of the earthen minerals. Without effective management, precipitation and hydrology may transport liberated minerals beyond their sources.

Air emissions are also part of mining. If not managed, excavation and transport of materials can be dusty activities. Further processing such as crushing, grinding, milling, and smelting produces several types of emissions such as particulate matter, combustion products, toxic air pollutants, greenhouse gases, and other categories of air pollutants.

Once mine excavation begins, overburden, waste rock, and tailings pose significant storage and management challenges. These waste materials are typically placed in managed stockpiles or engineered repositories that may or may not endure through the mine life. Tailings present particular environmental challenges because they are typically generated in large quantities and are made up of very fine particles that can retain and seep water. That seepage may contain contaminants of concern (COCs) from geochemical reactions resulting from the effects of processing and exposure to oxygen and water. The same effects can be seen in many overburden and waste-rock piles.

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Source: NASA Earth Observatory image by Robert Simmon using Earth Observing-1 (EO-1) Advanced Land Imager data provided courtesy of the NASA EO-1 team.

Figure 25.1 Black piles of slag define Khirbat en-Nahas, a copper mining and smelting site, in this satellite image from August 11, 2010

The life cycle of a new mine can be divided into the following basic stages:

- Project proposal and planning, environmental review, and permitting
- Project construction
- Operations
- Modifications (if any are pursued), environmental review (for significant modifications), approval, and permitting
- Closure and reclamation
- Post-reclamation

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Each mine is unique and timelines vary. Mine sites around the world can be found in virtually every stage of the mine life cycle, including those currently in operation, mines being proposed and undergoing review and permitting, mines under construction, closed mines, and abandoned mines. Some mines currently in operation were begun decades or even centuries ago. Regulatory agency approvals and permitting may not have followed a rigorous process or, in some cases, any process at all.

In general, mines have the following characteristics:

- Operations can vary from several years to more than 100 years.
- All mines involve an excavation, whether underground or open pit. Both types of excavations will cause inflow of groundwater that will have to be managed and may need treatment prior to discharge.
- All mines and/or their surface processing facilities impact surficial hydrologic processes, with alterations or the potential for alterations to both the physical characteristics of surface water features and the water-quality characteristics of surface waters.
- Mine structures include
  - The excavation in the form of pits or shafts;
  - Stockpiles of waste rock and overburden;
  - A tailings storage facility;
  - Processing and material handling structures and equipment;
  - Roadways and buildings;
  - Product handling, load-out, and transport structures; and
  - Pollution control and management equipment, often including air pollution control equipment and wastewater treatment systems.
- The water balance at a mine typically includes pit or shaft water inflow, ore processing demands, tailings water, and surface and stormwater management. Water demands from a mine during operations can be significant to the point that a mine can be a net water user. However, in many scenarios including reclamation and closure, mines generally have excess water that must be evaluated for treatment needs prior to discharge.
- Permits and other regulatory approvals addressing emissions and discharges or mandating specific practices and other environmental obligations often govern the mine throughout its life cycle.
- Financial assurance instruments supporting closure, reclamation, and other needs are requirements in parts of the United States and in developed countries such as Canada and Australia.
- When operations are discontinued, mine closure and reclamation proceed, with site restoration being a prime objective. Buildings and structures are often removed and land disturbances regraded and vegetated. However, permanent structures often left in place include tailings facilities, excavations/

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pits/underground workings, and in some instances, waste rock, overburden, and/or ore stockpiles.
- Air emissions during operation generally include particulate matter, combustion products, and other pollutants. When operations are discontinued and reclamation complete, mine closure generally reduces air emissions to miscellaneous sources of particulate matter from wind erosion.
- Water discharges potentially with COCs may continue from the permanent structures left at the site. Long-term management and care of the facility will generally include engineering controls and environmental monitoring with particular focus on water discharge, seepage, and contaminant fate and transport.

MINING—THE CURRENT REGULATORY REGIME

In many countries, industrial activities including mining are reviewed and/or permitted by an environmental ministry or similar entity. In general, an environmental impact assessment (EIA) is a first step in reviewing the acceptability of a proposed project. As described by the International Association for Impact Assessment, (IAIA), an EIA can be defined as

> ...the process of identifying, predicting, evaluating and mitigating the biophysical, social, and other relevant effects of development proposals prior to major decisions being taken and commitments made. (IAIA 1999)

In the United States, mining project review and permitting are overseen by a complex regulatory regime administered by a cadre of agencies that can be different from project to project. Although some of the terminology may be different, the concepts of the EIA can be seen in the U.S. environmental review process and, if one is developed, the EIS. The EIS focuses on the description of the environmental and social effects of a proposed project for decision making and stakeholder participation. State and federal agencies may participate and/or lead an environmental review and the development of an EIS. The U.S. Environmental Protection Agency (USEPA) reviews all EISs, regardless of who the lead and participating agencies are. The oversight is anchored in the National Environmental Policy Act (NEPA) of 1969 (42 USC § 4321 et seq.). NEPA established the national policy and statutory framework aimed at promoting the enhancement of the environment.

National Environmental Policy Act

In most countries, major legislation or governing acts are passed at a high level and codified by administrating agencies or ministries. In the United States, NEPA is the governing act that requires proposed projects of significant magnitude to develop an EIS through an established NEPA environmental review process. NEPA requires

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federal agencies that are responsible for deciding to approve significant actions (projects) to undertake an assessment of the environmental effects of the proposed actions prior to making decisions. Two major purposes of the environmental review process are better informed decisions and citizen involvement.

New mines and major modifications or expansions of operating mines generally require an environmental review. Although some mines are small enough not to trigger an environmental review, most mines are significant enough to do so and are the focus of this chapter. To document and substantiate decision making, the EIS must include a plausible description of the potential impacts that a project may incur. Mines can be large in scale, and historically speaking, some have incurred significant environmental impacts on the surrounding environment and communities. To prevent detrimental environmental effects, adequate monitoring and engineering controls should also be described in the EIS.

The federal NEPA process is outlined in the Code of Federal Regulations, 40 CFR Parts 1500 through 1508. The NEPA process encompasses several goals and responsibilities, including the need to describe environmental effects of a proposed project (and alternatives); the impacts on social, cultural, economic, and natural resources; and provision of numerous opportunities for stakeholders to engage and voice their opinions. The term *stakeholders* is a broad term defined in Merriam-Webster as "one who is involved in or affected by a course of action" (Merriam-Webster 2014). Stakeholders can encompass many groups and individuals, hence a messy and raucous process may unfold for a proposed mine seeking a final (approved) EIS and associated permits.

Describing Environmental Impacts

The terms *impacts* and *effects* are often used interchangeably. Environmental impacts are categorized as direct, indirect, and cumulative. In 40 CFR Part 1508, these terms are defined as follows:

> "Cumulative impact" is the impact on the environment which results from the incremental impact of the action when added to other past, present, and reasonably foreseeable future actions regardless of what agency (federal or non-federal) or person undertakes such other actions. Cumulative impacts can result from individually minor but collectively significant actions taking place over a period of time.
>
> "Effects" include:
>
> (a) Direct effects, which are caused by the action and occur at the same time and place.
>
> (b) Indirect effects, which are caused by the action and are later in time or farther removed in distance, but are still reasonably

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Table 25.1 Categories and examples of impacts at mining facilities

Direct Impacts	Indirect Impacts	Cumulative Impacts
Land disturbance from facility construction and operation	Light and noise impacts	Permanent structures
Loss of wetlands within the facility footprint	Fragmentation of wetlands and habitat	
Loss of habitat		
Presence of a facility	Impacts from adjacent current and planned facilities	
Water use, rerouting natural water flows	Local and regional hydrological impacts	
Water discharge, quantity, quality		
Water inflow into an excavation		
Effects on threatened and endangered species and associated habitat		
Waste material stockpiles	Weathering of materials, emissions, drainage	
Air emissions	Regional haze, acid rain, deposition effects	

> foreseeable. Indirect effects may include growth inducing effects and other effects related to induced changes in the pattern of land use, population density or growth rate, and related effects on air and water and other natural systems, including ecosystems. Effects and impacts as used in these regulations are synonymous. Effects includes ecological (such as the effects on natural resources and on the components, structures, and functioning of affected ecosystems), aesthetic, historic, cultural, economic, social, or health, whether direct, indirect, or cumulative. Effects may also include those resulting from actions which may have both beneficial and detrimental effects, even if on balance the agency believes that the effect will be beneficial.

Although the categories assist in understanding the intent of impact definition, in reality, the categories can become muddled and somewhat irrelevant. Table 25.1 presents examples of common environmental impacts at mining facilities. Depending on time frame and perspective, many impacts cross categories. For example, any structure or material left in place permanently will generally be a direct impact, an indirect impact, and eventually cause one or more cumulative impacts.

Describing environmental impacts to a reasonable degree is one of the challenges of environmental review: first to the satisfaction of the approving agency, and second to withstand any follow-up opposition. Litigation against the adequacy

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of EISs has been increasing (Smith 2005), and one of the more common objections opponents use has been that the cumulative impact analysis is not adequate (Smith 2005; Burris and Canter 1997).

UNCERTAINTY IN MINING PROJECTS

Uncertainty plays a key role in all decision making. Uncertainty can be described as a state of having limited knowledge wherein it is not possible to exactly describe or forecast an existing state or future outcome. Uncertainty is often a function of space and time, and can exhibit varying magnitudes as a result of such scales. Accordingly, uncertainty can decline or transition toward certainty with activity such as data collection and time.

Uncertainty in the planning, permitting, and operation of mining projects encompasses a wide range of forms. Common examples include

- An unknown distribution of hydraulic conductivity within a host rock surrounding a mine;
- Unknown temporal distributions of precipitation and evaporation during mine operation and in the decades following mine closure;
- The inability to know future land-use developments in a project vicinity that might mitigate or acerbate environmental impacts from a project currently in the planning stage; and
- The inability to know if or when a natural catastrophe (such as an earthquake or flood) might occur and what its magnitude might be.

This list captures only a fraction of the types of uncertainty faced by project planners involved in mine development. Uncertainty can also arise from physical features ranging from those that are fixed throughout time but vary in space (hydraulic conductivity), to those that are fixed in space but vary in time (an earthquake along a known fault), to those that vary in time and space (precipitation and evaporation).

Uncertainty is generally addressed through one of two major types of analysis. Unfavorable outcomes arising from uncertainty can be addressed through *deterministic analysis* (an analysis that produces a determined result for given assumptions) coupled with conservative or safety factor inputs. Conservatism or safety factor analysis essentially addresses uncertainty in parameters and variables by selecting those inputs that embody the worst possible conditions and ensuring a design is developed that is robust enough (overdesigned enough) to allow regulatory and project objectives to be met. An example would be designing a tailings dam using worse than record-indicated rainfall inputs and equipping the dam with twice the freeboard than an average-conditions analysis would warrant.

Alternatively, uncertainty can be addressed by *stochastic* or *probabilistic analysis* that seeks to statistically quantify the variability or uncertainty of the process,

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parameter, or variable of interest. This is often done through extensive data collection followed by the development of probability distributions for each of the uncertain processes, variables, parameters, and so on. Such probability distributions can then be incorporated into elaborate computer models that link related processes and their probability distributions to create a population of predicted outcomes. Each individual predicted outcome is referred to as a *realization*. Subsequent analysis of the group(s) of realizations allows analysts to evaluate the probability of all outcomes. This type of probabilistic analysis warrants several clarifying remarks:

- It is not always warranted for every project or every element of any one project.
- It is complicated and expensive.
- It offers the potential for a much better understanding of potential project impacts and appropriate engineering solutions.
- It offers the potential for greater confidence and comfort in decision making among regulators and project engineers.
- It serves as an ongoing project management tool when regularly updated with ongoing data collection and observations.
- Many stakeholders find these methods difficult to understand if they are unfamiliar with probability concepts or engineering principles.

Regardless of the choice of deterministic/conservative analysis or probabilistic analysis as the tool for addressing spatial and temporal uncertainty, no project can be designed, constructed, and operated with certainty in all regards. Understanding this reality leads to the acknowledgment that projects should be developed in a manner that allows adaptation to change or unexpected outcomes and the need for an adaptive planning and management tool.

PROPOSED MINES, MODIFIED MINES, AND ENVIRONMENTAL REVIEW DECISION MAKING

Having established some generalities about environmental issues at mining facilities, the foundation regulatory regime, and the concepts of uncertainty in describing environmental impacts, this section focuses on how the various responsibilities, activities, and issues interact on a timeline. This section also describes the challenge of managing uncertainty in impact analyses and environmental reviews, and introduces the concept of AEMPs as a method to manage uncertainty.

A view of mine life cycle and associated activities are shown in Table 25.2. In this table, column headings loosely follow stages in a mine life cycle. Participants, roles, and activities are categorized in the "Project Proposal, Environmental Review" column of the table. The regulatory approval "Decision" column (shaded column on the left side of the table) is a crucial milestone and the focus of an environmental review and EIS. The significance of this decision is paramount from several perspectives:

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- For a newly proposed mine, the decision represents allowing events that can have permanent consequences. Mine structures are shown mid-table and, as can be seen, structures such as the excavation, stockpiles, and tailings storage facility are essentially permanent, necessitating long-term monitoring and engineering controls, and potential water treatment.
- Uncertainties are identified (shaded row toward the bottom of Table 25.2), however, at the time of a decision. A larger proportion of uncertainties are theoretical and based on predictive modeling or baseline data given that no facility exists. As the timeline unfolds, if a mine is allowed to proceed, uncertainties and risks still exist. However, as operational data and impacts become real and more measureable, the character of uncertainty becomes more known. Thus, the crucial decision to approve a project must be made when knowledge of uncertainties is based more on predictions, comparable sites, or baseline data and less on known and measured quantities of an operating facility.
- Pressure and concerns from stakeholder groups are often at a high level prior to an initial decision. Contributing factors include anxiety about uncertainties as well as the inherent leverage and the attention the project has. Stakeholder opposition to a project before it is approved has more leverage than when a later attempt to reverse a decision or halt an approved project under construction is made. The change in state that the initial environmental review decision represents (from current conditions to the presence of an operating mine) has substantial implications on the affected human communities (social, economic, recreation, etc.) and their continuing access to local natural resources.
- A decision to allow a project to move forward must be substantiated to withstand continued scrutiny and potential litigation. Litigation adds uncertainty, expense, and acrimony for all parties and stakeholders. A clear and substantiated decision provides a reduction in project and economic uncertainties, which benefits project stakeholders including project proponents, regulatory agencies, and the affected community.
- The AEMP is highlighted in the mid-section of Table 25.2 and is shown from project development through post-reclamation, if needed. It is shown as a project-related activity, primarily prepared and implemented by the project proponent and mine owner/operator although arrows indicate input from agencies. The AEMP initially considers the work done in support of the environmental review, including baseline studies, impact identification, predictive modeling, and engineering control design (arrows). After the facility begins construction, real impacts are initiated. As shown, the AEMP becomes informed by real circumstances, and revisions should take those under consideration. Similarly, uncertainties also begin incorporating real

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components to their character. After the EIS decision, the AEMP continues to receive input by the agencies involved in permitting. Further discussion and examples of this mechanism are presented in the case studies that follow. This mechanism for regulatory guidance and direction is key to the effectiveness of the AEMP.

ROLE OF THE AEMP IN ENVIRONMENTAL REVIEW DECISIONS AND BEYOND

AEMPs are not solely "owned" by the mine owner/operator, although the owner/operator does have primary responsibility to prepare, maintain, and implement the plans. This section describes in greater detail how the AEMPs can be a valuable tool to the regulatory agencies tasked with approving and overseeing the project. Taking a prominent role in the AEMP enhances an agency's ability to manage its own uncertainties and decisions. The agencies have the ability to influence and actually direct the contents and focus of an AEMP, linking it to financial assurance requirements and thereby protecting the interests of those whom the agencies represent. This can begin in the environmental review stage, benefitting crucial project approval decision making. When the project moves forward, the influence and direction of the approving authorities can transition to the permitting staff and be informed by inspections, reporting, and compliance monitoring.

The mechanism for the agencies to initially direct the AEMP is the EIS, then the permits. Financial assurance requirements, if applicable, interact with both, as shown on Table 25.2. Initially, the project proponent can engage with the responsible agencies through an AEMP (and many other avenues), working toward a positive decision to allow the project to move forward. A transition of staff or agency may occur as the project commences. For example, in the United States, agencies that routinely lead EIS preparation on mining projects include the Bureau of Land Management, U.S. Army Corps of Engineers, U.S. Forest Service, and USEPA. These agencies may team with state or other federal agencies on a particular project. Once the project proceeds, permits are pursued much like other projects prior to construction. The major permits that may be needed for a mine are:

- Mining permit,
- Water use or appropriations permit(s),
- Water discharge permit(s) (may address discharge to surface waters including stormwater and/or groundwater),
- Dam safety permit,
- Wetlands permit(s),
- Air permit(s),
- Waste disposal permit(s),
- Threatened and endangered species taking permit(s), and
- Hazardous waste permit(s).

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Table 25.2 Overview of the mine life cycle, project and U.S. regulatory activities, and the AEMP

	Project Proposal, Environmental Review	Comment Period	Decision	Permits	Project Commencement
Project-Related Activity	Develop environmental baseline studies.				Design and construct facility.
					Real impacts begin.
	Identify potential impacts: • Direct • Indirect • Cumulative			Submit permit applications	Direct impacts: • Wetland displacement, land disturbance • Water drawdown, displacement, withdrawal/use
	Evaluate potential impacts: • Analysis • Predictive modeling			Obtain permits	Indirect impacts: • Habitat, infrastructure • Economic changes
	Design: minimize/mitigate impacts, risk.				Initiation of water discharge, active treatment, and best management practices
	Facility, operations, engineering controls				**Mine Structures** • Mine excavation waste rock and overburden stockpiles, tailings storage facility • Processing and material handling structures and equipment • Roadways, buildings, product handling, and loadout • Air pollution control equipment • Water treatment systems, engineered controls
	Facility and operations design/planning				
					Potential Litigation
					Prepare environmental management system (EMS)
INTERACTION	Prepare initial adaptive environmental management plan(s).				Revise adaptive environmental management plans: Update impact analysis and predictive modeling, manage and monitor potential impacts, revise engineering controls as needed. Employ new strategies and technologies. Respond to new requirements.
Stakeholder Activity	**Stakeholder Input**				
Agency Activities	Responsible regulatory agency(ies)		Record of decision, financial assurance requirements	Various agency permitting departments	Construction: Issue permits to construct. Transition into operations permits.
Regulatory Mechanism	Environmental review/environmental impact statement (EIS) preparation and process	Public comment		Permits; implement financial assurance requirements	Permit administration and compliance; regular updates and revisions to financial assurance.
Financial Assurance	Required by some provinces/states. Prepare reclamation plan and financial assurance estimate, and negotiate instruments.				Establish financial assurance accounts.
Uncertainty	Uncertainties and risks—more theoretical/unknown and fewer real/known				Uncertainties and risks—more real/known and fewer theoretical/unknown
Timeline	1–10+ years	~1–5+ years	1 year	0–2 years	1–10 years

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	Operations			Closure and Reclamation	Post-Reclamation
	Facility Modification				
Project-Related Activity	Impacts become real, may or may not match predictions. Ground disturbance, water drawdown. Permitted discharges to environment: water discharge, air emissions, waste generated. Permit compliance: prepare annual reports, update plans, apply for permit renewals. Modifications/expansions. More likely for facilities with longer operations. Discharges/emissions/waste may change from original quantity and quality.			As operations cease, reduction in operational discharges and/or emissions. Decomissioning, reclamation activities.	Long-term care, monitoring, and maintenance of closed facility.
	Water Discharge Operational water: actively treated prior to discharge →			Reduction and transition in water discharge and treatment needs	Water discharge from permanent structures continues. Treatment needs reduced; transition to passive treatment.
	Mine Structures • Mine excavation, waste rock and overburden stockpiles, tailings storage facility → • Processing and material handling structures and equipment → • Roadways, buildings, product handling, and loadout → • Air pollution control equipment → • Water treatment systems, engineered controls →				
	Potential Litigation				
	Maintain EMS				
	Revise adaptive environmental management plans: Update impact analysis and predictive modeling, manage and monitor potential impacts, revise engineering controls as needed. Employ new strategies and technologies. Respond to new requirements.				
Stakeholder Activity	**Stakeholder Input**				
Agency Activities	Operations: permit compliance and administration	May need an EIS from state or federal agencies	**Decision**	Operations continue Closure reclamation	Post-reclamation
Regulatory Mechanism	Permit administration: compliance, permit renewals, annual reporting, adaptive management plan updates, reclamation plan updates, response to new requirements	Prepare and finalize supplemental EIS and permit modifications		Permit administration continues	
Financial Assurance	Revise and update financial assurance estimates and accounts, informed by facility status, AEMP, and regulatory requirements and discretion.				
Uncertainty	Uncertainties and risks—more real/known and fewer theoretical/unknown				
Timeline	5–100+ years	1–5 years	5–100+ years	1–10 years	Future →

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Permits are issued from an array of federal, state, and local agencies (provincial, county, and municipal). Most of the United States has multiple state-level agencies involved in issuing permits for mining facilities. For example, a department of natural resources (DNR) can house a land management or mine and minerals management department responsible for administering mining permits. The DNR can also contain a department of environmental quality or pollution control that administers air and water permits. A health department may be involved as well. Permitting is typically administered by a department dedicated by media (air, water, solid waste, land use, etc.). Certain overall requirements of the facility, such as financial assurance (described in the next section), are administered in one of the permits, if applicable. As with any large organization, communications and coordination among departments (or agencies) can be challenging at times. Benefits of the AEMP, if well-designed, include its ability to serve as one repository document for multiple agencies and departments and to transition in a fairly continuous manner across changeovers in authorities and agency directors, maintaining the body of knowledge and previous planning through its revisions.

FINANCIAL ASSURANCE

Financial assurance is prominent in two arenas of environmental regulation regarding industrial facilities: mining and solid waste disposal (landfills). The connecting factor is the permanency of the waste disposal facility—tailings in the case of mining and solid or hazardous wastes for landfills. Both types of facilities are heavily regulated, have long-term liabilities and costs, and historically some have failed in meeting long-term responsibilities.

Financial assurance rules may or may not be clear or dictated in applicable regulations for mines. Agencies may have discretionary authority to impose financial assurance requirements, and in reality, each mine is unique in how financial assurance may be applied. In the United States, there are no requirements in NEPA and associated regulations that mandate financial assurance on mining projects. The USEPA encourages the incorporation of financial assurance requirements into EISs; however, the responsible federal agencies are not mandated to do so. Financial assurance requirements are administered for many facilities by the states or provinces. At this level, these agencies and governments have an upper hand in financial assurance negotiations because they set up and enforce the requirements of financial assurance obligations and applicability. The use and relevance of financial assurance is compelling. The permit obligations are leveraged not only by agency enforcement authority, violation potentials, and penalties, but also by additional financial resources originating from the permittee and under control of the agency. Since those resources are under agency control, they can be used to prevent or mitigate environmental impacts originating from the mine fairly quickly, avoiding delaying action if responsibility is unclear. This is particularly important to the regulatory

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agency, because it will likely not have the staff to perform tasks on-site nor will have access to state funds to pursue environmental cleanup without legislation enabling such funding. That funding would originate from state taxpayers or via fees or funding from regulated communities and would need to be specified for the required uses.

The leverage financial assurance provides lies in the potential interaction of strong financial assurance requirements with an AEMP. The regulatory agency has the ability to influence, contribute to, or at times direct the AEMP to serve its (and other stakeholders') agenda(s). Although that may appear counterintuitive to the interests of the mine owner/operator because it could increase upfront requirements, the case to approve a project is strengthened, which is consistent with the interest of the project proponent.

Financial assurance is negotiated between the responsible agency and the mine owner/operator within the framework and requirements of the agency rules and expectations. There are a variety of instruments and methods for setting financial assurance funds aside, some of which may require a large amount of up-front funding, while others may be funded with regular deposits or premiums. The amount varies depending on what is covered, the life cycle of the mine, the length of obligation, and the expectations of the agency.

Financial Assurance Basis

Depending on regulatory requirements, the intent of financial assurance is to ensure that the agency has the financial resources to complete closure of a mine and to pay for the associated reclamation costs and any long-term monitoring in the event that the mine owner/operator is unable to do so. Corrective actions such as spill cleanup and remediation may be needed and may include known issues and some contingency for unknowns and potential future needs. Cost may vary widely depending on extent of any contamination, cleanup approach, and the necessary scope of investigation and action. Financial assurance will include administration costs, the cost to hire a third party to implement the reclamation and post-reclamation activities, remediation of any contamination of the surrounding environment, and contingency costs. The cost estimate is dependent on the mine conditions and operations, where the mine is in its life cycle, environmental requirements, and many other variables. The agency and the project proponent will be highly interested in an accurate accounting of these costs, the duration, and a methodology of revision. The environmental impact of the mine and the predictive knowledge of impacts will be very influential on these costs. These impacts, which should be described in the AEMP, should inform the financial assurance estimate and, as the AEMP is revised over the life of the mine, will inform the revision of the financial assurance basis.

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Mine reclamation varies as the mine operations expand the mine footprint. Reclamation begins during mine operations and continues after operations cease and at a certain point is accomplished. Reclamation includes

- Regrading and revegetating disturbed land and material piles to reduce erosion and dust, and route stormwater;
- Removing buildings, equipment, and structures; and
- Generally restoring the land to a pre-mining or agreed-upon state for a new use.

Long-term monitoring is a future cost that will reflect potential impact issues noted in the AEMP. General monitoring of groundwater and surface water, biota, and other environmental media will be part of long-term monitoring. Long-term monitoring should clearly reflect identified environmental impacts. For example, if water leachate from tailings management facilities has COCs being removed by a treatment system, groundwater and surface water will be tested for fate and transport of that contaminant for long time periods. Monitoring will also be in place to document the effectiveness and performance of engineering controls. Regular sampling, lab analysis, and documentation contribute to costs of long-term monitoring. Long-term maintenance and replacement costs of engineering controls, water treatment systems, liners, reclaimed areas, and any permanent structures will be included in the plan and cost estimate.

Criteria for Release or Reduction in Financial Assurance

Financial assurance follows the mine life and, therefore, is a mechanism of responsibility and obligation that has a longer life than the mine operation. The mine owner/operator will be very interested in having its funds restored as completely and early as possible and being released from permit obligations. The agency will be very interested in having the site and environment restored to the highest extent possible and ensuring that no present and future issues have been overlooked. Releasing the permittee from financial assurance is at the discretion of the agency, in accordance with the requirements outlined by the agency. The agency can determine whether reclamation activities have been completed and to what specification. Any corrective actions, including remediation, will have been resolved, and remaining structures left in a stable and durable condition. Long-term monitoring and maintenance should factor into the considerations.

The AEMP can be influential in estimating costs, time frames, and issues to be resolved in the mine owner/operator's plan to apply for release from financial assurance obligations. The mine owner/operator has incentive to reduce the amount of the financial assurance by demonstrating that the environmental impacts of the facility are demonstrably benign. The identification and outcome of any environmental issues being investigated or monitored, having been documented in the

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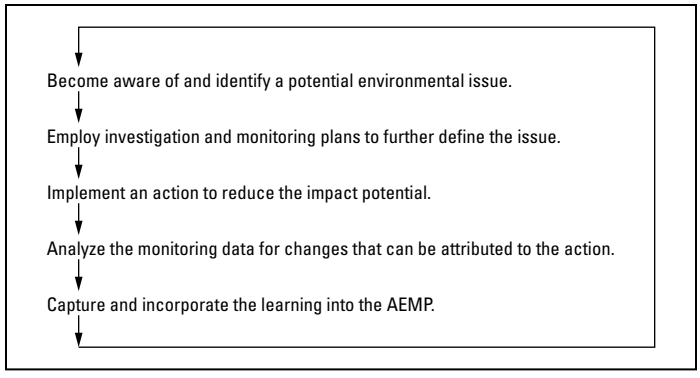


Figure 25.2 Adaptive management cycle

AEMP on an ongoing basis, can be reviewed by the agency in its evaluation of the site condition and in its decision of whether to release or reduce obligations. If the agency has provided prudent guidance to the AEMP, the document can provide them with an authoritative evaluation of allowable final site conditions.

ADAPTIVE MANAGEMENT AND THE AEMP

The origin of adaptive management is attributed to Frederick Taylor in the early 1900s (Haber 1964). Adaptive management is an iterative process for decision making in systems with significant uncertainty. That uncertainty can be reduced over time through a cycle of planning, action, implementation, monitoring, and learning. Adaptive management is a tool that can be applied to not only change a system, but learn about the system (Holling 1978). Essentially, environmental application of adaptive management is most developed in managing ecosystems such as forest conservation (Williams et al. 2007). As can be gleaned from the background discussion, however, adaptive management as applied to mines through an AEMP is clearly useful in documenting and managing potential environmental impacts from mining. Adaptive management is practiced in the mining industry, however, in a less formal or recognized manner than that seen in the ecosystem management practice.

At the foundation of adaptive management is an active investigatory or learning component that capitalizes on the results as inputs to the next adaptation. Iterative decision making is in part based on the investigatory results. The AEMP sets up the feedback between monitoring (those actions that are put in place to evaluate the effect of a preventive or mitigative action) and the learning and decision-making steps. Figure 25.2 shows an illustration of this concept.

Adaptive management as implemented through an AEMP will be unique to each mine. The AEMP should not only contain the facts, data, recommendations, learning, and so on supporting the goals of the plan, it should be structured in a

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Table 25.3 Example components and references of an AEMP for a mine

Component	Comment
Title	This should be suited to the facility, but recognizable to others.
Introductory Sections	
Table of Contents	This should employ clear terms and section headings, and enable the addition of more sections and materials over time.
Description of Revisions and Additions	This is a summary or listing of revisions and additions as well as version control as warranted.
Acronyms, Definitions, Glossary	Acronyms are commonly used throughout industry, and they tend to develop within organizations as well. Clarity is enhanced with a written listing and description. This assists not only new mine employees, but helps avoid broader misunderstandings among users. Definitions and a glossary of appropriate terms are very helpful to multi-disciplinary teams, multiple organizations, and for individuals not well-versed in a particular subject.
Introduction/Goals and Scope of the AEMP	A concise introduction, goals, and scope of the plan are very helpful to clarify the document purpose and extent for all reviewers and users of the document, especially over the long term.
Body of AEMP	
Environmental Issues to Manage Strategies to Manage Environmental Issues Reports Addressing Each AEMP Cycle	This section is comprised with the unique issues of the facility and presented in a manner that suits the mine and regulatory agency(ies).

Table continues next page

manner that can be easily revised, appended, and updated. As a living document spanning over years, decades, and potentially longer, managing its structure and flexibility will enhance its usefulness. Example components and reference documents of an AEMP are listed and described in Table 25.3 to assist in visualizing how a plan may be structured (recognizing, however, that other approaches may be better suited for a particular facility). Table 25.3 focuses the document body on environmental issues that may be undergoing an adaptive management process. Supporting materials and documents are listed under References and may be maintained separately. Flexibility of an AEMP to easily incorporate additional components and references over time will be helpful, especially if accommodations are made early in the document's development.

A strategy used in the United States that is closely related to adaptive management is the use of an environmental management system (EMS). Introduced through Executive Order 13423, the policy targets federal agencies and the facilities

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Table 25.3 Example components and references of an AEMP for a mine (continued)

Component	Comment
References	
Description of the Facility	This should include a description of major and minor structures and may encompass design information.
Comprehensive Design and Drawings of the Facility	This should include documentation on designed, engineered, and constructed parts of the mine. Construction, as-built, and other drawings and figures documenting the physical parts of the plant are very useful.
Equipment Description and Information	This should list purchased or fabricated equipment descriptions and references.
Materials On-site	This might include material safety data sheets, manufacturer's information, lab analyses, and purchasing records.
Description of the Environmental Setting	This can address major subjects such as geology, hydrology, air, and watersheds. It may be part of the original environmental review or permit application documentation.
Mine Reclamation Plan	This should be maintained and updated separately.
Financial Assurance Estimates and Documentation	This should be maintained and updated separately.
Monitoring Plans	This should be maintained and updated separately.
Other	
Appendices	
Data from Sampling, Lab Analyses, etc.	
Previous Versions of the AEMP	
Other	

they manage to "strengthen the environmental, energy, and transportation management...". As described in *A Citizen's Guide to the NEPA* (CEQ 2007), an EMS is a systematic approach to identifying and managing an organization's environmental obligations and issues that can complement many aspects of the NEPA review process. EMSs are used by agencies and other organizations to set up procedures that assist them in complying with requirements such as those in air and water permits. The guide states that

> EMSs can be particularly useful in NEPA in the context of post-decision monitoring and mitigation. Using the procedures provided by an EMS, agencies can better ensure [there is] proper implementation of mitigation measures and provide a mechanism for monitoring the actual effects of the mitigation.

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The goals and themes of EMSs and AEMPs are similar and overlapping, but the AEMP recognizes certain issues more explicitly than an EMS. The EMS and AEMP are shown separately in Table 25.2, although the facility may manage the goals of the two plans together. Even though permit compliance is inherent in AEMPs, the focus is on managing uncertainties, and identifying and addressing potential future environmental impacts. EMSs are focused on achieving and maintaining permit compliance with a lesser degree of proactivity than the AEMPs. The recognition and actual embrace of uncertainty is more present in AEMPs than in EMSs.

The AEMP is prepared and implemented by the mine owner/operator, but can be under the influence of, and at times direction of, the governing regulatory agency. Case studies highlighting issues that benefit from adaptive management are used in the final illustration of AEMPs in this chapter.

CASE STUDIES

This section provides two examples portraying mining applications of adaptive management. The two case studies have been prepared by reviewing publically available documents, mostly EISs and permits of mining projects available on the USEPA Website (www.epa.gov) and a variety of state agency Websites. Although the information is in the public domain, the selection of a particular mine as a case study might be interpreted as a negative implication or as a highlight of an environmental issue of concern. As such, the case studies are based on current mining operations in the United States; however, descriptions are generic, and specific locations and details have been removed.

Case Study 1

Mine Description, Regulatory Background, and Financial Assurance

This case study addresses two neighboring mines (Mine A and Mine B) with the same ferrous ore mineralogy. With their close proximity and similarities, considering the two mines together makes their differences and AEMPs particularly interesting.

Mine A pursued an EIS and was approved to reactivate a closed mine and mill. The updated facility included a mill with a blast furnace and pelletizing operations, thus modifying and renewing previous operations. The site already had a large pit, tailings basin, and considerable amounts of stockpiled waste rock from previous operations at the site. The more current project was proposed within the last 10 years and was successfully approved with a final EIS. After design and construction of the approved facility commenced, the owner/operator decided to increase the facility capacity and shorten the mine life from 20 to 15 years to achieve the same ore excavation. This required a supplemental EIS (SEIS), which was recently

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finalized. In the EIS and SEIS, financial assurance was initiated for the newly proposed operations. The project is close to completion and commencement of operations.

Neighboring Mine B has been in continuous operation for at least 50 years. Pelletizing has been performed through several methods over the years as upgrades were completed. Original mining operations began prior to NEPA and a significant state regulatory structure. The facility obtained a mining permit during the 1980s; however, no financial assurance was required at that time. The mine has had air and water-discharge permits in place for decades. Current financial assurance arrangements are not known. An expansion was proposed in Mine B that required an EIS, which was approved. The planning horizon is 25 years for additional operations. Should the mine be viable beyond that, another EIS would have to be pursued to continue operations.

Both mines have large tailings basins that were constructed with the original operations. Tailings in slurry form are pumped (Mine B) or planned to be pumped (Mine A) to their respective tailings basins. Tailings basin discharges at both facilities have higher than desired levels of a certain COC. Mine B (currently operating) has an outfall to surface water and a seepage to groundwater around and under the large area of the basin. Mine A (under construction) currently has only seepage to groundwater (no surface water discharge), and this will continue through operations because the water demand will exceed water supply, and excess water from the tailings basin will be routed to the mill. The new tailings basin can be constructed with a layer of impermeable material that can reduce leakage through the bottom. However, the tailings present will continue to contribute to the COC load in seepage.

Environmental Setting and Issues

Mines A and B both reside in the northern United States where the climate has heavy winter snow and temperate summers. The surrounding area has many lakes, streams, and wetlands, and is heavily forested. The geochemistry of excavated material is not particularly acid-producing; however, weathering produces heavy metals and anion leachate from stockpiled materials and exposed excavation walls. The area has been heavily mined for more than a century, and the land disturbance is widespread. This heavy mining activity likely contributes to background exceedances in some water quality parameters.

The lakes and rivers around the mines are enjoyed recreationally and highly valued by the surrounding communities and the state in general. Water quality standards for several parameters are very stringent. Several COCs are present in mine waters that are particularly challenging and expensive to reduce in discharge streams (e.g., mercury). Mechanical wastewater treatment achieves satisfactory effluent quality; nevertheless, capturing seepage from a tailings basin requires an

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engineered design to collect water for treatment and maintain the desired hydraulic gradients. Seepage from the perimeter can be collected effectively; however, seepage from areas toward the center of the basin is very difficult to collect and typically has a direct pathway to groundwater rather than to the tailings basin perimeter. One COC has been identified in tailings basin discharges as affecting a certain plant species that is highly valued by local tribal groups as a historic food source. Recently, the water quality standard of that COC has been reduced to one of the most stringent levels in the nation. This COC can be removed from the water discharge with a mature wastewater treatment technology, but it is expensive, especially when large quantities of water are involved.

Description of Impacts and Uncertainties Managed by an AEMP

Mine A, still under construction, has impacts that have just started transitioning to real impacts. Although permits have been issued, routine compliance, learning of operations, and real facility impacts have just begun.

Mine B has been operating under its water and air permits for decades. The state has lowered the water quality standard for the identified COC to a more stringent concentration over several years. The facility and regulatory agency recognized an environmental compliance issue in that this COC was ubiquitous throughout the operations. Therefore, achieving the water quality standard at an end of pipe was going to be challenging and would likely take a lengthy effort to attain. The regulatory agency developed a compliance schedule that was incorporated into the water-discharge permit, clearly connecting the responsibilities and leveraging mechanisms into the enforcement and long-term financial assurance implications available through that venue. A facility-wide investigation, incorporating water management and COC reduction studies, was initiated to evaluate alternatives, economics, and predicted effectiveness.

One opportunity was pursued successfully: air pollution control equipment in the mill was using a water stream as the media to reduce air pollutants from stack exhaust. Transferring the pollutant to the water stream, however, added to the wastewater load for the identified COC. Through investigation and results, and planning and implementation, the equipment was changed out to a different technology that does not rely on water. Additional monitoring after the new equipment was in place showed that the identified COC was reduced in the tailings basin surface water discharge, and the reduction was attributed to changing out the equipment.

This cycle of investigating, evaluating, implementing, and monitoring is the process called *adaptive management*, integrating facility decision making and the water- and air-permitting regulatory agency departments. Should lab analysis have shown that the COC in the surface water discharge was not satisfactorily lowered, iterating through the adaptive management cycle would have been pursued one or

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more times, all being documented in the AEMP. Documentation of these steps in the AEMP is important, showing trial and error as well as the efforts put forth in pursuing a correction. This information can be used in discussions with the regulatory agencies to show progress in addressing environmental compliance issues. In the case of Mine B, the reduction was satisfactory for surface water standards; however, the tailings basin leakage to groundwater continued to be considered.

Cumulative Impacts and Long-Term Care Issues

Seepage from the center of the tailings basin at Mine B transports the COC to the groundwater, although it does not exceed the groundwater standard in this case. Eventually the groundwater rises to the surface with its COC load and flows into a local lake. Both tailings basins of Mines A and B happen to contribute to the groundwater surfacing at that same lake. Because the surface water quality standard for this COC is so stringent, modeling predicts the lake will be above the water quality standard for this COC. The lake receives additional COC loads from other contributing sources outside of the facility boundaries for Mines A and B.

The environmental compliance issue with this COC has time and spatial components, indicating cumulative impacts should be considered. The uncertainty of when and to what degree the COC will be reduced, coupled with the multi-facility contributions, makes this identified potential cumulative impact a long-term care issue for both mines.

Predictive modeling has been prepared by both facilities and incorporated into their respective AEMPs. Both have water-discharge permits issued by the same agency department; therefore, the knowledge and learning from both AEMPs can be understood by the regulators with minimal coordinating by the two mines. Uncertainties in outcomes and COC reduction efforts as seen in the lake monitoring is iterated and directed by the regulatory agency through the two AEMPs.

Depending on when one facility discontinues operations, its long-term care estimate may be affected by the condition of the lake and the continuing operations of the neighboring mine. One component to the long-term care for both mines is the water treatment systems needed in post-reclamation. The longer the mechanical wastewater treatment system is needed, the more expensive the operation and maintenance will be and the less likely that permitting conditions will be reduced or lifted for either mine. Under some circumstances (such as those in case study 2), long-term treatment of water associated with permanent structures can transition from active (mechanical) treatment to passive treatment design, such as wetlands or passive reactive barriers. Passive treatment requires much less attention and has greatly reduced operating and maintenance costs. Whether and when transitioning to passive treatment can be done affects financial assurance obligations. The long-standing guidance, study, and documentation developed in the AEMP will be a powerful tool in how the long-term care develops for either facility.

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Case Study 2

Mine Description, Regulatory Background, and Financial Assurance

The mine in this case study is a nonferrous precious metal mine with an open pit excavation. The land is owned by the state and an associated trust. Original operations began in 1994, and the facility underwent the EIS process when it proposed a heap leach facility be added to ore processing operations. Final permits were obtained on the modified facility in 2007. Closure, reclamation, and long-term care were presented in the mine permit application for the modified project. The state administers financial assurance in a structured manner, provides public access to the amounts and signatories on the documents, and updates the information annually. The amount of financial assurance on the mine is tens of millions of dollars.

The mine includes a mill that produces a slurry concentrate directed through leach tanks and a cyanide process. A tailings storage facility (TSF) is on-site. The TSF is an earthen structure of more than 1,000 acres designed to hold tailings and process water from the mill as well as surface water runoff. Seepage is minimized with a clay seal on the embankment, and low-permeability materials have been installed prior to tailings placement. A drain system allowing continuous and effective drainage is part of the configuration. A well system within the embankment foundation intercepts drainage. Drainage water is recycled to the mill and heap leach pad.

The heap leach project proposal was to install this new ore processing operation above and adjacent to the TSF, and once installed, the two structures would become an integrated structure. The heap leach pad is an engineered structure designed with multiple liners and a leachate collection and recovery system. The system extracts metals from ore placed on the pad by applying chemical solutions and collecting the resulting metal solution for further processing. The structure is large (hundreds of acres), open to precipitation, and uses several harsh and toxic chemicals.

Environmental Setting and Issues

The mine is in a far northern location with snowy winters and temperate summers; therefore, snowmelt, storm events, and snow loads influence structure design and operation. The site is in a remote mountainous region.

During operations, the water balance is such that the TSF will not discharge and the solution from the heap leach pad is completely collected. The drainage collection system servicing the TSF is monitored by groundwater wells downgradient of the TSF and surface water monitoring in the surrounding area. A well-designed monitoring system with regular monitoring and close evaluation of the results keeps the system's effectiveness under scrutiny. Results and analyses of system performance are documented in the facility AEMP.

The mine has been operating for almost 20 years. The installation of the heap leach pad and new process represents a change in condition and risk. Environmental

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concerns associated with the described structures center on potential spills and overflows, loss of integrity, or structural failure of the existing TSF or new heap leach embankments. Many malfunction scenarios could lead to highly damaging environmental impacts, especially during operations. No permit compliance issues have been identified.

Description of Impacts and Uncertainties Managed by an AEMP

Water containment and contaminant transport management are highly scrutinized. Proper installation, operation, and maintenance of the structures and engineering controls are essential to prevent malfunctions. Information on system performance during operations and the predicted condition of the site as the facility transitions through closure is the focus of the AEMP at this site.

Cumulative Impacts and Long-Term Care Issues

Modeling the TSF operation and its ultimate closure was performed to plan for long-term seepage rates, to optimize the water balance as operations are closed, and to predict the water quality changes at downgradient monitoring locations. Modeling and evaluation of operational data prior to closure informs the water treatment ultimately needed in closure and postclosure. This affects the reduction and/or release from financial assurance obligations and liability from environmental issues. The cumulative impact from the facility focuses on maintaining water quality in the area and minimizing effects from the TSF and heap leach pad operation and closure.

Closure of the TSF and heap leach pad is focused on water drainage and reducing the geochemical reaction potential to a steady and manageable state considering precipitation and weathering. The reclamation plan outlines installation of berms and spillways to enhance controlled drainage to achieve the desired steady state as soon as possible. Minimizing the process water in the TSF, continuing operation of the seepage collection system, and pumping the seepage to the flooding mine pit during the first 2 years after the mine closes are planned. The agency explicitly states the reclamation expectations in the current solid waste permit: current modeling indicates that when the pit lake fills to the point of discharge, the discharge will meet water quality standards. Should this not occur as anticipated, the mine owner shall propose a plan for water treatment or other corrective action.

The current reclamation plan and financial assurance are based on adequate water treatment being provided by a constructed wetlands system to route and treat seasonal surface water flows from the closed TSF and heap leach pad. The seepage management system will gradually be shut down but will remain intact in the event further operation is required to achieve water quality standards. The reliance on a passive water treatment system is very attractive. However, the presence and potential reinitiation of an active mechanical wastewater treatment system is present

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in the permit language and long-term care description. The AEMP includes monitoring the effectiveness of planned engineering controls and stipulates outcomes if conditions are not met. The responsibilities and consequences to the owner are expressed and directed by the regulatory agency through the AEMP.

CONCLUSIONS/SUMMARY

This chapter presents the background, regulatory foundation, and the concept of adaptive management as applied to mining facilities through the development and use of AEMPs. Should an AEMP be prepared for a mine, it should be set up consistently with the environmental issues at the mine, any regulatory agency's requirements, and the stakeholders' and the mine owner's preferences and needs. An example AEMP outline is provided to assist in visualizing an AEMP.

Over the life cycle of a mine, an AEMP can interact and support various compliance and financial assurance obligations through postclosure. An AEMP is useful throughout the life of a mine and can be initiated at any time. The background discussion provides an understanding of the concepts, and two case studies illustrate AEMP concepts in specific settings. The case study mines use adaptive management concepts to address potential and/or ongoing environmental impacts, with consideration of maintaining ongoing permit compliance as well as the long-term closure issues.

Benefits of an AEMP to the project proponent, mine owner/operator, regulatory agencies, EIS process, operations, closure, and reclamation are described throughout the chapter. Mine operations and environmental impacts have a variety of uncertainties that need to be managed by mine owners/operators and regulatory agencies. The AEMP is a useful mechanism that capitalizes on and documents the learning process and integrates that learning into other mechanisms to manage liability such as financial assurance. This assists in managing environmental impacts and protecting the public. Over time, the AEMP sustains the decision to move a project forward through an environmental review.

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PART VIII

CRISIS MANAGEMENT

Michelle E. Jarvie-Eggart

Safety is undeniably one of the most relevant and regulated social issues within mining. Safety programs are meant to prevent worker accidents, and whole texts have been dedicated to the topic of health and safety at mines. For more information, the reader is referred to the following texts: *Mine Health and Safety Management* by Michael Karmis, published by SME in 2001, and *Race Against Time: Building a Culture of Mine Safety* by Gregory M. Anderson and Stephen R. Rosene, published by Moody International in 2008.

Mines with excellent safety cultures must also be prepared in the event of a crisis, such as a cave-in at an underground mine or a fire, tornado, or other situation, which involves many workers or even the whole mine site. Mining facilities must be prepared to respond to these situations with a coordinated effort, often involving communication with emergency response personnel, government agencies, the press, families of those working at the mine site, and corporate offices. Emergency and crisis management planning helps facilities to prepare for the unpredictable. SME and Moody International provide specific guidance for members when it comes to emergency and crisis preparedness.

The International Council on Mining and Metals (ICCM) has a project area on emergency response. In 2005, the ICMM published "Good Practice in Emergency Preparedness and Response" to help companies collaborate with local authorities and communities to prepare for possible emergencies. The Mining Association of Canada's Towards Sustainable Mining Program includes a protocol on crisis management planning, separate from their protocol on safety and health. The protocol requires that member companies have a crisis management plan in place that has corporate and facility requirements. It also provides specific details as to

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what must be included in crisis plans. It requires that companies regularly review and update their crisis management plans, regularly test their plan notification systems, and conduct annual "table-top" crisis simulation exercises at the site and corporate levels.

The Mining Association of Canada also provides a *Crisis Management Planning Reference Guide* (2013), which includes a sample crisis management plan. This guide is meant to help facilities when developing, revising, or assessing plans. The guide explains when to initiate a crisis plan and includes information on site vulnerability assessments, crisis plan objectives development, crisis management teams, plan activation protocols, crisis communication, debriefing post-crisis, crisis management plan training, and review of crisis plans.

Chapter 26 examines the legal definition within the United States of a *disaster* versus an *accident*. It then presents the typical members and roles of a crisis management team, notification to regulators and the public, damage control measures, liability, the importance of having an emergency response plan, and emergency response drills. Together with the Mining Association of Canada's guidance on what should be included in a plan, these materials can help mine sites prepare themselves for handling crisis situations.

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CHAPTER 26

Mine Disaster Crisis Management from the Operational and Legal Perspectives

Marco M. Rajkovich Jr., Joseph J. Zaluski, Elaine Cullen, Mary B. Korpi, J. Steven Gardner, and Joshua Hoffman

INTRODUCTION

No discussion of managing social, environmental, and economic impacts of mining can be complete without addressing the worst nightmare that a mining professional can face—notification of a disaster at the operation. A mining disaster not only affects the particular mine, but the mushrooming consequences of a disaster can permeate throughout the entire community and beyond. The possibility that lives can be lost or changed forever necessarily demands that measures be taken to prevent such calamities from happening in the first place. Nevertheless, plans must also be made in advance to deal with a disaster when it strikes.

This chapter examines the issues, concerns, and ramifications of a "disaster" and then presents a systematic crisis management response. Obviously, the relationship established with the surrounding community *prior* to any disaster will certainly have a major impact on the outcome. Without question, no two disasters are alike, yet general guidelines for forming an effective plan of action can be formulated—and if a mining operation is to have any chance of survival *after* a disaster, such a plan *must* be formulated.

Two major focal areas of concern regarding disaster response are the actions that must be taken during the crisis and the actions that must be taken in *advance* of any possible crisis. These two focal areas are interdependent. What is done during a crisis is predetermined by a well-tailored plan formulated before disaster strikes. What is done in advance of a crisis is predetermined by actions that have proven effective and *ineffective* in dealing with disasters of the past.

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The first focal area addressed in this chapter, actions taken during a crisis, involves five aspects: the crisis management team; the protection of human life; notification; damage control; and liability. The second focal area, actions taken in advance of a possible crisis, involves two aspects: the emergency response plan and preventive maintenance.

DISASTER VERSUS ACCIDENT

Disasters and Legislation History

One definition of a *mine disaster* is any mine "accident" claiming five or more lives.[1] To effectively prepare for and then deal with a disaster, it is necessary to take note of the past. In bygone years, mine disasters were quite commonplace, tragically.[2] Up through 1875, there were 19 documented coal mine disasters and 4 metal and nonmetal mine disasters.[3] The year 1907 was a very dreadful year in mining history, with 18 coal mining disasters, 2 metal and non-metal disasters, and the worst coal mine explosion in history.[4] That year, Fairmont Coal Company's Monongah Nos. 6 and 8 mines exploded killing 362 miners.[5] That particular incident prompted Congress to create the federal Bureau of Mines in 1910.[6] The bureau was actually given no inspection authority until 1941, and it was not until 1947 that Congress authorized the first code of federal regulations for mine safety.[7]

Large-scale mine disasters have often spawned legislation geared toward improving mine safety and awareness toward disaster prevention. An explosion and fire at the Consol No. 9 mine in Farmington, West Virginia, in 1968 led to the enactment of the Federal Coal Mine Health and Safety Act of 1969 (the "Coal Act"), which was the most comprehensive mine safety legislation of its time.[8] Up to that point, the Federal Coal Mine Safety Act of 1952 provided for annual inspections in certain underground coal mines and gave the Bureau of Mines limited enforcement authority.[9] The 1952 act also authorized the assessment of civil penalties for noncompliance with withdrawal orders and for refusing access to mine property.[10] In 1966, Congress extended coverage of the 1952 act to all underground coal mines and also passed the Federal Metal and Nonmetallic Mine Safety Act of 1966 to regulate noncoal mines.[11] However, the enforcement authority under the 1966 act was minimal.[12]

The Coal Act was much more stringent than any previous federal legislation and extended coverage to surface mines as well.[13] Born out of the Coal Act was the Mining Enforcement and Safety Administration (MESA), a separate agency, created by the U.S. Secretary of the Interior in 1973 to assume safety and health enforcement functions formerly carried out by the Bureau of Mines.[14]

Three years later, on March 9, 1976, an explosion ripped through the Scotia mine of Blue Diamond Coal Company in Oven Fork, Kentucky, killing 15 miners.[15] Two days later during the rescue and recovery efforts, a second explosion claimed the lives of 11 more miners, including three MESA inspectors.[16] That

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incident raised such a furor that Congress passed the Federal Mine Safety and Health Act of 1977 (the "Mine Act"), which transferred responsibility for mine safety enforcement from the U.S. Department of the Interior to the Department of Labor.[17]

The passage of the Mine Act also followed the Buffalo Creek dam failure in 1972.[18] A series of coal waste dams located on the Middle fork of Buffalo Creek in Logan County, West Virginia, failed, killing 125 people and injuring 1,100 in communities downstream of the dams.[19]

Prior to the 1977 Mine Act, metal–nonmetal mines (M/NM) were not included in federal safety and health enforcement functions. A fire at the Sunshine mine in Kellogg, Idaho, in 1972—which killed 91 miners, two-thirds of the underground crew working that day—focused national attention on the need to protect noncoal miners as well as coal miners. The Mine Act did just this, bringing enforcement of M/NM mines under the Mine Safety and Health Administration's (MSHA's) jurisdiction.

Following passage of the Mine Act, additional miner training, increased enforcement, and upgraded fire prevention standards came into place as "lessons learned" from the noncoal mine fires at the Sunshine mine (1972) and the Cargill salt mine in Belle Isle, Louisiana (1979).[20]

Subsequent to the passage of the Mine Act, unfortunately, disasters continued to plague the mining industry. An explosion took the lives of five miners at the Ferrell No. 17 mine of Westmoreland Coal Company in Uneeda, West Virginia, in 1980.[21] In 1981, mine explosions occurred at the Dutch Creek No. 1 of Mid-Continent Resources Inc. in Redstone, Colorado (15 miners); the No. 11 mine of Adkins Coal Company in Kite, Kentucky (8 miners); and the No. 21 mine of Grundy Mining Company at Whitwell, Tennessee (13 miners).[22] The Wilberg mine fire of Emery Mining Corporation in Orangeville, Utah, took the lives of 27 miners in 1984.[23] A mine explosion claimed the lives of 10 miners at the William Station No. 9 mine of Pyro Mining Company in Wheatcroft, Kentucky, in 1989; and another explosion in 1992 killed 8 miners at the No. 3 mine of Southmountain Coal Company in Norton, Virginia.[24] A welcomed hiatus in disasters occurred for the remainder of the twentieth century, which ended in 2001 with the mine explosion at the No. 5 mine of Jim Walter Resources Inc. in Brookwood, Alabama, which took the lives of 13 miners.[25]

In the wake of the Sago mine explosion of Anker West Virginia Mining Company Inc. in January of 2006 at Buckhannon, West Virginia,[26] legislation was once again spurred. The Mine Improvement and New Emergency Response Act of 2006 (the "MINER Act") was signed by President George W. Bush on June 15, 2006.[27] Tragically, another mine explosion (killing five miners) had preceded passage of that act at the Darby No. 1 mine of Kentucky Darby LLC in Harlan County, Kentucky, in May of 2006.[28] The MINER Act amended the 1977 Mine Act and contained a number of provisions to improve accident preparedness.[29]

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In 2007, disaster struck again with the mine collapse at the Crandall Canyon mine of Genwal Resources Inc. in Huntington, Utah.[30] Three years later in 2010, however, the Upper Big Branch mine of Performance Coal Company in Montcoal, West Virginia, claimed the greatest amount of lives (29) in the previous 16 years since the Wilberg mine fire.[31] In June of 2007, a bill titled the Supplemental Mine Improvement and New Emergency Response Act (the "S-MINER Act")[32] was introduced into the United States House of Representative as a supplement to the MINER Act; however, the bill died in a Senate committee on April 12, 2010.

Accidents

Although disasters involving at least five persons garner much publicity and attention, accidents involving a lesser number of persons, even one, are events that must be handled with as much attention and care. Under the regulations, an *accident* is defined in terms of an event that could involve only one "individual" at the very least,[33] and includes

1. A death of an individual at a mine;
2. An injury to an individual at a mine that has a reasonable potential to cause death;
3. An entrapment of an individual for more than 30 minutes or that has a reasonable potential to cause death;
4. An unplanned inundation of a mine by a liquid or gas;
5. An unplanned ignition or explosion of gas or dust;
6. In underground mines, an unplanned fire not extinguished within 10 minutes of discovery; in surface mines and surface areas of underground mines, an unplanned fire not extinguished within 30 minutes of discovery;
7. An unplanned ignition or explosion of a blasting agent or an explosive;
8. An unplanned roof fall at or above the anchorage zone in active workings where roof bolts are in use; or an unplanned roof or rib fall in active workings that impairs ventilation or impedes passage;
9. A coal or rock outburst that causes withdrawal of miners or disrupts regular mining activity for more than 1 hour;
10. An unstable condition at an impoundment, refuse pile, or culm bank that requires emergency action in order to prevent failure, or that causes individuals to evacuate an area; or, failure of an impoundment, refuse pile, or culm bank;
11. Damage to hoisting equipment in a shaft or slope that endangers an individual or interferes with use of the equipment for more than 30 minutes; and
12. An event at a mine that causes death or bodily injury to an individual not at the mine at the time the event occurs.[34]

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"Accidents," as that term is defined by the regulations, carry immediate notification requirements. The mine operator is required to immediately contact MSHA through a toll-free number within 15 minutes once that operator knows or should know that an accident has occurred involving

a. A death of an individual at the mine;
b. An injury of an individual at the mine that has a reasonable potential to cause death;
c. An entrapment of an individual at the mine that has a reasonable potential to cause death; or
d. Any other accident, as defined above.[35]

This definitely weighs heavily into any plan geared toward dealing with accidents and disasters.

Accidents Rising to the Level of a Disaster

Any host of accidents that may or may not claim as many as five lives can certainly rise to the level of a "disaster" given the fallout of liability and litigation in today's society. The Martin County, Kentucky, coal impoundment collapse in the fall of 2000[36] claimed no lives. The flow of slurry out of the mine resulted in flooding and downstream black-water contamination of Wolf Creek and Coldwater Fork.[37] Although no fatalities or personal injuries resulted from the breakthrough or mine inundation, extensive environmental damage occurred in these waterways and successive downstream areas.[38] Naturally, public relations were at the forefront, and the aftermath of litigation was enormous.

Beginning in 2001, Black Wolf Coal Company Inc. operated the Quecreek No. 1 mine, an underground coal mine in Somerset County, Pennsylvania.[39] On July 24, 2002, miners working in the 1-Left section broke through the working face into the room of an abandoned coal mine known as the Harrison No. 2 mine.[40] The breakthrough resulted in a serious inundation of water from the Harrison No. 2 mine.[41] Nine miners were able to escape by wading through chest-high water and changing their route several times when they encountered impassable areas, while nine other miners were trapped underground.[42] The nine trapped miners were ultimately rescued, following dramatic rescue efforts over a four-day period.[43] This chronicle garnered national attention at the time and spawned prolific litigation.

Although no fatalities occurred at either Martin County or Quecreek, no one can discount the impact that each of these incidences had in the future of mining.

In January of 1991, an explosion ripped through Fire Creek Inc.'s No. 1 mine killing two miners in Superior, West Virginia.[44] Although the number of fatalities was fewer than "five," the results were certainly disastrous. MSHA issued citations and orders to Fire Creek, Southern Minerals Inc., and True Energy Coal Sales Inc., contending that the companies were jointly and severally liable as operators of the mine.[45] Southern Minerals and True Energy denied they were operators

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and asserted that they were not liable under the Mine Act; however, the case was eventually settled.[46]

An explosion that occurred on November 30, 1993, at the Elmo No. 5 mine of AA&W Coals Inc. in Pike County, Kentucky, took the life of one miner.[47] Following an investigation of the accident, MSHA issued approximately 225 citations and orders for alleged violations of mandatory safety and health standards to AA&W Coals and to Kyber Coal Company, Jesse Branch Coal Company, Berwind Land Company, and Berwind Natural Resources Corporation claiming that the latter four entities were jointly and severally liable as operators of the mine with AA&W Coals.[48] Six years after the explosion, the Federal Mine Safety and Health Review Commission issued its decision, which included one main opinion and five separate opinions by each of the commissioners, in this extremely protracted litigation involving a morass of issues regarding liability of the entities involved.[49]

THE CRISIS MANAGEMENT TEAM

Kravitz and Peluso, in their paper "Crisis Management Training," note that a crisis can be characterized by three major elements: threat, time, and surprise.[50] A *threat* is a potential hindrance to some original goal desired and occurs if the decision makers recognize it and believe that it will hinder attaining that goal.[51] The *time* element in a crisis is short when the original situation will be altered in the near future, after which no decision can be made, or the decision can be made only under less favorable circumstances.[52] The *surprise* element refers to a lack of awareness by the decision makers that the crisis situation is likely to occur, which is ever present even if prior plans exist to handle crises.[53] Other authors have identified a crisis as

- A turning point in an unfolding sequence of events or actions;
- A situation in which the requirement for action is high in the minds and planning of participants;
- A situation followed by an important outcome whose consequences and effects will shape the future of the parties to the crisis;
- A convergence of events whose combination produces a new set of circumstances;
- A period in which uncertainties about the assessment of the situation and alternatives for dealing with it increases;
- A situation in which control over events and their effects decreases;
- A sense of urgency, which often produces stress and anxiety among people;
- A circumstance or set of circumstances in which information available to participants is usually inadequate;
- A situation of increased time pressures for those involved;
- Marked by changes in the relations among participants; and
- A situation which definitely increases tension among people.[54]

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Crisis management is not mismanagement.[55] Effective crisis management demands development of a set of special skills for managing an organization under conditions of intense stress.[56] No disaster response is going to be effective without some "command structure" in place. It is absolutely imperative that an emergency response plan (discussed later in this chapter) be executed by a predesignated crisis management "team." The crisis management team should include the following members, at a minimum.

Team Leader

The company team leader is a management person designated to be in charge of all company efforts to deal with the crisis. As previously noted, every crisis will most likely be a surprise that poses a threat that must be dealt with in a short amount of time for decision making and reaction.[57] That person must embody certain *proven* personal qualities that will be stretched to the utmost during the peak times as the crisis unfolds. The team leader must be coolheaded and decisive, yet willing to consider and accept alternatives that might differ from his or her own. The team leader must possess authority to act quickly, or have the capability of obtaining such authority. He or she must be thoroughly knowledgeable of the particular mine or facility that is in the midst of the crisis. The team leader must also have personal knowledge of the management personnel, and preferably the key nonmanagement personnel, who may be involved in the crisis. He or she must have the capability to effectively deal with all "responders"—regulatory, medical, political, media personnel, security, local law enforcement, and the general public. That person must have a working support of security personnel assigned to the operations, as well as an integrated relationship with off-site security. The team leader must be someone who will always bear in mind that he or she is leading a *team* and not a personal crusade.

Safety Department Representative

Most mining operations have a safety-trained group of individuals, or at least one individual, whose jobs are devoted to safety-related compliance of state and federal mine safety law at that particular mine or facility. The safety department representative on the crisis management team is likely to be a person drawn from that group. That person must have certain *proven* qualities that can hold up under pressure. The safety department representative must have a solid command of all applicable state and federal safety laws that apply to the crisis situation as well as mine emergency and rescue experience. He or she must also have a thorough knowledge of the mine or facility and its safety compliance history. The safety department representative should have an established rapport with the local regulatory agency safety personnel given that his or her sole job is to coordinate communications and cooperation among all such agencies.

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Public Relations Person

Without question, community and social impacts of the mining industry become burdensome whenever a disaster strikes. Public relations are critical to ensure that communications reach all relevant stakeholders. The public relations person coordinates all incident-related media and public relations activities and is the company representative to the media and other external audiences. It should be anticipated that external stakeholders will very quickly become concerned and expect immediate information from the company. Because these concerns can rapidly escalate and misinformation often gets circulated, it is essential to have a public relations person mobilized *from the onset* of any disaster. That person should be either a trained in-house public relations person or a professional consultant whose sole task is to communicate with the media and the general public.

The MINER Act provided for MSHA to assign an individual to serve as a family liaison between MSHA and the families of victims of mine tragedies involving multiple deaths.[58] In accordance with an MSHA Program Policy Letter, a separate MSHA official (senior MSHA official on-site and/or media specialist) must also serve as the "primary communicator" with the mine operator, miners' representative, media, and general public during a disaster, and the primary communicator must collaborate with the family liaison to ensure that consistent, timely, and accurate information is disseminated to the public and the families.[59] Nevertheless, nothing in this policy prohibits the mine operator from establishing communication with the families or the public.

It is *not* a good idea for the company president or the company attorney to fill this role during the chaotic time of a disaster. Public relations savvy is essential during this time, but placing a company executive and/or counsel in this position creates a host of confidentiality and attorney–client privilege issues. There will be ample time later for a company executive to make appropriate statements, as they fit with the public relations communications.

Engineering/Environmental Department Representative

One of the first documents needed in any rescue or recovery effort in the wake of a disaster is the current mine map along with several copies. Depending on the circumstances, surveying and location work may be needed quickly as well. For example, during the rescue efforts to reach the nine miners trapped in the Quecreek mine (described earlier in this chapter), engineers and surveyors were summoned to locate the surface area for the drilling of the rescue borehole through which all nine were eventually retrieved.[60] Accordingly, the crisis management team must include an engineering/environmental department representative. Preferably, that person should be a licensed professional engineer and/or licensed land surveyor whose sole job is to coordinate all needs for mapping and engineering services that might be involved, including interface with governmental regulators. Environmental

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concerns are always a factor in any disaster, and the engineering/environmental department representative must have a thorough knowledge of all environmental compliance at the operations. Depending on the complexity of the circumstances, other consulting engineers may have to be engaged to provide specialized services. The engineering/environmental department representative should also be knowledgeable of qualified persons who may be called on immediately to provide such services.

Site Communications Person

If rescue operations are under way, there will be communications between the central surface location and the underground (in the case of underground operations), or the central surface location and other mine site areas (for any operation). Such communications are vital during rescue and recovery operations. Although there can be several teams of rescuers underground and several teams of recovery persons on the surface, it is critical to have one main line of communication between the two. During the rescue efforts of the 2006 Sago mine explosion (described earlier), there was an erroneous early report that 12 of 13 missing miners had been found alive when, in reality, a miscommunication had occurred and only 1 miner had survived.[61] The site communications person must be someone knowledgeable about the physical layout of the mine whose sole job is to handle the communications for that one main line of communication.

Off-Site Communications Person

In the chaos of a crisis, the telephones will be ringing incessantly, e-mail will rapidly inundate the inbox, and people will be appearing in droves—some to render assistance and some to satisfy their own curiosity. Important, and possibly life-determining, communications will need to flow from the site to the outside world and vice versa. The off-site communications person must be knowledgeable of the local area. His or her sole job is to handle all incoming and outgoing communications from the plant site and will most likely work closely with the public relations person. Those duties will also necessarily include relaying messages to and from the site communications person.

Supply Person

During a mine crisis, a host of equipment, materials and services are needed. A facilities warehouse can be depleted rapidly if an outside supply line and network is not established early. Basic construction materials may be needed for any recovery operations. Medical supplies and first-aid items may be in high demand. Food and provisions for rescuers and responders will be in constant demand. A supply person is essential for keeping the supply lines going and the needs met. The person chosen

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for this task must be knowledgeable of on-site and off-site resources and is placed in charge of procuring and distributing needed supplies.

Legal Counsel

As soon as a disaster is known, it is imperative to have a seasoned attorney involved. This is not an opportune time for on-the-job training. Although the company may have its own legal staff, the far-reaching legal issues emanating from a crisis will soon overwhelm an in-house legal staff that must continue to provide the day-to-day consultation to the company on its routine matters. Moreover, the legal issues that develop in the wake of a mining disaster often call for those attorneys who have experience in the mining industry and/or mining disasters. Legal questions will begin to surface as the disaster extent becomes known and as rescue efforts unfold. Document control is an absolute necessity. In the chaos of dealing with a crisis, a flurry of documents can be requested and disseminated, and some could be misplaced or simply lost in the shuffle. An investigation by all participating regulatory agencies is a certainty. It is highly likely that regulatory enforcement will result in violations being issued because most agencies are empowered to issue violations and impose penalties.[62]

All members of the crisis management team must be prepared to move into action at a moment's notice. A rapid and simple notification system needs to be tailored for each mine or facility to quickly mobilize each team member at the onset of a crisis. Obviously, each team member's contact information must be conspicuously posted at the mine or facility so that all employees know who they are and how to contact them in an emergency.

In today's world, replete with cell phones, smartphones, texting, and e-mails, there remains the possibility that some team member may not be available when disaster strikes. A company should name alternate team members in the event that any selected team member is unavailable. In addition, these alternate team members are necessary to provide relief for events that can occur for extended periods.

The crisis management team needs to have complete mastery of the emergency response plan (described later in this chapter) so it knows what to do during a crisis. The team needs to meet periodically to review the plan, revise procedures as needed, and to remain well-versed in case it is called into action. The team should also consider taking some proactive "preventive maintenance" actions, as described later in this chapter.

PROTECTION OF HUMAN LIFE

The primary concern as any disaster unfolds[63] is the protection of human life. The next immediate concern is any assistance that may be needed given the magnitude of the situation. A continuum of concern is "damage control." A paramount

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consideration in any disaster is the preservation of life. In a disaster, it is possible that miners could be trapped or imperiled as a result of a mine explosion or mine inundation (for underground operations), a highwall collapse (for surface operations), or as a consequence of well-meaning "rescuers" who might make some hasty actions based on rash judgments. There may be potential victims at peril in some disastrous situations off-site from the mine or facility such as residents adjacent to the mining operations.

The first response should always be to dispatch quick and effective communication to all persons who could possibly be affected to assess their firsthand knowledge of the extent of injuries, peril, or damage; and/or to notify them of the impending danger. Underground and surface mine communication systems and tracking equipment must be kept in top working order and maintained in accordance with applicable federal and state regulations governing such communications. MSHA inspectors must verify that communication and tracking systems have adequate backup power capacity to ensure operation during fan stoppages or a mine power outage for the period of time specified in the emergency response plan, and they must also confirm that the backup power supply is adequately charged.[64]

As for residents in the immediate area of the mining operation, a plan must be in place to notify them of the situation and any potential impending danger. Every mining facility should have an easy, readily accessible emergency contact list that has contact persons prioritized with all available emergency telephone numbers listed. This contact list, at a minimum, should list telephone numbers for the nearest ambulance service, the closest medical facility, nearest mine rescue team, local civil defense disaster officer, local and state police, applicable local and state regulatory emergency contacts, and company officials.

In response to two significant releases of toxic chemicals that caused significant loss of human life (Union Carbide plant releases in Bhopal, India, and Institute, West Virginia, in 1984 and 1985, respectively), Congress passed the Emergency Planning and Community Right-to-Know Act (EPCRA)[65] in 1986. EPCRA places requirements on government entities and industry for emergency planning and reporting of hazardous and toxic chemicals that are used or stored at a facility. This information is made available to the public and is a tremendous asset in protecting the public health and environment in the event of a release, because specific constituents and quantities are known.

NOTIFICATION TO REGULATORY AUTHORITIES AND THE PUBLIC

Presuming that the first step in the emergency response is well under way—namely, the immediate rescue effort and preservation of life—prompt notifications must be given to all regulatory agencies that have jurisdiction over the various aspects of the disaster. All health and safety enforcement agencies, such as MSHA and the

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respective state mine safety and health regulatory agencies, must be notified within 15 minutes of the operator's knowledge that an accident has occurred.

In accordance with the MINER Act, federal regulations[66] now mandate the 15-minute rule for occurrences constituting accidents, as previously discussed. Many state legislatures have also enacted similar statutes and regulations requiring the 15-minute notification.[67] Common sense and the nature of the emergency alone mandate that such notification be given immediately. State and federal agencies will most likely mobilize their own mine rescue teams to assist in the emergency efforts, and they also bring specialized training, experience, and knowledge in dealing with emergency situations.

Local civil defense and disaster agencies should also be promptly notified in the event that it is necessary to evacuate homes or take other measures to protect life and property. Given that many local governments may not be experienced or equipped to handle disaster response, there should be a list of a previously selected and notified local officials whom can be contacted on an emergency basis and relied on to take any necessary action for the protection of the public.

If the disaster could affect streams, land, or atmosphere, then all relevant federal and state environmental regulatory agencies must be contacted. Regarding the mining aspect, the nearest federal Office of Surface Mining Reclamation and Enforcement (OSMRE) should be contacted and any state environmental regulatory agency. Additionally, the nearest office of the U.S. Environmental Protection Agency (USEPA) must be notified. If any "navigable waters" of the particular state (and the United States) may be affected, the local Coast Guard office must be notified.

Pursuant to the provisions of EPCRA[68], facilities must immediately notify the local emergency planning committee of the release of any reportable quantity of a hazardous substance into the environment. Notifications can be made by a variety of methods, including telephone, radio, electronically, or in person. Any emergency notification from a facility must include several pieces of information so that emergency responders can be adequately prepared:

- Name of the chemical constituent
- Quantity of the release
- Time and duration of the release
- Known or anticipated acute or chronic health risks
- Information for contact person at the facility

These notification provisions can go a long way in mitigating damages and protecting human health and the environment, because they provide the necessary information for an effective response.

In short, the crisis management team must be able to act with lightning speed in determining the magnitude of the disaster, the potential impacts, and the regulatory agencies that will have to be involved at all stages.

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DAMAGE CONTROL

In the midst of rescue efforts and emergency procedures, there always exists the possibility that such efforts themselves could cause additional problems.

The 1976 Scotia mine disaster in Utah was a terrifying case in point. The first explosion had occurred on March 9, 1976.[69] Under pressure from elected officials at the scene, three federal MESA inspectors entered the mine on March 11 with two rescue teams equipped with self-contained breathing equipment at approximately 4:30 p.m. to attempt rescue/recovery.[70,71] They were in the process of removing the coupler from a pump trailing cable when another explosion occurred at approximately 11:30 p.m.[72] MESA investigators concluded that the March 11 explosion resulted from a lack of sufficient air to ventilate the area and remove the known methane accumulations from the mine.[73] They believed that the second explosion occurred when a methane–air mixture was ignited by one of five possible sources: an electric arc or spark from a battery-equipped deluge system; three battery-equipped telephones; scoop batteries; residual fires; or a frictional spark from a fall of mine roof on a roof-bolting machine.[74]

Another frightening occurrence was the Crandall Canyon incident in Utah. On August 6, 2007, at 2:48 a.m., a catastrophic coal-outburst accident occurred during pillar recovery in the South Barrier section.[75] The outburst initiated near the section pillar line (the general area where miners were working) and propagated toward the mine portal.[76] Coal was expelled into the mine openings on the section, likely causing fatal injuries to six miners.[77] The resulting magnitude 3.9 seismic event shook the mine office 3 miles away.[78] On August 16, 2007, at 6:38 p.m., a coal outburst occurred adjacent to rescue workers as they were completing the installation of ground support behind the continuous mining machine.[79] Coal ejected from the pillar dislodged standing roof supports, steel cables, chain-link fencing, and a steel roof support channel, which struck the rescue workers and filled the entry with approximately 4 feet of debris.[80] Two mine employees and one MSHA inspector received fatal injuries.[81] Six additional rescue workers, including an MSHA inspector, were also injured.[82]

The 1972 Sunshine fire was a disaster not only for the mine and miners, but for the families and communities as well. No one knew who was in the mine, or how many might have escaped, because the only records kept were with the shift foreman who was trapped underground. No managers were on-site the day of the fire because of a large stakeholders' meeting scheduled that day, and coordination of rescue and recovery efforts was largely nonexistent for the first few days. Misinformation was rampant, and families turned to media, which were largely uninformed and speculative. The Silver Valley communities waited for accurate information about their loved ones for 13 days, when the lowest levels of the mine were finally reached by rescuers, who had to work in deadly smoke as the fire continued to burn. Only two miners were brought out alive, after being trapped for 8 days. Everyone else died.

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In the wake of a mine explosion, the underground mine atmosphere can be drastically and dangerously changed. For example, a fireball from an explosion will usually eliminate nearly all of the oxygen in a mine atmosphere, causing certain asphyxiation for any person entering without a self-contained breathing apparatus. Burning debris left in the mine could indicate enough oxygen in the atmosphere to serve as an ignition source for a buildup of explosive methane gas. A violent explosion could also disrupt roof conditions, giving rise to the possibility of roof falls and/or coal pillar failures.

Underground disasters could also cause a buildup of water in certain locations of a mine, which could entrap miners underground or create a dangerous situation for a rescue team approaching the area. Although the Quecreek mine rescue was a technological success story, the potential for a failed rescue effort loomed and could have cost the lives of all the trapped miners.

Rupture of surface impoundments poses the threat of emptying untold volumes of contained materials into surface streams and private properties. Some method for immediate plugging of a rupture must be quickly put in motion. In October of 2000, the Big Branch slurry impoundment of Martin County Coal Corporation ruptured causing more than 250 million gallons of slurry to inundate an old mine and exit through two creeks along the surface.[83] Rapid detection and astute work allowed for a combination of four bulldozers to quickly dig enough fill material to swiftly plug the breakthrough area, thus preventing further inundation.[84]

The remedial actions necessary to repair a ruptured impoundment are only part of the problem. Surface impoundment ruptures spawn the potential for downstream flooding and extensive property damage. Therefore, plans should be implemented to

1. Evacuate any people who may be in danger from potential flooding;
2. Build up the creek banks to prevent overtopping of streams;
3. Advance dredge stream banks to contain the additional flow; and
4. Establish containment barriers to slow or stop slurry flow into larger waterways.

Municipal water systems may also be in jeopardy. Most such systems often have water intakes in larger streams, and measures must be taken to insulate those water intakes from the contamination.

Every disaster has a potential domino effect. A competent, well-selected crisis management team has to evaluate the changing conditions as they arise in an attempt to identify consequences to prevent the disaster from intensifying.

LIABILITY

After the people have been rescued, the public protected, and the immediate danger contained, the handling of a disaster turns to a different perspective. An investigation will follow every disaster, and the search will commence to find the guilty

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regardless whether there exists any real guilt at all. Most courts will likely ignore an "Act of God" defense. Inevitably, attention will turn to civil and criminal liability. It is essential that experienced legal counsel be on-site early on to advise the company in dealing with the various regulatory agencies and the aftermath that will follow.

Ironically, most serious charges arising from a disaster *do not* arise as a result of what actually happened. During the chaos surrounding a disaster, it is very easy for overworked, exhausted employees and management to take hasty and poorly reasoned actions, for whatever reasons, that taint or destroy evidence or to make inadvertent remarks that could prove costly. A person is well advised to take the position that *no statement* made to any governmental agent is ever "off the record." Although every person has a moral and ethical obligation to always tell the truth, every person is also protected from self-incrimination by the Fifth Amendment to the U.S. Constitution.[85]

Every regulatory agency that participated in any manner most likely has the power to issue violations and impose penalties.[86] Possible criminal charges could be brought by the U.S. Attorney under federal law or the Attorney General for state law infractions.[87]

In a disaster, any number of regulatory agencies will likely conduct interviews of all employees and witnesses to finalize their own investigations into the cause of the disaster *and* any suspicious actions that occurred *during* the recovery. Although these interviews may be voluntary, individuals should be advised that they could become targets of the investigation and are most often entitled to have a representative attend the interview with them. Under the Mine Act, for example, the representative could be anyone, but it is most effective if the person is an attorney or other trained professional.

In most cases, a company will elect to provide separate counsel for any individual who believes there might be some conflict between the company's interest and the individual's interest in the investigation. In this situation, it is proper for the company to pay the attorney's fees and expenses for such representation as long as the retained attorney is given the freedom to represent the individual to the fullest extent. It is quite common that additional or special investigations will be conducted to determine whether there was any deliberate or intentional conduct on the part of the company and/or its management force in *any* action. Such investigations could examine time periods long before the disaster struck, and the consequence may be that charges could be brought on incidences that may have had *nothing* to do with the disaster. Should an agency determine there are possible criminal infractions, the case against the company and/or any number of individuals could be turned over to the U.S. Attorney's office for prosecution.

A federal investigation will not preclude a separate state investigation, and the state agency could also impose violations for infractions and take action against the individuals as well. In some states, it is the state agency that issues mine licenses to

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companies, certifies individuals to be mine foremen, and may certify individuals as miners. The possible consequences could range from suspension of a mine license, foreman certificate, or miner's certificate to the imposition of penalties and/or criminal prosecution under the respective law.

Regarding compliance with the Surface Mining Control and Reclamation Act of 1977 (SMCRA)[88], there could be a state agency investigation if that state has primacy under the act. In accordance with SMCRA, a state may institute its own program for regulatory enforcement wherein the OSMRE relinquishes primary jurisdiction for enforcement, but retains oversight powers. The state environmental agency can also issue violations and impose penalties on companies, and it could turn over the case for criminal prosecution under state law as well. Where a state does not have primacy, the OSMRE acts in an enforcement capacity. The OSMRE could refer the case to the U.S. Attorney for prosecution of SMCRA infractions. The USEPA could also have jurisdiction and could impose penalties of its own. The agencies can also refer cases to the U.S. Justice Department for prosecution of environmental crimes.

When more than one person is involved in a disaster, there is always the potential for conspiracy charges under state or federal law. The Racketeer Influenced and Corrupt Organizations Act (RICO)[89] was initially enacted to deal with the influence of organized crime such as the Mafia. RICO charges could be imposed as well under certain circumstances. It has since been used to impose sanctions on any group of individuals that acts together as an organized unit to propitiate crimes. Consequences of RICO charges could be imprisonment and enhanced fines or penalties.

In summary, there is an entire array of various state and federal criminal or quasi-criminal charges that could be levied for acts deemed causative of the disaster or for actions taken in the wake of a disaster. For example, the British-owned company Costain Coal owned Pyro Mining Company, the western Kentucky mine where 10 workers died in a methane explosion in 1989.[90] Costain Coal pleaded guilty to a pattern of safety misconduct issues at the mine and agreed to pay a fine of $3.75 million to the government.[91] Three Pyro executives were sentenced to prison for lying to inspectors and failing to follow safety procedures.[92] The former general superintendent was sentenced to 18 months in prison and fined $3,000. A second executive was sentenced to 6 months, and the third to 5 months.[93] In connection with the 1992 Southmountain mine explosion, a mine operator received 6 months' imprisonment and a mine foreman was sentenced to 3 months of community confinement for criminal violations of federal mine safety laws.[94] The sentencing concluded federal criminal proceedings in which Southmountain Coal Company and five individuals pleaded guilty and fines totaling $2,016,000 were imposed for criminal violations of federal mine safety requirements.[95]

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In addition to these types of sanctions, there is a real threat of civil lawsuits arising from the consequences of such a disaster. The disaster could trigger wrongful death civil suits should any fatalities result or civil actions for personal injuries. While most state workers' compensation statutes may provide some protection for the company regarding such civil actions, plaintiff's attorneys have increasingly attempted to pursue parent companies, subsidiaries, or any other corporate entities that may have been connected in some manner to the mining operation, to avoid any workers' compensation roadblocks. Damage claims from adjacent property owners is also a possibility. A company could also face damage claims from any business that may have experienced interruptions during a far-reaching disaster. Municipalities may claim damages to their water intake systems or damages resulting from the interruption of water supply. Depending on whether harmful or hazardous substances have been discharged, there may be some claims for personal injuries based on exposure to such substances. The possibility of natural resource damages must also be considered. Fish kills, hazards to wildlife, and/or destruction to wildlife habitats and wetlands could carry significant monetary ramifications.

THE EMERGENCY RESPONSE PLAN

The first step in dealing with a disaster, however, begins long before danger strikes—formulation and implementation of an emergency response plan.

The MINER Act (Public Law 109-236) requires operators of underground coal mines to improve accident preparedness. The legislation demands coal mining companies to develop an emergency response plan specific to each mine they operate, and further requires that every mine have at least two rescue teams located within 1 hour.[96] The MINER Act essentially requires a plan for evacuation of an underground mine.[97] Required items include postaccident communication, tracking, breathable air, and lifelines.[98] The Act mandates requirements for mine evacuation and fire-fighting as well as the logistics of security, command centers, family centers, and media communication facilities.[99] Although this legislation is specific to *underground coal mining operations*, the basic principles certainly form guidelines for emergency response plans that can be formulated for all mining operations.

Emergency response plans required under EPCRA[100] contain critical information that community and emergency response officials can use in the event of an accident. These plans must be updated annually and must contain the following information:

- Facilities and transportation routes of extremely hazardous substances
- Emergency response procedures, on- and off-site
- Designation of a community coordinator and facility coordinator(s) to implement the plan
- Emergency notification procedures

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- Description of how to determine the affected area and population by releases
- Description of local emergency equipment and facilities, and identification of the person(s) responsible for them
- Evacuation plans
- Training programs for emergency responders (including schedules)
- Methods and schedules for exercising emergency response plans[101]

Having a response plan in place with these elements can save lives, limit environmental damages, and provide the necessary guidance during an emergency. Without a plan in place, an accident could lead to human casualties, significant property and environmental damages, and possible financial ruin of the company. Another benefit of the response plan is that shortcomings or other issues that may be identified during creation of the plan. Deficiencies identified during formation of the plan can be addressed before an emergency happens.

PREVENTIVE MAINTENANCE

The quest for all mining professionals is to learn from a disaster so as to never endure it again. Nevertheless, preparedness is an essential part of "dealing" with a potential disaster. Many companies have taken proactive steps in making sure their operations are "ready" for adversity. Arch Coal, Alpha Natural Resources, and Peabody Coal Company have teamed with federal, state, and local agencies to conduct mine emergency response drills (MERDs) at their operations in recent years. The MERD is an excellent tool in this regard.

The concept of a MERD is that a hypothetical mine disaster is planned and formulated with the details kept confidential. An actual mine site is used with company personnel playing the roles that they would in an actual disaster. Each is given a partial script of developments, but only the originator knows the full hypothetical problem. Its challenges unfold and evolve throughout the day, employing special effects and including local, state, and federal regulators, along with attorneys and medical personnel—none of whom know the full theoretical predicament, yet all must react to the evolving events of the day.

MSHA is very supportive of MERD exercises. In November of 2008, more than 150 MSHA members took part in an MERD at the Mine Health and Safety Academy in Beaver, West Virginia.[102] Mine rescue team members, in accordance with 30 C.F.R. § 49.60 of the MINER Act, are required to participate in two local mine rescue contests each year.[103] MSHA notes that mine rescue contests, including MERD exercises, "serve a vital role in achieving the purpose of the MINER Act to improve the safety and health of miners."[104] To fulfill the requirements of a mine rescue contest for the purpose of 30 C.F.R. § 49.60, MSHA requires a MERD exercise to be conducted in the United States; use MSHA-recognized rules; use trained judges who time and evaluate the performance of each team, providing

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written feedback; have a minimum of three teams; have participants wear oxygen breathing apparatus and have other equipment necessary to work the problem; have one or more problems conducted on one or more days; and have a winner.[105]

Obviously, a MERD requires a huge resource commitment. An operation will necessarily be idle from actual production for the period of time that the MERD is conducted. Regulators and other noncompany participants will be taken away from their daily duties to concentrate on the drill. This is no small "expense" for these participating companies. The benefit, however, can be invaluable. It is preventive maintenance.

Many companies have focused their preventive maintenance in efforts to *prevent* disasters and to better educate their workforce on mining safety. Although the Upper Big Branch mine explosion of 2010 was indeed a tragedy, Alpha Natural Resources has shown that good results can come from agonizing situations. One year after the Upper Big Branch explosion, the company acquired Massey Energy, the parent company of Upper Big Branch. Alpha Natural Resources worked out an agreement with the Department of Justice to invest $80 million in various health and safety measures, which also included a state-of-the-art training facility with a full training curriculum for its miners and which would also be available to other mining companies.

CONCLUSION

Unfortunately, many companies have failed to survive following a disaster. Scotia mine is long gone. Pyro Mining Company no longer exists. The parent company of the Sago mine was purchased. The Upper Big Branch mine of Performance Coal Company was included in the purchase of Massey Energy. Those that have survived have done so by taking swift, intelligent action early on in an effort to deal with a serious situation in the best possible manner while mitigating the damages.

Survival through a disaster actually begins with a well-thought-out emergency response plan. When calamity strikes, it is absolutely imperative to put this response plan in motion with well-prepared, coolheaded individuals at the helm, guided by sound advice from preselected attorneys and professionals.

The first and foremost objective is to save lives and to prevent danger to others. Nevertheless, the best defense to a disaster is to have a strong offense. Mining personnel need to be well-trained and well-equipped to do their jobs. That can only happen if companies take the initiative to give them these additional emergency planning tools.

NOTES

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Index

10 Principles for Sustainable Development, 7–8, 13, 17, 69–71
  See also International Council on Mining and Metals (ICMM)

Abandoned mines
  geothermal energy recovery, 375–378
  See also Closures
Aboriginal communities. *See* Indigenous peoples
Accidents, 758–760
  vs. disasters, 756–760
  See also Crisis management
Acid mine drainage (AMD), 461–462, 553–555, 570–572
  Benambra Legacy Tailings, 567–568
  East Sullivan mine case study, 566–567
  Elliot Lake and Copper Cliff tailings, 570
  geochemical treatment processes, 467–470, 557–561, 564–566, 568–570
  microbial actions, 561–564, 567–568, 570
  origins, 555–556
  reducing acid generation rates, 556–564
  Savage River Rehabilitation Project, 564–566
  silicate neutralization, 557–561, 564–566, 568–570
  Waite Amulet tailings storage, 568–570
Adaptive environmental management plan (AEMP), 579–580, 725–726, 750
  and adaptive management, 741–744
  Case Study 1, 744–747
  Case Study 2, 748–750
  financial assurance, 738–741
  role of, in environmental review decisions, 735–738
Adaptive management, 725, 750
  and AEMP, 741–744
Aganippe Castellum, 277–287
Alaska
  Pebble Project case study, 452
Anglo American, 452
Appalachia
  coal mines, 664–666
  Forestry Reclamation Approach (FRA), 667–677
  FRA Case Study 1 (Tennessee), 677–680
  FRA Case Study 2 (Kentucky), 681–686
  FRA Case Study 3 (Virginia), 686–694
Appalachian Regional Reforestation Initiative (ARRI), 579, 676–677, 696–697
Aquaculture, 602–603
Argyle mine, 449
Artisanal and small-scale mining, 23, 56–57
Australia
  Argyle mine case study, 449
  Benambra Legacy Tailings, 567–568
  Koolyanobbing Iron Ore Project, 277–287
  Koolyanobbing joint project case study, 263–274
  mine closure requirements, 583–604
  mining industry history, 64–66, 115–119
  mining jobs, 120–121, 145–147
  Olympic Dam case study, 449
  Savage River Rehabilitation Project, 564–566
  spiders, 277–287
  Stawell Gold Mine case study, 639–659
  water sector, 73–76

Bacteria. *See* Acid mine drainage (AMD): microbial actions

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Barrick Gold Corporation
Homestake mine case study, 450–451
Basin dams. *See* Dams, tailings
Benambra Legacy Tailings, 567–568
BHP Billiton, 449
Bighorn sheep, 304–314
Biodiversity, 25–26, 32, 53–55
assessments, 259–261
and Australian mining industry, 77–78
and Canadian mining industry, 101–104
defined, 259
Koolyanobbing joint project case study, 263–274
offsets, 77–78, 289–290
Stawell Gold Mine case study, 639–659
Biofuel, 601–602
Biomass, 408–410, 601–602
Bruce Mines case study, 378–384
Brundtland Commission, 2, 6, 67
Business
closures as assets, 598–603
sustainability as a concept of, 4–5, 349–350, 369, 697

California
bighorn sheep, 304–314
Project Phoenix case study, 347–369
San Bernardino Mountains case study, 289–315
Canada
Bruce Mines case study, 378–384
East Sullivan mine case study, 566–567
Elliot Lake and Copper Cliff tailings, 570
and FNITR, 232–243
mining industry history, 85–86
Quintette Coal Mine Project, 243–253
Waite Amulet tailings storage, 568–570
Carbon emissions, 24, 322–323, 343, 602
Carbonate Habitat Management Strategy
adaptability and stability, 303–304
area of study, 290–292
bighorn sheep management, 304–314
conservation credit, 294, 299–303
conservation value, 294, 297–299
Cushenbury Bighorn Collaborative, 306–314
history of carbonate endemics, 292–293
mine revegetation, 299–303
strategy overview, 293–304
Ceres Principles, 39–40
Chemicals, management of, 29
Cliffs Asia Pacific Iron Ore
Koolyanobbing Iron Ore Project, 277–287
Koolyanobbing joint project case study, 263–274
Climate
and ecosystem rehabilitation, 620
fundamentals of, 323–325
history, 325–328
projections, 328–334
water management solutions, wet/dry, 452–453, 454–458
vs. weather, 323–324
Climate change, 19, 24, 317–319
disclosures, 44–45
history of climate science, 322
impacts on mining industry, 334
MAC impact management, 96–99
and mine planning, 321, 334–343
mitigation measures, 341–343
See also Greenhouse gas emissions
Closures, 25, 57, 252–253, 339, 577–581, 603–605
aquaculture uses, 602–603
as assets, 598–603
biomass and biofuel uses, 601–602
community implications, 596–598
costs, 588–589
and EIAs, 591
environmental impacts of, 586–588
and financial security, 593–596
plan guidelines, 590–593
and renewable energy, 600–601
Stawell Gold Mine case study, 639–659
and sustainable development, 583–586
tourism and recreation uses, 603
water uses, 599–600
See also Bruce Mines case study; Geothermal energy recovery; Meirama Brown coal mine; Reclamation; Rehabilitation

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Coal mines
Appalachia, 664–666
Forestry Reclamation Approach (FRA), 667–677
FRA Case Study 1 (Tennessee), 677–680
FRA Case Study 2 (Kentucky), 681–686
FRA Case Study 3 (Virginia), 686–694
Meirama Brown coal mine case study, 497–512
Quintette Coal Mine Project, 243–253
Communities of interest (COIs), 92, 95–96
and biodiversity conservation, 102–104
and environmental monitoring, 152–154
and mine closures, 596–598
See also Community Environmental Monitoring Program (CEMP); First Nations Independent Technical Review (FNITR); Indigenous peoples
Community Environmental Monitoring Program (CEMP), 112–113, 152–154
creating, 193–200
defined, 191–192
at Eagle Mine, 171–181
implementation of, 200–209
Community scorecard, 153–154
Eagle Mine, 212–229
Conflict minerals, 52
Conservation
bighorn sheep, 305–306, 311–313
desert tortoise, 365
and fire management, 269–271
and flora and fauna management, 268, 271–274
and mining, 18
regional habitat plans, 290
spiders, 286
Conservation credit, 294, 299–303
Corporate social responsibility (CSR) reports, 10, 42
Australian, 66, 67, 69
See also Sustainability reporting
Crisis management, 753–754, 755–756, 773
damage control, 767–768
disasters vs. accidents, 756–760
elements of a crisis, 760–761
emergency response plans, 771–772
liability, 768–771
MAC, 99–101, 753–754
mine emergency response drills (MERDs), 772–773
notification, 765–766
protection of human life, 764–765
regulatory oversight, 756–760
team composition, 761–764
Cushenbury Bighorn Collaborative, 306–314

Dams, tailings, 524–532
basin reclamation, 543–549
Benambra Legacy Tailings, 567–568
deposition of tailings, 533–535
monitoring, testing, and analysis, 528–532
observational approach to construction, 526–528
operations and maintenance, 535–536
transportation of tailings, 532–533
and water management, 536–542
Democratic Republic of the Congo, and conflict minerals, 52
Desert tortoises, 365
Deterministic analysis, 732
Development
community, 22
partnership priority areas, 21–22
See also Communities of interest (COIs)
Disasters, 759–760
vs. accidents, 756–760
See also Crisis management
Disclosure, 44–45, 53–58
Do you need a CEMP? (Plastrik), 182–211

Eagle Mine, 112–113
case study, 155–181
CEMP case study, 182–211
CEMP development, 171–181
community scorecard, 212–229
risk management, 163–167
East Sullivan mine, 566–567
Ecosystems
abiotic management, 620–623

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biotic management, 623–627
and habitat development, 627–629
and mine-site rehabilitation, 616–618
natural-novel paradigm, 612–615
rehabilitation goals, 609–612, 618–629
and soil, 623–625, 694–695
and vegetation, 626–627, 695–696
See also Forestry Reclamation Approach (FRA)
Elliot Lake and Copper Cliff tailings, 570
Emergency response, 28–29
See also Crisis management
Endangered Species Act of 1973, 292, 295–297
Enduring Value Framework (MCA), 9, 66, 70–73, 80
Energy management, 97–98, 317–319
benchmarking, 395–400
conversion grid superstructures, 412–415
energy vs. utility, 393–395
geothermal energy recovery, 371–378
operational considerations, 410–412
renewable energy technologies, 407–410, 600–601
storage systems, 405–407
See also Optimal mine site energy supply (OMSES)
Environmental effects, defined, 730–732
Environmental Impact Assessments (EIAs), 264–267, 729
Meirama Brown coal mine, 503
See also First Nations Independent Technical Review (FNITR)
Environmental Impact Statements (EISs), 725–726, 729
AEMP Case Studies, 744–750
Minnesota Steel case study, 444–448
Environmental impacts, defined, 730–732
Environmental management, 76–77, 590
Environmental Management System (EMS), 742–744
Essar Steel, 444–448
European Union, and mine water law, 492–497
EVF. *See* Enduring Value Framework (MCA)
Fatality prevention, 27
Fire management, 268, 269–271
First Nations Independent Technical Review (FNITR), 113–114
origins and application, 232–235
Quintette Coal Mine Project, 243–253
review process, 235–243
success of, 253–255
Forest restoration. *See* Forestry Reclamation Approach (FRA)
Forestry Reclamation Approach (FRA), 579, 663–664, 696–699
Case Study 1 (Tennessee), 677–680
Case Study 2 (Kentucky), 681–686
Case Study 3 (Virginia), 686–694
scientific principles, 694–696
steps, 667–677

Geothermal energy recovery, 318, 371–375
applications, 375–378
Bruce Mines case study, 378–384
potential, 384–385
GHG emissions. *See* Greenhouse gas emissions
Global Reporting Initiative (GRI), 13
Comprehensive reports, 43
Core reports, 43
economic indicators, 43–45
effluents and waste concerns, 55
environmental indicators, 45–47
and external assurance, 41–42
history of, 39–40
metrics, 42–53
mining and metals indicators, 53–58
partnerships, 59–60
reporting framework, 8–9, 30–31
reporting levels, 58–59
social indicators, 47–53
water indicators, 73–76
See also International Council on Mining and Metals (ICMM)
Gove Peninsula (Australia), 117–119
Greenhouse gas emissions, 19, 24, 47, 60, 88, 317–319
Project Phoenix, 367–368

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and TSM protocols, 96–99
See also Climate change
Green-washing, 41
GRI. *See* Global Reporting Initiative (GRI)

Habitats, 298
Health and safety, 26–29, 104–108, 342–343
See also Crisis management
Hibbing Taconite Company, 709–710
HIV/AIDS, 27
Homestake mine, 450–451
Human rights
and GRI, 49–50
and ICMM, 20–21
and MCA, 65
Hydroelectricity, 407–408

ICMM. *See* International Council on Mining and Metals (ICMM)
Indigenous peoples
Australia, 64, 116, 145–147
Canada, 93–96
and EIAs, 231–256
and FNITR, 232–243
and GRI, 49–50, 55–56
and ICMM, 19, 21
Koolyanobbing joint project, 267, 269
and VET programs, 112
Yolngu clans (Australia), 117–121
See also First Nations Independent Technical Review (FNITR); Vocational educational training (VET) programs
Infectious diseases, 27
International Council on Mining and Metals (ICMM), 13, 317
environment and climate change work program, 8, 24–26
governance, 14–17
GRI reporting level requirements, 58
health and safety work program, 26–29
history of, 7, 14
and human rights, 20–21
and indigenous peoples, 19, 21
material stewardship work program, 8, 29–30
and MCA, 68–70
member reporting, 30–31
membership, 14–17
mine closures, 585
mine water management solutions, 448–451
partnerships, 31–33
position statements, 18–19
social and economic development work program, 8, 20–23
See also 10 Principles for Sustainable Development; Global Reporting Initiative (GRI)

Kentucky, 681–686
Koolyanobbing Iron Ore Project, 277–287
conservation status review, 286
field surveys, 278–283
spider relocation, 284–286
Koolyanobbing joint project
origins, 263–267
outcomes, 269–274
scope, 267–269

Land management
Laurentian Vision Partnership (LVP), 716–722
Western Mesabi Mine Planning Board (WMMPB), 713–716
See also Land-use planning; Natural resource management
Land-use planning, 76–77, 577–581
habitat designations, 298
and indigenous peoples, 145–147
land-use hierarchy, 592
Laurentian Vision Partnership (LVP), 716–722
Legacy mines, 25, 32
Lemeisa, 497–512

MAC. *See* Mining Association of Canada (MAC)
Malaria, 27
Materials stewardship, 29–30, 57–58
MCA. *See* Minerals Council of Australia (MCA)

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Meirama Brown coal mine, 497–500
permit issuing, 502–506
pit lake characteristics, 507–511
pit lake description, 500–502
pit lake flooding, 506–507
Mercury, risk management of, 18
Mesabi Iron Range, 521–523
Laurentian Vision Partnership (LVP), 716–722
taconite tailings management, 524–550
Western Mesabi Mine Planning Board (WMMPB), 713–716
Metals, exposure limits for, 28
Metapopulations, 289
Mine disasters. *See* Disasters
Mine planning, and climate change
closures, 339
development, 336–337
exploration, 335–336
operations, 334–335, 337–339
Mine Safety and Health Administration (MSHA), 49, 757, 762
Mine water
biological treatment processes, 469–470
chemical treatment processes, 467–469
EU definition, 493
European law, 492–497
ICMM solutions, 448–451
ion exchange treatment processes, 467–469
passive treatment processes, 469–470
physical treatment processes, 465–466
treatment, 437–438, 465–471
vacuum membrane distillation (VMD), 482–484
Water Framework Directive (WFD), 493–497
See also Acid mine drainage (AMD); Water; Water management
Mine Water Solutions Conference, 451–453
Mineral revenues and royalties, 18, 138
Minerals Council of Australia (MCA), 9–10, 80–81
Aboriginal and community outreach, 93–96
alternative frameworks, 76–77
and biodiversity management, 77–78
and COIs, 92
and the EVF, 70–73
and ICMM guidelines, 63, 68–70
regulatory framework, 66–67
stakeholder interests, 78–80
sustainability efforts, 67–68
and the WAF, 73–76
Mining
and environmental review decision making, 733–735
overview, 726–729
regulatory oversight, 729–732
and uncertainty, 732–733
See also Adaptive environmental management plan (AEMP)
Mining, Minerals and Sustainable Development (MMSD) project, 6–7, 14, 32
Mining Association of Canada (MAC), 10, 85–86
biodiversity conservation management, 101–104
crisis management, 99–101
health and safety management, 104–108
tailings management, 90–93
and TSM program, 86–90
See also Towards Sustainable Mining (TSM) Program (MAC)
Minnesota
Hibbing Taconite Company case study, 709–710
Laurentian Vision Partnership (LVP), 716–722
Mesabi Iron Range, 521–523
mining industry history, 705–708, 712
Minnesota Steel case study, 444–448
United Taconite case study, 708
Western Mesabi Mine Planning Board (WMMPB), 713–716
Minnesota Steel, 444–448
Molycorp Inc., 347–369
Mountain Pass facility, 350
See also Project Phoenix
MSHA. *See* Mine Safety and Health Administration (MSHA)

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National Environmental Policy Act (NEPA), 729–730, 742–744
Natural gas, 358–359, 364, 367–368
Natural resource management, 76–77
  See also Land management; Land-use planning; Sustainable development
Natural-novel ecosystems paradigm, 610–611, 612–615
  abiotic management, 620–623
  biotic management, 623–627
  consequences for mine-site rehabilitation, 616–618
  determining ecosystem type, 618–620
  and habitat development, 627–629
  and soil, 623–625
  and vegetation, 626–627
Nhulunbuy Indigenous VET program. *See* Vocational educational training (VET) programs
Northern Australia Bauxite and Alumina Company (NABALCO), 119–123
Northern Dynasty Minerals, 452
Northern Yilgarn project. *See* Koolyanobbing joint project

Offsets, 77–78, 98
Olympic Dam, 449
OMSES. *See* Optimal mine site energy supply (OMSES)
Open pit mines, 397–398, 417–421, 490–491, 601, 715
Optimal mine site energy supply (OMSES), 318–319, 389–390, 426–427
  application examples, 415–426
  connection distance analysis for remote mines example, 421–423
  demand consolidation example, 425–426
  and energy resources, 403–412
  energy usage patterns, 392–403
  load profiles, 400–403
  mathematical programming optimization framework, 390–392
  open pit mine example, 417–421
  operational considerations, 410–412
  renewable energy technologies, 407–410
  resilience map example, 424–425
  storage systems, 405–407
  superstructure modeling, 412–415
Ovis canadensis nelsoni, 304–314

Paste plants, 361–362
Pebble Limited Partnership, 452
Pebble Project, 452
Pit lakes, 490–491
  and European law, 492–497
  Meirama Brown coal mine case study, 497–512
  Water Framework Directive (WFD), 493–497
Probabilistic analysis, 732–733
Project Phoenix, 318
  background, 348–352
  design details, 361–364
  electricity, 358–359, 364
  goals, 350–352
  greenhouse gas emissions, 367–368
  realized benefits, 364–368
  tailings management, 353–355, 361–362
  wastewater management, 356–358, 359–360, 363, 365–366

Quintette Coal Mine Project, 243–253

Rare-earth elements (REEs), 348–349
Reclamation, 339–340, 342, 450–451, 577–581, 740
  Hibbing Taconite Company case study, 709–710
  of tailings basins, 543–549
  See also Forestry Reclamation Approach (FRA); Meirama Brown coal mine
Recycling
  East Sullivan mine case study, 566–567
  wastewater, 357–358, 359–360, 363
Regulations
  Australia, 65–66, 640–642
  Canada, 244–246
  emissions reporting, 343
  financial assurance, 738–741
  land-use planning, 76–77

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MCA framework, 66–67
Meirama Brown coal mine, 502–506
mine closures, 585–586
and mine disasters/accidents, 756–760, 765–766, 768–771
and mine water treatment, 437–438
and product responsibility, 52–53
reforestation, 675–677
Stawell Gold Mine, 640–642
surface mining, 664–666
taconite tailings, 522–523
United States, 706–708, 729–732
Western Mesabi Mine Planning Board (WMMPB), 713–716
See also Adaptive environmental management plan (AEMP)
Rehabilitation, 577–581, 587–588, 629–630
abiotic management, 620–623
biotic management, 623–627
ecosystem goals, 618–629
environmental, 26, 77
goals, 609–612
and habitat development, 627–629
natural-novel ecosystems paradigm, 612–618
soil influence, 623–625
Stawell Gold Mine case study, 639–659
vegetation influence, 626–627
Renewable energy technologies, 407–410, 600–601
Resettlements, 57
spider populations, 284–286
See also Communities of interest (COIs)
Resilience maps, 389, 424–425
Revegetation, 299–303, 342
Stawell Gold Mine case study, 639–659
See also Forestry Reclamation Approach (FRA)
Rio Tinto
Argyle mine case study, 449
CEMP case study, 182–211
community scorecard case study, 182–211
Eagle Mine case study, 155–181
Risk management, 4–5
Rio Tinto, 163–167
San Bernardino Mountains case study. *See* Carbonate Habitat Management Strategy
Savage River Rehabilitation Project, 564–566
Social license, 111–114, 697
Solar energy, 408
South Dakota
Homestake mine case study, 450–451
Spain
and European law, 492–497
Meirama Brown coal mine case study, 497–512
Spiders, 277–287
Stakeholders
defined, 730
and MCA, 78–80
See also Communities of interest (COIs)
Stawell Gold Mine case study
conclusions, 658–659
discussion of results, 653–657
field methods, 642–643
legislation and policy, 640–642
revegetation data analysis, 643–646
species diversity results, 646–653
Stewardship
materials, 29–30, 57–58
process, 29
product, 29
Subsistence mining. *See* Artisanal and small-scale mining
Surface mines
energy consumption, 397–398
See also Open pit mines
Surface Mining Control and Reclamation Act (SMCRA), 664–666, 676–677
Sustainability
Australia, 67–68
as a business concept, 4–5, 349–350, 369, 697
defined, 1, 2–4, 6
economic, 598–603
of vacuum membrane distillation, 484–485
Sustainability reporting
criticisms of, 31
defined, 41–42

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metrics, 42–53
See also Corporate social responsibility (CSR) reports; Global Reporting Initiative (GRI)
Sustainable development
10 Principles for Sustainable Development, 7–8, 13, 17, 69–71
Brundtland definition of, 6, 697
innovation and technology development, 710–711
MCA principles, 68–70
and mine closures, 583–586
resource conservation, 710
resource protection, 710
reuse of resources, 711
Sustainable Development Framework (SDF), 7–8, 13, 15, 31

Taconite
Mesabi Iron Range, 444–446, 521–523
tailings management, 524–550
Tailings management, 55, 519–520
basin dams, 524–543
Benambra Legacy Tailings, 567–568
Elliot Lake and Copper Cliff tailings, 570
MAC management of, 90–93
Project Phoenix, 353–355, 361–362
storage methods, 542–543
taconite tailings, 524–550
Waite Amulet tailings storage, 568–570
Taxation, 23, 410
TBL. *See* Triple bottom line
Tennessee, 677–680
Towards Sustainable Mining (TSM) Program (MAC), 10, 85
Aboriginal and Community Outreach protocol, 95–96
Biodiversity Conservation Management Framework, 101–104
Crisis Management Planning protocol, 99–101
Energy and GHG Emissions Management protocol, 96–99
program details, 86–90
Safety and Health protocol, 104–108
Tailings Management protocol, 91–93
See also Mining Association of Canada (MAC)
Traditional ecological knowledge (TEK), 247, 250, 253–254
Triple bottom line, 4, 41–42, 697
Tuberculosis, 27

Underground mines
energy consumption, 396–397
energy load profiles, 400–403
geothermal energy recovery, 371–378
Olympic Dam case study, 449
UNESCO World Heritage Sites, 24, 32, 603
United Taconite, 708
Unity of Place, The (Plastrik), 155–181

Vacuum membrane distillation (VMD), 472–473, 485
mass transfer, 474–477
membrane characteristics, 473–474
membrane fouling, 478–482
operation, 477–478
performance, 478–482
process for mine water treatment, 482–484
sustainability assessment, 484–485
Virginia, 686–694
Vocational educational training (VET) programs, 112
ALERT program, 123–131, 132–137
outcomes, 140–145
program assessments, 131–140
Ralpa and Goyurr programs, 125–131, 137–140
YNOTS program, 122–123

WAF. *See* Water Accounting Framework (MCA)
Waite Amulet tailings storage, 568–570
Walking the Talk: Community Rating of Eagle's Social Performance (Dixon and Zandvliet), 212–229
Waste rock, 519–520
Water, 24–25, 431–432
aquaculture, 602–603

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Australian water sector, 73–76
characteristics of mine water, 462–465
and climate change, 337–339
geothermal energy recovery, 371–378
hydroelectricity, 407–408
Mine Water Solutions Conference, 451–453
mining and processing uses, 434–436
sources of mine water, 436–437
wildlife water systems, 311–313
See also Acid mine drainage (AMD); Bruce Mines case study; Pit lakes; Tailings management
Water Accounting Framework (MCA), 63, 66, 68, 69, 73–76, 80
Water Framework Directive (WFD), 493–497
Water management, 433–434, 453, 489–491
Argyle mine case study, 449
climate solutions, wet/dry, 452–453, 454–458
closures, 599–600
deterministic modeling, 442–443
Homestake mine case study, 450–451
and ICMM, 448–451
mass balance models, 438–444
Olympic Dam case study, 449
Pebble Project case study, 452
stochastic modeling, 442–443
in tailings basin dams, 536–542
wastewater management, 356–358, 359–360, 363, 365–366
Water Framework Directive (WFD), 493–497
zero surface water discharge strategy, 444–448
See also Dams, tailings; Pit lakes; Recycling; Water Accounting Framework (MCA)
Weather
vs. climate, 323–324
extreme, 330–334, 341–343
and recent climate, 326–328
West Moberly First Nations, 243–253
Western Australia Department of Environment and Conservation (DEC), 263–274
Western Mesabi Mine Planning Board (WMMPB), 713–716
Whitehorse Mining Initiative, 10, 86
Wildfires. *See* Fire management
Wildlife, 250–251, 272–274
bighorn sheep, 304–314
desert tortoise, 365
spiders, 277–287
Wind energy, 408

Yilgarn Region, Australia. *See* Koolyanobbing Iron Ore Project; Koolyanobbing joint project
Yolngu clans (Australia), 117–121
See also Vocational educational training (VET) programs

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ISBN 978-0-87335-373-1
90000
9 780873 353731