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PROJECT MANAGEMENT AND IMPLEMENTATION

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ENVIRONMENTAL PLANNING FOR MINE CLEANUP AND DEMOLITION ACTIVITIES

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ABSTRACT

Environmental planning for final cleanup and demolition of mining facilities is a critical step in the overall reclamation of these sites. Identification and proper handling of a myriad of waste streams is important to complete before demolition of facilities commences. Additionally, issues such as utilities, soil and water pollution control, historic concerns, and permitting considerations must all receive careful consideration prior to demolition contractors mobilizing onsite. These decisions can affect the schedule and cost of the demolition activities because they may control how the demolition contractor will conduct his activities. Surveys should be completed to identify special building materials that may need to be abated prior to demolition such as asbestos and lead-based paint. Potentially recyclable materials should be identified and characterized to assess the owner's liability if these materials are recycled including: scrap steel, processing equipment, brick, and wood. Major demolition waste streams also need to be characterized for disposal in on-site or off-site landfills. Finally, all these characterization and environmental planning decisions should be documented in facility records, and written guidance on these matters should be prepared for the demolition contractor before he finalizes his bid for the work. The authors demonstrate how all this was done to plan for the demolition of the mill and numerous support facilities at the renowned Homestake Mine in Lead, South Dakota.

PROJECT SETTING AND DESCRIPTION

The Homestake Mine is located within the northern Black Hills in the town of Lead, South Dakota. During its 125-year life (1876 - 2001), mining was conducted both above and below ground, ultimately reaching a total depth of over 8000 feet. Mineral processing at the mine occurred at several sites, and included various methods such as gravity separation, mercury amalgamation, Merrill-Crowe zinc precipitation, carbon adsorption, and cyanide extraction. Recent surface facilities at the Homestake Mine were comprised of several dozen structures, including the main mill, two large sand plants, thickeners, lab facilities, and various mechanical and administration buildings. Many of these were constructed over the sites of older process buildings dating back to the late 1800's.

The Homestake Mine announced its shutdown in September of 2000, and in December of 2001 the last ore was mined. Final processing and gold recovery efforts continued until early the following year, and demolition of the first surface facilities was initiated in June of 2002. A total of 40 million ounces of gold were produced during the life of the Homestake Mine, of which over 60,000 ounces were recovered during the 2001 - 2002 cleanup and closure efforts alone. Another item of note occurred in December of 2001, when Barrick Gold Corporation merged with Homestake Mining Company, creating the third-largest gold mining company in the world. Reclamation and closure plans did not significantly change, as both companies are at the forefront of responsible mine operation and reclamation. Homestake Mining now operates as a wholly-owned subsidiary of Barrick Gold Corp.

ESTABLISHING CRITICAL PATHWAYS FOR THE PROJECT

Identifying critical pathways and anticipating "bottlenecks" was imperative in the planning of the surface facility demolition. Several noteworthy areas considered early in the planning phase are summarized below:

- Overall Project Schedule: The initial project involved the demolition of 28 surface structures down to their foundations. In order to have this completed in a region with a relatively short construction seasons, it was imperative that defined timelines were developed, followed, and met. Key personnel were selected for implementing and tracking all tasks. Bidding and contractor selection was accomplished as efficiently as possible to get these personnel involved in planning as well.
- Personnel: A primary goal was to retain and use existing employees wherever possible. This often involved moving employees from their existing roles into new environments particular to the mine shutdown, typically requiring some retraining. The benefit in keeping these individuals rather than hiring outside contract labor was in the retention of their institutional knowledge of the facility.
- Interfacing with Operations: Final gold recovery efforts were still ongoing in the early months of 2002, sometimes creating difficult planning scenarios for the demolition team. Remaining personnel were often charged with multiple responsibilities significantly different than those they were accustomed to while the mine was operating, at times mandating additional training.
- Interfacing with Community: Potential conflicts with city utilities such as power, water, street closure/utilization, noise, air quality, and general traffic patterns were identified and mitigated.
- Material Disposition: Safety, environmental, and cost concerns all were key factors in determining ultimate material disposition. Detailed inspections and procedures were developed for each facility to identify materials of concern. An on-site landfill was specifically permitted for this project to accept all demolition materials other than those shipped out for recycling or those identified as hazardous waste.
- Permits & Notifications: The age of many of the structures mandated historical consideration. Other necessary permitting and notifications had to also be planned for, such as asbestos abatement and RCRA-related sampling and follow-up. Permits requiring public notice periods were identified and submitted early enough to not hinder the schedule.
- Manpower & Equipment: With the work force being reduced weekly, the demolition preparatory work had to be carefully orchestrated in order to not create labor shortages. Other mines within the company were also beginning to salvage equipment for their own use, creating the need to identify and tag critical spares for remaining operations.
- Site Utilities: Electricity, gas, water, sewer, and compressed air all had to be considered. Additionally, many city utility lines ran through or beneath the existing project site. Determining where and when they could be disconnected without impacting remaining work efforts or the community was critical. If re-routing were necessary, routes, which could be utilized, that wouldn't interfere with demolition efforts were implemented.

- Weather: The Black Hills area generates extreme weather patterns, including heavy snows, rains, wind, and hail. Time contingencies allowing for weather delays had to be considered in planning all activities related to the demolition project.

REGULATORY AND POLITICAL CONCERNS

Homestake insured community concerns were identified and addressed throughout the project, and assigned an individual specifically to the task of community affairs relative to the mine closure. Both social and economic concerns were expected, not only from layoffs associated with the mine closure, but also changing attitudes associated with the end of a mine, which was integral to the community for over 125 years. Prior to demolition, alternate uses for buildings slated for removal were considered, as well as traffic impacts, parking, noise, dust, and overall aesthetics. Community meetings were held to allow local residents to voice any concerns over the upcoming project, and a specific "Complaint Hot-Line" was initiated for phone calls. Tours were also conducted daily through the local visitor's center.

Agency contacts were initiated early to provide ample time for agency input. In a small community such as Lead and in sparsely populated states such as South Dakota, regulators are often more accessible to the general public than in more urban regions. Regular communications as to project progress and planning were necessary to keep these agencies from feeling uninformed or unable to answer constituent's questions. Weekly meetings were also conducted to involve interfacing with local law enforcement and emergency services.

A number of general regulatory hurdles were identified early in the project-planning phase, specifically those related to:

- Identification and characterization of waste streams that would or might be produced during demolition;
- Management of demolition wastes in compliance with applicable State and Federal requirements; and
- Determination of applicability of regulations for certain beneficiation and mineral processing materials.

The demolition project was also critically reviewed to identify other waste streams that were likely to be produced during the demolition work. These included:

- Containers of chemical products, lubricants, reagents, and maintenance materials;
- Electrical equipment with possible PCBs or mercury content;
- Asbestos containing materials;
- Wood or steel coated with lead paint;
- Tanks, piping, sumps, and other equipment containing mill slurry or reagents;
- Scale, sludge, rock and other beneficiation-related materials under tanks and floors;
- Recyclable material such as scrap metals, equipment, and possibly wood from old structures and wood tanks;
- Petroleum contaminated soil or concrete from past spills;
- Wood treated with creosote and other preservatives;
- Common demolition debris;
- General trash or other municipal solid waste, and;
- Stormwater runoff from the site.

Once the potential waste streams from the decommissioning and demolition project were identified, specific management strategies were developed for each waste stream. These

management plans addressed the practical aspects of how, when, and where the materials would likely be produced; if they were recyclable materials or wastes; the economic aspects and comparisons related to any management options; and how the materials were regulated by local, State, and Federal requirements.

All the demolition waste streams were objectively reviewed with regard to how they were regulated under State and Federal hazardous waste rules. A number of exemptions from these rules were identified for certain waste streams, these were found to include:

- Scrap metal that was recycled [40 CFR 261.6(a)(3)],
- Mill sludge, scale, and other beneficiation or processing material that was recycled for gold recovery [40 CFR 261(a)(16) and 261.6(a)(2)],
- Lamp bulbs, batteries, and thermostats that were removed and handled as universal wastes [40 CFR 261.9],
- Mill equipment or debris that was in contact with beneficiation slurries, reagents, and solutions [40 CFR 261.4(b)(7)],
- Wood that is arsenical treated [40 CFR 261.4(b)(9)],
- Wood that is recycled for further use [40 CFR 261.2(e)(1)] and
- Used oil that is recycled [40 CFR 261.6(a)(4)].

These exemptions were incorporated into the planning of the materials management for each of the demolition waste streams. Use of these exemptions was also documented in the planning records.

PRE-DEMOLITION ACTIVITIES

Safety and environmental track records were considered paramount in selecting a demolition contractor for this project. Because of the mine's location within the city limits, the utmost precautions had to be taken to insure the safety and welfare of not only the public, but also the remaining workforce and the environment. Numerous walk-throughs and screening interviews were conducted with prospective bidders to insure all issues were clearly identified, including the difficult topography and adjacent surface water bodies. Bidders were asked to provide templates of various documents such as Health & Safety Plans, Stormwater Plans, and methods for spill prevention, noise, and dust control. The successful bidder was required to submit acceptable final plans before commencing work.

Utilizing institutional knowledge from long-term employees along with historical documents, operating plans, and records, areas with pipelines and tanks long-since taken out of service were identified, inspected, drained, and rinsed as necessary. Personnel were assigned to catalog and file historical drawings and records to allow for retrieval in future years. Air and noise monitoring, including asbestos, were conducted in the work area and nearby community to establish a database of background levels prior to demolition commencement. Monitoring records from previous years were also used when appropriate. As the demolition preparatory work progressed, field surveys and inspections of buildings was ongoing to insure an up-to-date record was available for the different waste streams that would be generated.

Examples of these waste streams are described below:

- Containers: Inspections and inventories were made of tanks and containers of petroleum products, reagents, maintenance materials, and all other containerized material that would need to be emptied or removed from within the battery limits of the demolition project before demolition would begin. The description of these tanks and containers, along with

their contents, was entered into the planning records. Where a tank or container held a material that could not be readily identified, a sample was taken for characterization.

- Lead Paint: A survey was made for the presence of lead paint on all like-painted surfaces throughout the facilities and buildings to be demolished. The survey was conducted with a portable x-ray fluorescence (XRF) instrument. A report on the survey was prepared for incorporation into the planning records and to be transmitted to the demolition contractor for their use in complying with applicable OSHA regulations. Follow-up sampling was then conducted on specific areas based on the XRF study to determine RCRA status.
- Asbestos: A comprehensive asbestos survey had been conducted throughout the facilities in previous years. This information was copied into the project records and also provided to the demolition contractor who would be responsible for abatement of the asbestos as part of demolition activities. The asbestos consultant that completed the initial inventory was rehired to provide quality control inspections for Homestake during the abatement activities.
- Gold & Other Metals: The mill staff conducted sampling of certain mill equipment (scale and sludge), sumps, and floors along with the refinery floors and walls to characterize any mercury and gold contents of these materials. Material found to have sufficient metal content to be valuable was removed with hand tools and power equipment for recycling back to the mill circuit for recovery. Residual slurries and other process solids throughout the mill area were also picked up and recycled to the mill. The timing of this decommissioning activity was critical because certain parts of the operations had to be taken out of service for this metal recovery operation to occur while parts of the mill circuit were still operating. Records of this recovery process were kept including the chemistry and amounts of materials recycled.
- Electrical Equipment: As buildings and facilities were taken out of service, a mill maintenance crew inspected them for the presence of electrical equipment that might contain PCBs and/or mercury. This was especially important within certain motor control centers and control panels that had not been previously inspected because they were energized. Records of these inspections were kept for the project records. At this same time, lights, batteries and thermostats that could be managed as universal wastes were also removed.
- PCBs: A previous survey of transformers, switches and other large electrical equipment had been conducted to identify PCBs. This information was copied to the project records and used to identify potential areas where past spills may have contaminated floors or ground under electrical equipment that previously contained PCBs. As the equipment was de-energized and removed, surveys were conducted of specific sites to determine if there was PCB-contaminated concrete or earth that needed to be removed.
- Demolition Debris: Field surveys were conducted of the buildings to be demolished to describe each building or facility as a potential separate demolition debris waste stream. Approximate volume percentages of each major building component (walls, frame, roof, doors, etc.) were made for each building. Also, using the previous lead paint survey results, representative samples were taken of the different building components and composited to make a representative composite sample of the potential demolition debris for the entire building. Each of these composite samples was then analyzed for

hazardous waste characteristics. The sampling records, composite sample designs, and analytical results were entered into the project records.

- Concrete and Soil: A survey of the general mill site was conducted to identify potential locations of past spills of reagents, mercury, petroleum, mill slurries, and solutions where concrete surfaces or soil may have been contaminated. Once these sites were identified, grab samples of the concrete or soil were taken. Concrete cores were obtained from 22 locations and sampled in four intervals within the top 2.5 inches. Soil samples were taken with a Geoprobe under the concrete in some locations and outside of the buildings in other locations. Samples of concrete and soil were assayed for the RCRA metals (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver), total extractable petroleum hydrocarbons, and PCBs. A report was prepared by the consultant who did the work reporting and interpreting the results.

To assist with legal and regulatory documentation for the project, and to provide clear guidance to the demolition contractor and Homestake field personnel who would be involved with the demolition, a comprehensive Demolition Project Environmental Guidance Document was prepared for the project. This document assembled in one place the important environmental compliance information that was specifically applicable to the project. The information contained in this report is best shown by the table of contents for the report that is reproduced in Table 1.

A very important part of the Environmental Guidance Document is Section 5 that includes detailed descriptions of the designated management procedures for each of the main waste streams that were expected to be produced during the project. Each of the major waste streams had a narrative description of what materials were included in the waste stream, its physical characteristics, how it is regulated by State or Federal rules or site-specific permits, and specific handling procedures for the material. This part of the guidance manual was reviewed by legal counsel to make sure that the legal and regulatory aspects of the planning were correct and properly described.

The completed Environmental Guidance Manual was appended to the project specifications for use by the demolition contractor during the project, and was also included as an attachment to the contract itself. The Manual included requirements for verification and documentation that all applicable plans were being followed.

The final disposition of the major waste streams was determined through the environmental planning efforts. Interaction with the demolition contractor on feasibility and costs for the management of the different materials provided the opportunity to consider recycling potential as well. The major waste streams were handled in the following ways:

- Containers of chemical products, lubricants, reagents, and maintenance materials were either transported to other mine facilities for direct use, transferred to Homestake employees for their use, picked up by the original vendor for restocking, or disposed of in off-site facilities.
- All hazardous wastes were properly packaged for transportation and disposed of off-site in properly permitted hazardous waste management facilities.
- PCB containing electrical equipment was disposed off-site in a permitted facility.
- Mercury was recycled off-site.
- Asbestos containing materials were properly packaged and disposed of in a solid waste landfill permitted by the state to receive asbestos containing material.

- All wood was disposed of on-site in a lined, solid waste landfill that was specifically permitted and constructed for the demolition project.
- Steel tanks, structural steel, and other recyclable metal was visibly cleaned and transported off-site for recycling as scrap metal.
- Piping and other equipment containing residues or scale that could not readily be removed was disposed of on-site in the demolition project landfill.
- Petroleum contaminated soil was disposed off-site in a properly permitted municipal landfill or taken to a permitted land farm.
- Municipal-type trash such as paper, cardboard, and plastics were collected prior to building demolition and disposed of in local municipal landfills.
- Common demolition debris was disposed of on-site in the demolition project landfill.

Table 1. Table of Contents for Environmental Guidance Document

**HOMESTAKE MINE
SURFACE FACILITIES DEMOLITION PROJECT
ENVIRONMENTAL GUIDANCE MANUAL**

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ACTIVE DECOMMISSIONING & DEMOLITION

Keeping multiple contractors and multiple tasks on schedule was paramount to successfully completing the project in one field season. Subcontractors involved in the asbestos abatement had to be carefully scheduled to complete buildings in an order conducive to the demolition contractor's schedule. The steep topography of the area mandated the demolition in an uphill manner, and working and storage space for equipment and salvage stockpiles was at a premium due to the proximity to homes, streets, and other structures. Maps were updated continuously to provide all personnel involved with up-to-date schematics for project scheduling and staging.

The contractor, along with company representatives, were involved with community meetings and "question and answer" sessions to familiarize the community with personnel, proposed methods of demolition, schedule, and expected traffic impacts. During the course of the project, several comments were actually received from community members commenting as to how little impact they actually observed. Employment opportunities for local citizens were also made available whenever possible. Typical jobs included hand laborers, water truck operators, and flagmen.

Adverse environmental impacts did not develop, as the contractor adhered to their spill prevention program as well as site-specific duties for such items as dust control and stormwater protection. Continuous environmental monitoring by both the company and the contractor around the project site confirmed these results and provided documentation for the project record. A Homestake environmental representative was at the project site full-time providing additional photographic and text records of the project progression.

The extensive investigative and inspection work completed in pre-demolition activities proved successful in that no significant new wastes were uncovered during actual demolition, and no environmental spills or accidents occurred. Waste streams and other materials were managed according to the plans as follows:

- Electrical Equipment: Light ballasts, motor control centers, transformers, switches, control instruments, and other electrical equipment were examined and, as necessary, sampled for the presence of PCBs and or mercury. Usable electrical equipment was sold. Mercury-containing instruments and switches were packaged and shipped off-site for retorting and recycling of the mercury. Non-salable electrical equipment that was free of fluids or hazardous materials was disposed of in the on-site demolition landfill.

- Gold-bearing Material: Scale, sludge and concrete surfaces with appreciable gold values were removed with hand and power tools from specific equipment, sumps and mill or refinery areas. All of this valuable material was recycled to the mill to recover the gold.
- Mill Equipment: Mill piping, pumps or other equipment that contained mill scale or sludge could not be easily cleaned out for recycling so this material was placed in the on-site demolition landfill. Tanks, crushers, mills, bins, launders and other mill circuit equipment that could easily be cleaned of sludge or scale were recycled off-site as scrap metal. Old wood tanks were examined and sampled for cyanide, arsenic, or other components of mill slurries that could be a concern. None of the concentrations were significantly elevated and the materials were placed in the demolition landfill.
- Building Structures: Structural steel and other recyclable metal that could be removed from the buildings during demolition was shipped off-site to be recycled as scrap metal. All other building materials were disposed of in the on-site demolition landfill. Concrete foundations were not included in the first phase of demolition and were left in place for further investigation and planning related to eventual demolition and regrading of the former building sites.
- Asbestos Containing Materials: The demolition contractor provided asbestos abatement services early in the project. Using existing asbestos inspection documents and current visual inspections by Homestake and the contractor, asbestos containing building materials were specifically identified at the site and removed by trained and licensed workers prior to building demolition. Homestake conducted continual quality control inspections of this abatement activity using the same asbestos consultant who conducted the original inspection project. All removed asbestos was properly encapsulated or otherwise packaged for transportation to an off-site asbestos disposal landfill.
- Containers: Homestake conducted thorough inspections throughout all buildings to identify and remove all containers of petroleum products, reagents, maintenance materials and other chemical products. These were identified, inventoried, sampled if necessary, and either disposed of or recycled off-site. All hazardous wastes were carefully characterized, packaged and shipped off-site for disposal in a permitted facility. Homestake and demolition contractor inspectors carefully reviewed each building for any remaining containers or accumulations of chemical products before each building was demolished to prevent such materials from being incorporated into the demolition debris.
- Universal Wastes: Homestake decommissioning crews, with assistance from the demolition contractor, carefully inspected all buildings and removed all lighting, batteries, and thermostats before demolition began and packaged these materials for handling primarily as universal wastes.
- Beneficiation/Mineral Processing Wastes: Considerable effort was made during decommissioning to remove scale, sludge and mill solutions from the mill circuit equipment and the building floors and sumps prior to demolition. These materials were either recycled to the mill before it shut down or were disposed of in the current tailings impoundment. Any of these materials that were encountered by the demolition contractor were disposed of in the on-site demolition landfill.

POST-MINE USE

There are many factors to consider when formulating post-mine use land planning, nearly all of which can impact a project schedule. It is imperative to not limit or restrict post-mine land use options through the decommissioning, demolition, and reclamation process.

The Homestake Mine has not yet determined a final use of the land involved with this portion of the mine closure project. However, areas such as aesthetics, business opportunity, tourism, community needs, historical perspectives, environmental issues, and public safety are all being considered to leave a positive, post-mining legacy.

MINE RECLAMATION USING DREDGED MATERIALS AND COAL ASH

Preliminary Findings¹

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Bark Camp high wall, 1996



Bark Camp high wall, 2001

ABSTRACT

This is the final report of the project begun in 1995 by Pennsylvania DEP's Bureau of Abandoned Mine Reclamation and the NY/NJ Clean Ocean And Shore Trust, a bistate marine resources commission, to use dredged materials from New York Harbor, amended with pozzolonic wastes, to restore an abandoned strip mine in west-central Pennsylvania.

Since 1998, three quarters of a million tons of amended dredged materials from the Port of NY/NJ were used to return 11,000 feet of a double highwall 120 feet in height to its original contours of 75 years ago. The material was screened and pre-amended for shipping at port-side, railed to the mine site, further amended to initiate a pozzolonic reaction, and placed in lifts to recreate the hillside's original contours, covered with a manufactured soil and planted. Water quality testing from surface run-off and six deep wells below the site over three years showed non-detects for all organics, pesticides, VOCs and semi-VOCs. TCLP testing of the cured material yielded the same results. Over-wintering trout have returned to Bark Camp run below the site for the first time in decades.

The United States moves nearly half a billion tons of dredged materials from its navigational channels annually, while hundreds of individual dredging projects, such as those to restore reservoir capacity, can generate additional hundreds of millions of tons each. The US also

¹ The Final Report for this project was in production at the time of submission of this paper. We here present the project and our preliminary results in advance of the official final report

produces some 130 million tons of coal fly-ash annually. The following examines particulars of each component of this project and summarizes our preliminary findings.

BACKGROUND

Site. The project using fill manufactured from dredged materials and coal fly ash is located on Bark Camp Run, a small tributary to the Bennett Branch of the Sinnemahoning Creek near the town of Penfield in Clearfield County, west-central Pennsylvania.

The Bark Camp Mine Reclamation Laboratory began in the late 1980's as an effort to develop design criteria for artificial wetlands constructed to treat acid mine water. Over the years since then, it evolved into a mine reclamation research/demonstration laboratory, where several important mine reclamation demonstrations have taken place, including the use of fly ash as fill, and the creation of artificial top soils.

The watershed in the state forest portion was extensively mined prior to 1980. Abandoned, unreclaimed surface mines follow the contour of the valley on the west side of the stream from the headwaters to about halfway down the valley. Two coal seams were mined in some places, leaving a 120 foot high wall in two lifts along 11,000 feet of hillside.

Underground mining occurred under the hills on both sides of the valley. The mines were abandoned in the mid 1980's and the entryways closed by pushing rock and spoil material into the surface entrances. Portions of the mine down-dip from the entries, filled with water. The up-dip portions (more than a mile in length in places) flowed into the pool and overflowed through the entries. The resulting discharges from both mines were acid and contained dissolved metals. Sometime in the mid 1980s, the operator abandoned the site.

Process. The project involved dredging in marine and coastal waters in NY/NJ, and transporting the dredged materials to a portside facility located in New Jersey. There, the dredged materials were dewatered, off-loaded, screened to remove oversized debris, pre-amended to stabilize for transport, and loaded into railcars for shipment to Bark Camp. The pre-amended materials were off-loaded from the railcars at the Bark Camp rail siding and hauled in off-road trucks to the processing pad at the mine facility. The pre-amended materials were processed with additional admixtures to create the final manufactured fill product. This fill was spread and compacted in lifts along designated segments of the highwall. Details of the operation are presented in subsequent sections of this paper. This project is notable for several reasons: the magnitude of the AML features addressed; the prevention of AMD at its source, and its place in a larger scheme of the beneficial use of waste materials presently otherwise disposed of.

Abandoned Mine Lands. In 1995, The Bureau of Abandoned Mine Reclamation and the Bureau of Solid Waste and Land Recycling in Pennsylvania's Department of Environmental Protection were approached to examine the possibility of the beneficial use of dredged material in mine reclamation. Pennsylvania is noted for its share of AML problems and their magnitude, estimated as requiring \$15 billion for the basic remediation of over 5600 sites deemed a human health hazard out of their 9000 abandoned mines. Pennsylvania has over 800 incidents of mine subsidence each year; 45 underground mine fires (including the famous Centralia Mine Fire which has burned for 39 years) and 3000 miles of AMD impacted waterways. The fill requirements of these features are immense. Several individual sites (like the Jeddo Mine Tunnel and the twin 32-mile-long crop falls in the anthracite region) require in excess of one billion cubic yards of fill each. The state's fill requirement is in excess of 10 billion cubic yards. Having

successfully experimented with the sealing of AMD-causing formations with fly-ash grouts. PaDEP suggested the examination of the use of the dredged material as an aggregate in a manufactured fill bound with pozzolonic fly ash, another waste disposal problem.

Dredging. On average, the United States annually dredges and disposes 300 million tons of sediments from its ports, dams, reservoirs and navigational channels. However, individual projects exist with like volumes, such as the deepening of channels to accommodate new generation shipping vessels, and the restoration of silted up hydropower reservoirs. The Port of New York/New Jersey alone is expected to generate 250,000,000 tons of dredged material from the deepening and maintenance of its navigation channels over the next 40 years. Dredged material is significant not only for the remarkable volumes generated (for general purposes, a ton of dredged material is equal to one cubic yard of volume) but for the fact that the means of their disposal- ocean dumping- is ceasing to become an option because of concern over the potential bioaccumulation of trace agricultural and industrial contaminants in the marine food chain. The maritime community saw the cost of dredging and disposal go from \$5 per cubic yard to \$125 practically overnight. Maintenance dredging went undone, container ships and tankers had to carry partial loads or transfer cargoes to off shore barges. The 165,000 port jobs and annual \$20 billion contribution to the region's economy was threatened. Relocation of major shipping companies to deeper ports would have impacted the entire northeast region whose imports and exports are served by the Port of NY/NJ.² This regulatory change has impacted the regions economy and employment, imports/exports and transportation patterns, requiring the development of an affordable, long term upland disposal option.

Coal Fly Ash. The physical and chemical properties of coal fly ashes have been studied for over 20 years and their pozzolonic (cementitious) binding properties are well known, being a significant additive in Portland cement. The United States produces an estimated 130 million tons of fly ash annually in the burning of coal that generates half the nation's electricity. However, less than one third of it is used in manufacturing while the rest is disposed of in over 750 sites around the country, from lined landfills to massive open stockpiles. Coal ash disposal has been relatively free of federal regulation, but recently, however, coal ash only narrowly escaped significant regulatory oversight from the US Environmental Protection Agency, with the likelihood of increased scrutiny over the next year.¹ The amount of ash generated will only increase due to energy demand and Clean Air Act requirements for the addition of more scrubbing materials (like lime) during the combustion process. Coal ash's well known property of expansion during chemical hydration also limits the amount that can be used in cement manufacture.

Project Concept. In considering these three problems a pattern of complementarity emerges: massive volumes of disposal materials / massive voids requiring fill, acid generating voids / alkaline materials requiring confined disposal, a problematic wet material / a binder that initiates hydration reactions. It was decided to test the use of dredged material as an aggregate in a fly-ash bound manufactured fill, to restore the original contours of a hillside that was striped into a 120 foot high-wall extending for eleven thousand feet. Since the issues of abandoned mine lands and coal fly ash used in their remediation are well known, this paper will emphasize the dredged material portion of the project. As important as the physical description is a brief treatment of public attitudes towards such projects, and the means of their financing.

² It should be noted here that known or suspected threats to human or environmental health by the disposal of dredged sediments in the ocean is a separate issue from the policy decisions made in the region.

METHODS AND MATERIALS

Dredged material. *Dredged material* is the generic term for the wet sediments removed, or dredged, from navigational channels, reservoirs and so on.³ Because they are in aquatic environments, they are mostly water (usually 65%) with the remaining solid portion being the constituent sediments of natural erosion processes and storm water runoff. Depending on their location along watercourses, the solid portion of dredged materials may range from sand, to a mixture of sand, silt and clay, and up to 7% decaying organic plant matter (common mud). We are here largely concerned with the later characterization, since clean sand is generally used for beach replenishment or aggregate, and particle size is a key factor in contaminant adsorption. This mud is often described as black mayonnaise, its small particle size making it readily adhere to surfaces and its decomposing organic material giving off the smell of hydrogen sulfide. This is true of pristine wetlands sediments as well and is not an indicator of their relative environmental health as sediments. Being mostly water, the material sloshes readily and must be transported carefully, even in barges. Their physical properties are important in considering their handling and transportation, and in their perception by the public. Coming from areas adjacent to human activities, these materials contain a certain amount of natural and man-made debris, and trace contamination of agricultural and industrial runoff, including metals and organic compounds including dioxins and PCBs. The issue of sediment contamination is complex but will be presented here in brief.

Contaminated Sediments. Many of the chemical substances of concern came into question recently with the ability to detect concentrations at parts per trillion and quadrillion. The difficulty arises when societal concerns meet (or ignore) science. The toxicity of a substance involves a complex set of circumstances including species, exposure, pathways, age and sex of subject and so on. Controversy rages over the health impacts of even the more notorious contaminants like dioxin. It is not known what level of trace concentrations of contaminants pose a threat, to humans or the marine environment.

Five major types of pollutants are found in sedimentsⁱⁱ:

Nutrients, including phosphorous and nitrogen compounds such as ammonia. Elevated levels of phosphorous can promote the unwanted growth of algae. This can lead to the amount of oxygen in the water being lowered when the algae die and decay. High concentrations of ammonia can be toxic to benthic organisms.

Bulk Organics, a class of hydrocarbons that includes oil and grease.

Halogenated Hydrocarbons or **Persistent Organics**, a group of chemicals that are very resistant to decay. DDT and PCBs are in this category.

Polycyclic Aromatic Hydrocarbons (PAHs), a group of organic chemicals that includes several petroleum products and byproducts.

³ Dredged Materials should be distinguished from sludge (treated human waste) and other materials, the names of which are often inaccurately applied.

Metals, including iron, manganese, lead, cadmium, zinc, and mercury, and **metalloids** such as arsenic and selenium.

Interestingly, the banning of ocean disposal of dredged materials is in some ways more the result of the continuing momentum of anti-ocean disposal actions over the last century regarding far more obnoxious substances. Ocean disposal of garbage was banned in the 1930's, disposal of acid waste some time after that, treated sewage sludge in the 1980's, and the burning of wooden marine debris out at sea was stopped in the 90's. Now, ocean disposal of even mildly contaminated sediments has been virtually phased out, and it seems that even virgin clay material from the last glaciation will not be ocean disposed.

PaDEP has established a pass/fail standard for maximum levels of contaminants acceptable for this demonstration. A complete list of over 300 analytical parameters sampled for the dredge material project available via their website:

http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/BAMR/bark_camp/barkhomepage.htm

Analytical parameters are general chemistry, inorganics, organics, pesticides and PCB's and are also listed in alphabetical order in the website. Perhaps most easily understood, Pennsylvania will not accept material categorized as hazardous. Ceilings for dioxin levels are at 530 parts per trillion and for PCBs at 4 parts per million (mg/l).

Disposal options became limited to physical decontamination of the sediments, upland disposal, or their beneficial use in brownfields remediation, wetlands restoration or even as daily landfill cover.

Coal Ash. The manufacture of cementitious grouts from ashes for large applications relies upon alkali activation to initiate hydration reactions. Structures dating from ancient Roman and Greek cultures, many still standing today, were constructed from this type of cementitious material. A pozzolan can be defined as a siliceous or siliceous and aluminous material, which possesses little or no cementitious value but will, in finely divided form and in the presence of moisture, react with calcium hydroxide at ordinary temperatures to form compounds possessing cementitious properties.

From the point of view of dredged material disposal, this project amounts to contaminant sequestration. Fine particle sizes in dredged solids provide immense surface areas. A gram of mud has 760 square meters of surface area, providing myriad sites for the attachment of contaminants and the cause of concern when the material is digested by benthic organisms. When the material is hardened into a cement matrix, the same gram of material has a surface area of about 1 square inch, about one-millionth that of the unconsolidated material. The reduction in surface area available to chemical attack alone would be a significant safeguard to the leaching of contaminants. But Toxicity Characteristic Leachate Testing show that the material is chemically bound in the cement matrix, as described below.

PROJECT OPERATIONS

It is important to note that the demonstration site was chosen strictly for scientific reasons and not logistical ones. In many ways Bark Camp is not an ideal site, requiring much re-handling and transportation of the material on site.

The dredging is performed utilizing a dredge-plant mounted on a spud-barge and equipped with various types of clamshell buckets, and two hopper barges. Local tug service is used to transport the hopper barges to and from the transfer facility.

Off-loading of the dredged material at the facility is accomplished utilizing a 50-ton crane equipped with a clamshell bucket. As necessary, the loaded barges are moored at the facility to allow the sediment to settle for dewatering of the barges prior to off-loading. Water decanted from the loaded barges is pumped through a particulate filter to portable frac-tanks. After an adequate period of settling, the water in the tanks are tested for compliance with discharge criteria contained in the Water Quality Certificate. Upon confirmation, the decanted water is discharged from the tanks to the local waterway.

The raw dredged material is off-loaded into a large receiving hopper and through a series of screens to separate debris from the sediment. This debris includes tires, pilings, timbers, large metal objects, concrete, and similar unsuitable materials and is staged for transport and disposal at an alternate approved disposal facility. The dredged material is placed into a pugmill where it is mixed with coal fly ash to pre-amend (physically stabilize) the material for transport to Bark Camp. The raw material is solidified to ensure that no free liquid is present in the material that may leak out or shift the load during transport. From the pugmill, the pre-amended material is discharged via a radial-stacking conveyor to a temporary storage area. The material is loaded from the stockpile into 110 ton gondola rail cars for transport to the Bark Camp Facility.

The pre-amended dredge material is transported to the Bark Camp facility via rail. All rail cars are covered with tarps during transport. The railcars are unloaded at Bark Camp utilizing an excavator located on an elevated off-loading structure. The material is placed directly into off-road trucks and transferred to the final processing area. There the material is blended with additives in a pugmill system according to a pre-determined mix design, and discharged onto a radial stacking conveyor. The final manufactured fill is transported utilizing off-road trucks to the reclamation area of the highwall. The fill is spread in two-foot thick lifts with a low-ground-pressure bulldozer and compacted using a vibratory roller.

Sampling And Testing Protocol. This project is conducted pursuant to all local, state, and federal regulations applicable to the dredging, processing, transport, and beneficial use of the dredged sediments and additives. Certain permits were required for each location and/or operation of the project. The testing protocols include full Toxicity Characteristic Leaching Procedure (TCLP), organics, inorganics, metals, pesticides, herbicides, PCBs and dioxin/furans. Composites taken during shipping undergo TCLP and analysis for PCBs and dioxins. The final product undergoes the Synthetic Precipitation Leaching Procedure (SPLP).

Quality Control measures for this project included characterizing the chemical and/or physical properties of the raw dredged sediment and any additives utilized in the treatment process prior to commencing dredging. The physical and chemical properties of the additives were determined from testing and analytical results provided by the generators of these materials. Vendors supplying coal ash products were required to demonstrate that the ash materials meet the PADEP Module 25 chemical criteria for ash placement in mine reclamation. Additionally, Material Safety Data Sheets (MSDS) that are available for these materials are kept on file in the administrative office at the Bark Camp facility.

The chemical analysis protocol for the dredged sediment intended for Bark Camp consists of three stages. These include the core sampling and analysis of in situ dredged material (Stage I); the sampling and analysis of the dredge material at the portside offloading facility, which is intended to confirm that the material being shipped is similar to the in situ materials (Stage II); and the sampling and analysis of the treated materials at the Bark Camp facility to assure that the manufactured materials comply with the criteria established in the Beneficial use Order (BUO), (Stage III).

The sampling and analysis is conducted in accordance with the requirements of the BUO and the New Jersey Department of Environmental Protection (NJDEP) guidance manual entitled The Management and Regulation of Dredging Activities and Dredged Material in New Jersey's Tidal Waters; October 1997. The New Jersey manual (the "Guidance Document") specifies sampling and analytical requirements for upland disposal and beneficial use of dredged materials in the State of New Jersey. The manual specifies sampling procedures and frequency requirements, target analyte lists, analytical test methods to be used, and acceptable method detection limits for in-situ sediment samples.

A Sampling and Analysis Plan (SAP) for the in situ sediment is prepared for this project and submitted for the NJDEP and PaDEP's review and approval. Individual core samples of the in situ sediment are taken to the proposed project depth plus allowable over-dredge. Composite samples are prepared from the individual core samples. The individual core and composite samples are subjected to the analysis specified in the Guidance Document and the approved SAP.

Bench tests utilizing the sediment from the in-situ testing and various percentages of additives are performed to simulate the creation of the manufactured fill. The bench test product samples are analyzed in order to chemically and physically characterize the manufactured fill and to determine the ability of the fill from each mix design tested to stabilize chemical constituents found in the in-situ sediment. The analytical and test results for the Stage I in-situ sediment samples are submitted to the NJDEP and PaDEP for their respective review and approval. NJDEP issues the Waterfront Development Permit permitting dredging and PaDEP issues written approval for use of the dredged materials at Bark Camp.

Stage II testing occurs at the portside facility and is performed to confirm that the pre-amended dredged material is physically and chemically characteristic of the material sampled in Stage I. This confirmatory sampling is performed pursuant to the BUO, at a frequency of one composite per 25,000 cubic yards of dredged material. Accordingly, one (1) composite sample is chemically analyzed and geotechnically tested pursuant to the requirements specified in the BUO. The analytical and test results are reported to the PADEP for its review and information.

The final stage (Stage III) of the QA process is performed after the final amendment of the dredged sediment at the Bark Camp facility. One (1) composite sample of the manufactured fill is obtained pursuant to the BUO requirement of one composite sample per every 25,000 cubic yards of material. The composite sample is chemically analyzed and geotechnically tested pursuant to the specific requirements specified in the BUO for the manufactured fill. The analytical and test results are reported to the PADEP for its review and information.

A tabular summary of the analytical results for a set of in situ sediment samples, the pre-amended (portside) dredge material, and the manufactured fill placed at the Bark Camp facility are presented in the above listed PADEP website. A copy of the geotechnical test results of the manufactured fill sample is also presented there. These data demonstrate that the technology producing the manufactured fill derived from the dredged material has effectively stabilized the chemical constituents present in the in-situ dredge material, and that the manufactured fill is physically competent as an engineered fill material suitable for use in mine reclamation.

Quality Assurance measures (Stages II and III) for this project are implemented to confirm that the chemical and/or physical properties of the pre-amended dredged material transported to Bark Camp and the manufactured fill are similar to that of the in situ sediment sample properties.

CONCLUSIONS

The following conclusions can be made from monitoring the material first placed at Bark Camp three years ago and monitored since, and the material placed since then.

By adding and mixing the dredged material with specific quantities and sources of coal ash, the dredge material was successfully pre-amended at the portside facility, rendering a material that could be handled and transported by common earth handling techniques and equipment.

All railcars arriving at Bark Camp were successfully off-loaded at the rail siding with little need to modify the equipment or techniques planned for this aspect of the project. Laboratory chemical analyses and geotechnical test results indicate that the processes creating the recyclable fill manufactured at Bark Camp have successfully solidified and chemically stabilized the dredge material.

Over 80,000 analyses of dredged material products were performed by PADEP alone, from pre-dredging sampling to surface and ground water monitoring. DEP analyzed for over 250 substances in most of the samples even though only a small percent of the analytes had reportable results. For three surface and six groundwater-monitoring points, 81% of the analytes were not detected in the DEP tests.

The long-term ability of the manufactured fill to sustain these properties will be monitored via visual observations and groundwater & surface water quality monitoring at the Bark Camp facility by PADEP.

The project has had some significant benefits. The site, which was a disaster before DEP began to use it as a research facility, has been substantially improved. Surface runoff from the site has been controlled. The coal silt and refuse has been disposed in a safe manner. The abandoned surface mines have been returned to the original contour. All this was accomplished at little cost to the Commonwealth. Further, the placement of the fill material in the surface mines is sure to reduce the amount of water seeping into the deep mines. This should show an improvement in surface and groundwater quality during periods of normal stream flow. Synthetic Precipitation Leaching Procedure (SPLP) testing of the final product emplaced in the high wall shows non-detects for metals and organics

Water quality testing from six deep wells below the site and surface water collection points all pass drinking water quality standards. Water quality test points, maps and results are available at:

http://www.dep.state.pa.us/dep/DEPUTATE/MINRES/BAMR/bark_camp/WaterQdata/WaterQ.htm

The manufactured fill project has had no negative impacts on surface or groundwater quality. The project site has experienced severe drought conditions over the past two years so there are presently no measurable positive water quality impacts to report.. The stream flows are lower than normal fed in a large part by groundwater affected by coal mining. The discharge from the deep mines has been fairly constant over the same time frame. The few analytes that exceed the allowable limits are mostly mine water related and exceeded the limits before any material was placed in the abandoned surface mines. Placement of the material has not changed the concentrations of those substances. In addition, runoff from the abandoned mines is below normal because of the drought conditions of the past few years.

A 2001 biological survey by the Pennsylvania Fish and Boat Commission shows significant stream improvement adjacent to the site. The report states "The most notable changes

in the biological sampling can be shown at Station BC02 (near the mouth of Bark Camp Run). The qualitative macroinvertebrate sampling conducted in April 1982 revealed a total of 8 taxa with only 3 taxa from the orders EPT (ephemeroptera, Plecoptera, Trichoptera), indicating a stressed aquatic system”. The May 2001 results showed 20 taxa with 10 taxa from the EPT orders. The improvement is attributed to the reclamation activity on the watershed.

Geophysical tests were conducted in October 1999 by Lamont Dougherty Earth Observatory, including Ground Penetrating Radar, resistivity, conductivity and seismic imaging. These tests indicate that the placed material is uniform, solid, and has no water moving below it.

Future projects using dredged material, pozzolanic alkaline ash and a lime activator would be a benefit to abandoned mine reclamation efforts. Key aspects to the successful completion of this project included: proactive community outreach and participation; the setting of scientifically valid standards for acceptable and unacceptable materials; site selection with sufficient baseline environmental data to adequately characterize the site, spanning periods of high precipitation and high stream flows as well as periods of low precipitation and low stream flows.

Risk Communication. It is difficult to understate the complexity of communicating the benefit of shipping mud from New York Harbor into central Pennsylvania. Given that the Commonwealth already accepts much of New York and New Jersey’s solid waste, and that dredged material was vilified beyond any real threat to human or environmental health in the campaign to cease its ocean disposal, this task was especially sensitive, PaDEP is to be commended for an exhaustive effort in community outreach that preceded the project. Literally dozens of visits to gain background and to understand sensibilities were undertaken. PaDEP held several open houses regarding the project and worked closely with its Citizen’s Advisory Committee to gain support for an honest assessment of this concept’s potential.

Future Projects. This project was largely funded by a bond act passed in the State of New Jersey specifically to find solutions for the dredging issue, and by the Port Authority of New York/New Jersey. As stated above, Bark Camp was chosen for its scientific merits, and the operation was built around it, not the other way around. A future project would have to be sited in an area that balanced several considerations including: accessibility to rail, degree of impact on the local environment that is significant and remediable, availability of ancillary funding (like reclamation bonds); nearby sources of admixture and acceptance by the local community. The greatest cost-effectiveness and economies of scale are achieved by piggy-backing multiple missions onto single projects, such as AMD abatement, wetlands restoration, mine reclamation and dredged material and coal ash disposal.

The ability to beneficially use the hundreds of millions of tons of dredged materials and coal fly-ash produced world wide has unprecedented implications for the 560,000 abandoned mine sites in the United States

REFERENCES

ⁱ A Plan to Dump Coal Ash Adds Salt to a Wound, New York Times Business Section p1, April 14, 2000

ⁱⁱ EPA Office of Water website: <http://www.epa.gov/OST/cs/>

APPROACHES TO MINE SUBSIDENCE IN FOUR U.S. COMMUNITIES

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ABSTRACT

Millions of acres of land in the United States have been mined for coal and other mineral resources. Mine subsidence is a widespread problem in many of these areas. Coal mine subsidence has been documented in 31 states and on lands belonging to six Indian tribes. The authors propound the question — how are communities addressing mine subsidence problems? A response was sought from four communities with long histories of subsidence and significantly different State resources available for abating such problems. It was found that communities are seemingly most willing to accept hazard abatement by the State Abandoned Mine Land (AML) Program as a viable solution in addressing mine related problems. They also appear amenable to subsidence prevention via backfilling of mine voids provided State funds are available. One community encourages new construction to be subsidence resistant but does not mandate requirements. Land-use planning that includes zoning, enhanced building design, and backfilling select areas are favored by the authors but considered an anathema to city officials. All four communities encourage or require developers to review mine maps prior to designing new construction but none require avoidance of undermined areas. It is believed that, one day, communities will choose a more aggressive approach in minimizing the potential impacts associated with subsidence. When this choice is made, they will need the information we seek as AML Program managers to fully realize the scope of mine problems and have the tools necessary to take action. We suggest that State AML Programs can contribute significantly to minimizing subsidence impacts by collecting and preserving mine maps and by making them readily available so that the public and community officials can use them for making wise land use decisions. We present other ideas for State AML Program managers that may contribute to the implementation of wise land use practices by local communities.

INTRODUCTION

In the United States today, there are millions of acres of land that have been underground mined for coal and other minerals. Many of these lands are located within an easy commute of our modern cities and towns, and these communities are expanding toward and, in many cases, over undermined areas. As a result, residents and business owners are being exposed to dangerous mine-related problems. Such problems include mine subsidence, explosive and poisonous mine gasses, shaft openings, and mine fires. In addition to these hazards, there are unnecessary economic losses in terms of property damage, insurance loss, and disruption of commercial activity.

When the United States Congress passed the Surface Mining Control and Reclamation Act (SMCRA) in 1977, they authorized collection of funds to protect the public from past coal mining activity. In addition, SMCRA establishes Federal and State Programs to identify and abate mine-related problems. Congress identified priorities for expenditure of the funds and expressly identifies as the top priority for this legislation “the protection of public health, safety, general welfare, and property from extreme danger of adverse effects of coal mining practices.” This is known as “Priority One” of the Abandoned Mine Land (AML) Reclamation Fund. Congress went on to state in Section 409 of SMCRA that voids and open and abandoned tunnels, shafts and entryways resulting from any previous mining operation were a hazard to public health, or safety. This extended the reach of SMCRA to non coal mines which met certain conditions.

During the program’s 25 years of existence, much has been learned about mining and mine-related problems. Many of the problems have been remediated by State and Federal AML Reclamation Programs. The upcoming sunset of the AML fee collection authority in 2004 begs the question, “if the AML Reclamation Program were to end today, would there continue to be significant and life-threatening problems associated with old mines?” The answer to this question is an unequivocal “yes”. Increased development over abandoned mines will expose more structures and people to subsidence risks. Many of these problems will not surface for 5, or 20 or even 50 years. But when they do, they will have devastating consequences for the residents and businesses affected.

While the State AML Programs have done an excellent job of abating subsidence problems when they occur, they have little authority or ability to minimize risks of future subsidence. The responsibility to protect the public from these risks lies with local governments, which have the ability to implement zoning and building code restrictions that can reduce the hazard exposure. The authors have found that local governments are avoiding the issue. This paper will examine four typical communities whose response is considered representative of virtually all communities facing mining problems. We will speculate on why this is happening and provide suggestions of how State Abandoned Mine Land Reclamation Programs can help these authorities to act proactively and in a responsible manner. By doing so, the State Reclamation Programs can truly fulfill the intent of Congress and discharge their duties in protecting the public from all AML problems.

MINE SUBSIDENCE AND COMMUNITIES

Mine subsidence is the collapse of the ground surface over areas where coal or mineral ores were removed. Subsidence causes ground surface deformation resulting in a range of problems from deep holes with vertical sides that pose physical threats to people, to more subtle forms of subsidence characterized by sagging of the ground surface producing more damage, over larger areas, affecting nearly all man made structures. Frequently, water and gas lines are ruptured; roads, bridges and homes are damaged; and commerce is disrupted. Subsidence in developed areas is often classified a Priority 1 Problem under SMCRA.

Subsidence is an onerous problem. The underground mine lays dormant and forgotten until, one day, failure within the mine has progressed upward far enough that it reaches the ground surface. Subsidence damages, therefore, tend to be sudden and unexpected. History has demonstrated that nearly any undermined area regardless of depth, where significant volumes of coal or mineral ore were extracted, is susceptible to subsidence. As an example, coal mines in Illinois over 900 feet deep have subsided and continue to cause damages to modern improvements.

Today, we find that cities, towns, and individual homes and businesses are spreading rapidly across the lands underlain by abandoned mines. In Illinois, as in other areas of the Midwestern United States where the authors are most familiar, economic loss associated with mine subsidence affecting homes and businesses seems to be on the increase¹. The spread of community development over undermined lands is exposing the public to increasing safety and economic risks and costing communities millions in unnecessary repairs to public facilities and infrastructure.

IS SUBSIDENCE A WIDESPREAD PROBLEM IN THE US?

Subsidence over coal mines is documented in 31 states and on the lands of 6 Indian Tribes. While the extent of subsidence over non-coal mines is largely uncharted, we know that non-coal minerals have been mined by underground methods in nearly every state and that subsidence is associated with many of these mines as well. One of the most extreme cases of subsidence in Illinois formed over a mine that extracted the mineral, galena. In the Midwest, subsidence in towns and cities has been documented since the 1800's.

Preliminary findings from an ongoing study in Illinois (Gibson, Smith, Schottel, and Pearson) may be illustrative of the larger picture of the relationship between underground mines and development in cities across the country. The data are presented herein for discussion purposes only and formal findings will be published when the study is complete.

The Illinois Department of Natural Resources is producing a working set of data layers for a geographic information system that combines detailed mine maps with surface maps for the entire state. cursory inspection of maps for one city reveals that large areas of the city are undermined and that it is continuing to grow outward onto additional undermined areas. The continued urban development over the mines with apparent disregard for past mining is disconcerting. For example, nearly 86 large commercial and public buildings and 245 residential and multi-family dwellings are located over a single mine in this city. This particular mine underlies approximately 722 acres of land of which 441 acres (61%) has surface development. Given its location, continued commercial development is expected.

Recently, another layer was added to the map showing 348 known and/or suspected mine subsidence features for this particular city. This information is compiled from many sources and is updated with

new information. It includes data on subsidence events having formed during the past 80 years (at least). One source, John C. Quade, representing the Federal Land Bank of St. Louis, identified 103 subsidence problems having formed prior to 1934. The total area affected by the 348 subsidence features has been estimated to represent 3% of the 36,535 acres of land mined in the study area.

It would appear that, with such a long history of public exposure to subsidence across the nation, significant work might have been done by government agencies to reduce the risks to public safety and investment. Unfortunately, this does not appear to be the case.

WHAT CAN BE DONE TO PREVENT OR MINIMIZE SUBSIDENCE DAMAGE?

There are several actions that government agencies may take to prevent or minimize public safety risks and lessen damage due to subsidence:

- Fill mine voids with non-compressible materials.
- Encourage appropriate land use in subsidence prone areas through zoning.
- Encourage enhanced building and engineering codes to make structures safer, more durable and to facilitate repair.
- Take special precautions when constructing public works projects such as roads, bridges, sewers and public buildings.
- Provide education, map resources, and technical guidelines to the public and to developers.

If mine voids can be completely filled with a durable, non-compressible material, the potential for subsidence can be completely eliminated. Backfilling is perhaps most effective and cost efficient when used to protect a costly surface development covering a small surface area. Backfilling is, however, much more difficult to accomplish than one is often lead to believe. It is extremely costly to backfill entire mines regardless of the method used. It is more expensive and difficult in developed areas, with the added risk of perhaps inducing subsidence in the process. Backfilling has been used extensively on an emergency basis across the US to reduce the extent of subsidence damage to individual structures after ground movement has started. However, large area backfilling projects have only been undertaken in a few cities in the United States due to the high cost and risks associated, most notably in Rock Springs, Wyoming. It has been demonstrated that few state governments and even fewer local governments have the financial resources for such costly projects. Wyoming, with the immense coal production of the Powder River Basin, has used some AML money to proactively limit subsidence potential in Rock Springs. However, The cost associated with large-area backfilling projects prohibits their use in most situations. This leaves the remainder of the options stated above for use by local and State governments.

THE ROLES OF LOCAL AND STATE GOVERNMENT AGENCIES

In the United States, decisions regarding land use, development, and most building standards are generally made at the local level. Common building code manuals, such as BOCA, UBC, and the proposed IBC do not address the impacts of mining. State and Federal government entities tend to respect local government land use decisions. Some governmental entities, most notably the Abandoned Mine Land programs, have no authority to restrict building and land use development.

Land use and development decisions are based on seeking a balance between competing spheres of influence, most notably, technical concerns, public safety, economic well being, and special interest groups. The latter two exert tremendous pressure at the local level. There are several actions that local governments may take to prevent or minimize risks of subsidence in undermined areas:

- Implement restrictive zoning in subsidence risk areas.
- Implement building codes or engineering standards for subsidence risk areas.
- Take special precautions when constructing public works projects such as roads, bridges, dams, sewers, and public buildings.
- Provide education, map resources and technical guidelines to the public.

WHAT ARE LOCAL GOVERNMENTS DOING?

In 2001, the authors sought to determine what local governments were doing to lessen the potential risks associated with future subsidence. We chose four communities with long histories of subsidence and significantly different State resources available for responding to subsidence problems. These communities are:

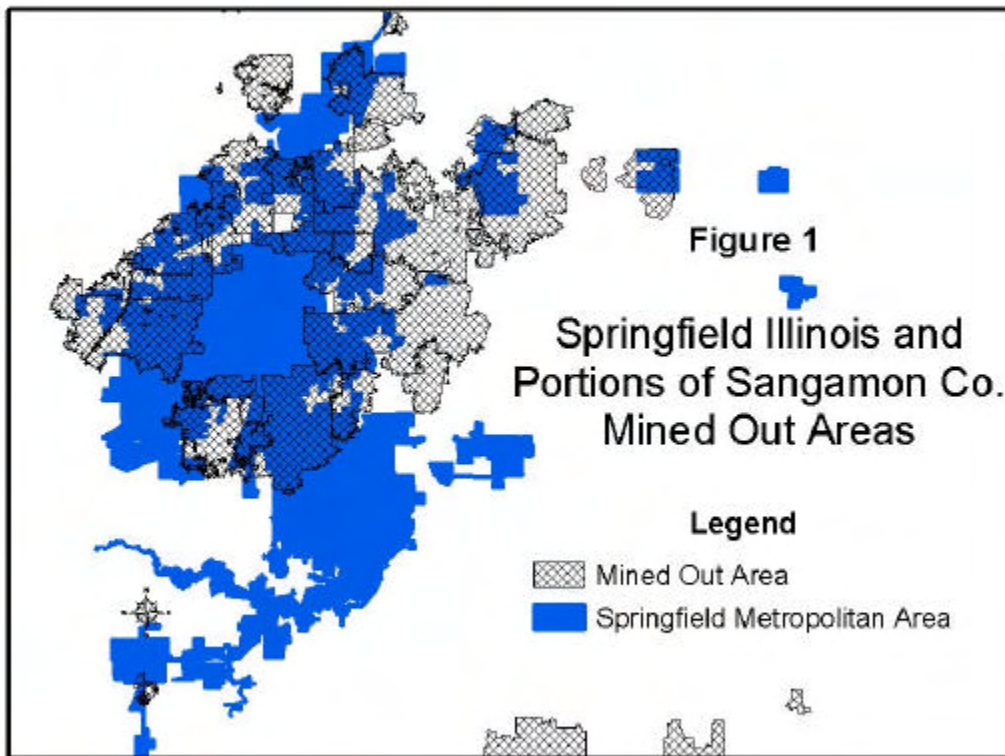
Springfield, Illinois
O'Fallon, Illinois
Pittsburg, Kansas
Rock Springs, Wyoming

In order to determine what actions were being taken by local authorities, the authors interviewed city engineers and/or Planning and Zoning Department managers in each community and asked the following questions:

- Does your community have and enforce special zoning restrictions for subsidence prone areas?
- Does your community have specific building codes or engineering standards for development over subsidence prone areas?
- Is subsidence insurance available?
- Does the city encourage developers to look at mine maps or consult the State AML office prior to designing new buildings and improvements?
- Does the city avoid undermined areas or use special engineering standards when locating new facilities or designing new buildings and infrastructure?

The results were a bit surprising. Following is a summary of the findings for each community.

Springfield, Illinois



Underground mines occur under a significant portion of the Springfield Metropolitan Area (Figure 1)². Sag subsidence is occurring on a regular basis in a number of areas including recently developed residential subdivisions and retail areas. Illinois has a subsidence insurance program and a state AML Emergency Program. City officials expressed concern about potential subsidence impacts on both existing structures and future development.

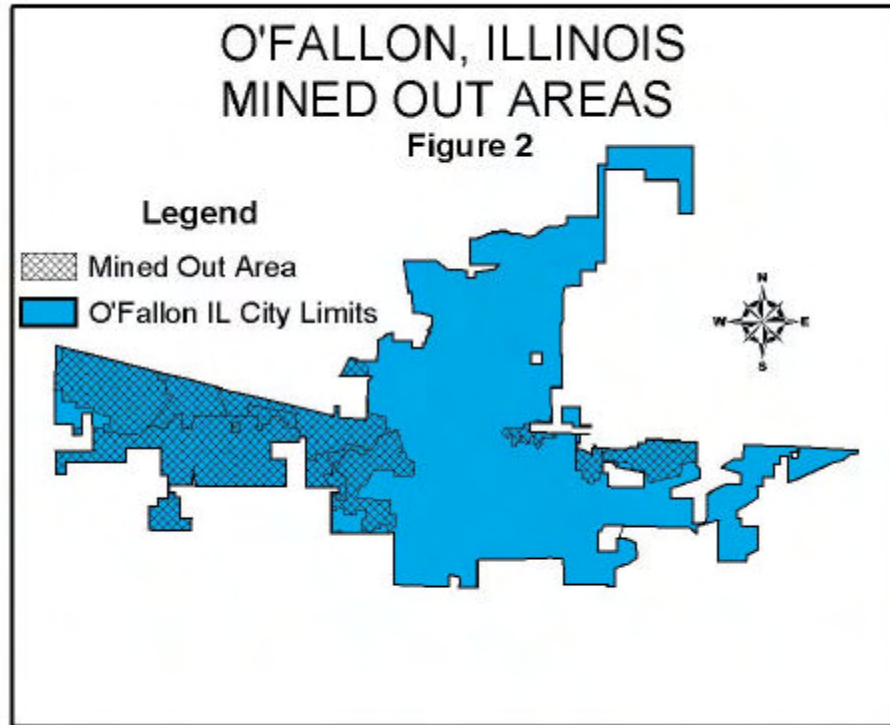
In spite of these issues and concerns, Springfield city officials told the authors that in subsidence-prone areas:

- They do not impose zoning restrictions.
- They do not advocate special building codes or engineering standards.
- They allow engineers and developers to review their maps of mining and subsidence activity.
- They do not, in general practice, use different engineering practices for public works.

This development policy results in continued growth over areas with significant subsidence potential. Buildings are being constructed without regard to mining. There is no

consideration in taking advantage of variance within mining geometry in order to select potentially stable areas for siting important structures. Any special actions that are taken to strengthen or protect new construction are entirely voluntary and up to the design engineer.

O'Fallon Illinois



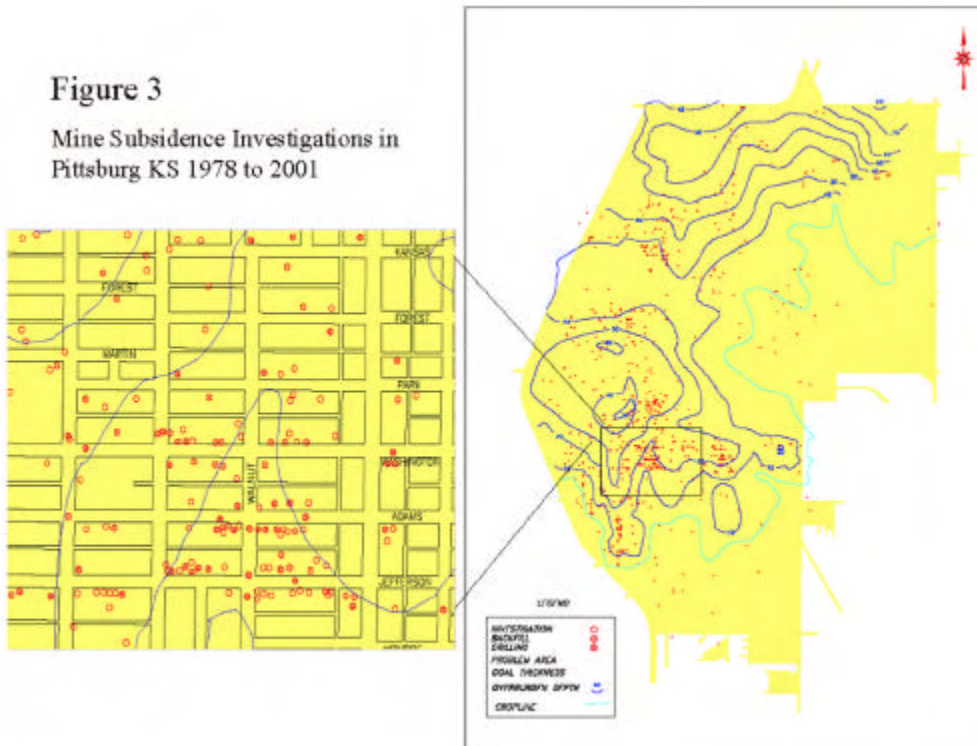
O'Fallon is another Illinois city where a significant portion of the community is undermined for coal (Figure 2)³. The city is land locked by other communities and cannot expand its borders. Therefore, O'Fallon is limited to developing the lands it already has within the city limits.

Interviews with O'Fallon community officials⁴ yielded similar results in that there are no zoning restrictions, special building codes, or engineering standards specific to subsidence. However, we did find differences. The city requires developers to consult with the State AML office regarding the location of underground mines, although it does not specify what the developer must do with the results of the consultation. O'Fallon is also in the process of redesigning a main forced sewer line that was recently damaged by subsidence. The new sewer is being built to resist future damages from subsidence in the area.

Pittsburg Kansas

Figure 3

Mine Subsidence Investigations in
Pittsburg KS 1978 to 2001



Pittsburg Kansas is a small city in southeast Kansas with a population of just over 19,000 residents whose mining history dates to the mid-1800's. Approximately 2/3 of the city is located above shallow coal mines that range in depth from less than 20 feet to about 50 feet. Figure 3⁵ shows the location of subsidence investigations within city limits over the past 23 years. The State of Kansas AML Emergency Program responds to an average of 40 mine subsidence emergencies per year. However, because underground mines only affect a small number of towns in Kansas, there is not sufficient support for a state-wide subsidence insurance program. Pittsburg officials responded to the authors questions as follows⁶:

They do not impose zoning restrictions.

They do not advocate special building codes or engineering standards.

They encourages developers to look at mine maps and consult the State AML Office prior to developing design plans.

They do not design public works projects to resist subsidence unless undertaking repair for subsidence damage.

They allow the public to view mined-area maps, but maps for many areas are not available.

Rock Springs, Wyoming

A large percentage of Rock Springs has been undermined for coal. The Wyoming AML Program has considerable monetary resources because of its current coal mining production allowing it to devote considerable funding to subsidence prevention. Wyoming

has backfilled the mine workings under most developed areas of the city using various mixtures of sand and grout. Undeveloped areas were not backfilled. Subsidence insurance is available in Rock Springs, and many lenders require it as a condition of loan approval.

Interviews with city officials⁷ revealed the following conditions:

They do not impose zoning restrictions.

- Proposed developments over non grouted areas must have foundations engineered to resist subsidence.
- Lenders require subsidence insurance.
- Public works projects are not designed to resist subsidence unless a repair for subsidence damage is being undertaken. High risk areas are avoided when possible.
- The city and state allow the public to view mined-area maps.

SURVEY CONCLUSIONS

In spite of ongoing subsidence problems, none of the four local governments chose to impose subsidence specific zoning restrictions. Three of the four communities do not impose subsidence resistant engineering standards or building codes. Rock Springs requires structures in non-backfilled areas to be designed to resist subsidence damage, but does not mandate specific criteria. None of the four communities routinely design public works in undermined areas to resist subsidence damages although several have recently begun designing repair and replacement projects for roads and sewers damaged by subsidence to be more resistant to future damage. Rock Springs officials stated that they were trying to avoid building public works over non-backfilled mines when other options are available.

The one positive, common condition among the four communities is that they all encourage engineers and developers to review available underground mine maps prior to project design. Unfortunately, the cities do not direct the builders to take any specific actions once the maps are viewed. In many cases, mine maps are unavailable or are poorly referenced to local coordinate systems and street maps. Based on the survey results and firsthand observation, the authors conclude that local governments are not likely to alter development based on subsidence potential or restrict building design in the near future.

WHY ARE LOCAL GOVERNMENTS HESITANT TO IMPLEMENT SPECIAL REQUIREMENTS?

From our perspective, there seems to be an incongruity between the level and amount of damage to surface development and public awareness and response. Perhaps it is because each subsidence event is somewhat isolated, and each event impacts relatively few people. In contrast, natural disasters such as earthquakes, floods, and major storms that affect a great many people in a short period of time focus public awareness. Perhaps another reason is that there is very little hard data documenting the impacts of subsidence

for a community and scant information at the regional and national level. Circumstantial evidence suggests that subsidence is pervasive but not sufficiently cataclysmic to draw significant public and political attention. What is this circumstantial evidence? In Illinois the following historical facts are suggestive:

- 1809 William Boone shipped coal from Illinois to New Orleans.⁸
- 1833, mines in St. Clair County, Illinois ship 6,000 tons of coal to St. Louis, Missouri.⁹
- 1880, in *Wilms v. Jess*, the Illinois Supreme Court handed down its first decision on coal mine subsidence.¹⁰
- 1916, the ISGS publishes “Surface Subsidence In Illinois”
- 1926, Mines and Minerals is established.
- 1975, Abandoned Mined Lands program is established to address environmental concerns.¹¹
- 1979, Subsidence Insurance Coverage is mandated.
- 1984, Illinois Emergency Program is established.

This pattern of mineral extraction, followed by legal contests, regional studies, and creation of institutions and policies, was also carried out in similar fashion in other states and on a national level. One might conclude from the discussion thus far that government institutions are proceeding very slowly in addressing the problems associated with mining. Some will argue that additional governmental response is not necessary. However, examination of the list suggests two things. First, there is a continuing conflict between mining and surface land use. Second, the impact on urban development is increasing even though the number of subsidence events may be constant. Preliminary and limited data in Illinois suggests that subsidence is more common than previously believed and that large mined areas apparently have yet to subside. Discussions with community officials suggest that there are insufficient economic incentives to merit limiting development in undermined areas.

ILLINOIS’ ATTEMPTS TO REDUCE SUBSIDENCE RISKS

In Illinois, local government has, for the most part, left the issue of subsidence to the State AML Program and to individual residents who are directly affected. State government has taken the lead in protecting the citizens in several important areas. Examples of State initiatives include providing the public information to avoid and cope with the problems associated with past mining.

Maps - AML Program staff feel that the best way to limit mine-related problems, such as subsidence, is to avoid mined areas all together or, if possible, to prevent the negative effects associated with mining. To do so, it is necessary to know where the mines are located relative to ground surface features and to be knowledgeable about the kinds of problems that can be expected. Such information has to be made widely known, readily available, and easily understood. The most common means is through the use of maps.

Illinois is trying to help the public avoid the effects of mined areas by making mine maps readily available. This is a continuing process.

Several kinds of mine maps have been developed for varying reasons, but most relate the location of the extracted mineral with respect to ground surface features. Illinois is attempting to compile all these maps into a "Computerized Mine Information Map" and make it widely available to the Public in an appropriate manner. Until then, the most widely available mine maps in Illinois are its mined-out area maps (MOA's). The current generation of MOA's are color maps made at a 1:24,000 scale and overlain onto USGS topographic maps. Each map is complete with a companion booklet that includes mine histories detailing production years, name changes, and other pertinent information. Such maps are available for purchase as "hard copy" or can be downloaded off the internet at no charge in 'PDF' or in GIS format.

Blue-line copies of the mine workings maps that exist for nearly 2000 mines have been stored in State Archives and are available for inspection. Age and continued handling have caused severe damage to the maps. In an effort to protect these maps for historical purposes and to make them more available, the maps were photographed and stored on microfiche. Microfiche copies were made available to the Public on demand at no charge. Technological advancements during the 1980's lead to the practice of scanning the images stored on microfiche and then saving the electronic image in digital format on compact discs. Apparently, this practice is also being carried out on a national level. The authors acknowledge that there are many good reasons supporting this decision including media durability, convenient storage, increased access and dissemination of information, and reasonable cost. However, the authors wish to make it clear that this practice should be employed only with the utmost care for quality control in order to insure image integrity. Furthermore, there can be significant degradation in the image quality that can mislead map readers into believing an area is not undermined. We advocate high resolution scanning of the earliest generation mine map available and saving this image to long-term storage media. This task is being undertaken in Illinois as a means to store each mine map for historic purposes and to make the images widely available on the internet. A complete discussion on this topic will be presented in a forthcoming publication.

The department has identified four critical needs in preserving mine map information and making it more readily available for future generations.

1) **Preserve and protect mine map information.** Create high quality copies of each mine map. Each mine map is to be scanned and stored in digital form. The resulting digital image will be the visual equivalent of the original map.

2) **Archival storage and retrieval of individual digital maps.** The scanned mine maps are to be stored onto CD-R media. Each map is to be uniquely identified so that individual mine images can be conveniently accessed from its stored location and displayed. Further, each mine map is to be cross-referenced with the Department's mine index number system.

3) **Reference mine map to a surface coordinate sytem.** Each map sheet is to be located with respect to surface features to within the same relative accuracy of the mine map and

the reference map (typically a USGS 7 - minute Topographic Quadrangle). The rectification process will employ the transformation method that minimizes total image distortion. In Illinois, map sheets will be referenced to the Universal Transverse Mercator map projection (North American Datum 27).

4) **Enhance Mine Map Availability.** The Public will have the option of ordering hard copy maps or viewing and printing maps using internet map server technology.

Model Ordinances - The Illinois AML program subcontracted with the Southwestern Metropolitan Planning Commission (SWMPC) to develop a resource document for cities and communities located in or near mined areas. This resource document contains educational material concerning mining and mine-related problems, a discussion on how to evaluate development risk and site public structures, a list of contacts that provide help should mine problems develop within the community and finally, a model ordinance the community can use to plan future development that minimizes the negative effects associated with mining. This resource document “ Mine Subsidence: A Guidebook for Local Officials” was written in 1983 and was sent to all local governments in mined areas in Illinois. While there has not been a follow-up study to verify whether a community has attempted to follow the Model Ordinance, the authors are unaware of any communities patterning new development after it. City officials appear to believe that such attempts will place their community at an economic disadvantage, and that businesses will choose to locate in communities with lesser restrictions given equivalent markets.

WHAT CAN STATE AML PROGRAMS DO TO LEAD THE WAY?

The AML program is a sunset program. Our legacy should be that we as program managers and policy makers develop the data base necessary to assess the probability of subsidence risk and make resources available for people to make educated decisions before such information is lost. What steps should we be taking?

Collect the maps before they are gone - First, we must be making significant efforts to identify and collect all existing mine maps. These resources are being lost at a rapid rate as mining companies are consolidated and as older miners are passing away, leaving stores of maps and records to be thrown out as trash by ill-informed employees and heirs.

Capture Map Data using GIS - We must be creating accurate geographic information systems that capture, archive, and display mine location and other valuable information that will help provide communities, businesses, and individuals the tools necessary to address problems associated with mined lands. In developing these geographic information systems, we need to document the current condition of past and existing mines. In addition, we need to document as much as possible the location, size and date of each subsidence event, and the typical conditions as well as any unusual conditions of the mine. For instance, there are mines in Illinois where unusually large caverns are created underground to facilitate coal separation and shipping. Such large caverns can cause atypical and extreme subsidence at ground surface. Other mine information such as

fires, back stowing, and backfilling also influence future mine stability and need to be documented. All such information needs to be placed on the mine map and saved for future reference.

Make data available to the public - Creating accurate maps and making them available to the public is the next step. Information is only useful to the public if it is available and understandable. A more innovative method for distributing the information to the public is the use of an internet map server to provide the public and community leaders the ability to create their own maps from their computers.

RECOMMENDATIONS ON ARCHIVING, GIS AND MAPPING

The authors believe it is important for each AML program to make digital copies of all mine maps for future use. One should assume that access to the original hard copy map will not be available for copying ever again. Therefore, extreme diligence in quality control is critical, and the digital copy should be the equivalent of the original map. Do not limit image quality based on file size concerns. Care should be exercised in choosing a scanner that keeps image distortion to an absolute minimum and is sized to make 1:1 ratio in copying. Finally, when choosing a file format for digital storage, consider one that can be used by many imaging programs and is not proprietary. Illinois is storing the digital information as TIFF files.

CONCLUSION

The lessons learned from 25 years of AML experience need to be applied towards efforts that prevent future damage and injury from mine subsidence. Collection, preservation, and digital mapping of underground mine information is critical to smart development and land use planning. Development and community planning, with an eye to subsidence damage minimization, can prevent underground mine features from becoming priority 1 and 2 AML problems. By making this information available to community leaders and informing the public of the importance of such knowledge, we will go a long way to meeting the first priority of the AML Reclamation Fund “protection of public health, safety, general welfare and property from extreme danger of adverse effects of past coal mining practices”. While we, as state and Federal AML professionals, cannot take direct actions to regulate development of undermined lands, we can collect, preserve, and provide to the public the information that will be essential in making informed land use decisions in the future. The AML Programs are the only organizations with the direct authority to capture and preserve this valuable information and make it available to this and future generations.

This kind of information becomes vital should cities chose to plan their development over mined areas. Without question there are structures, perhaps many, being built over mined areas without adequate protection. It seems a matter of time before a massive failure with serious consequence occurs causing unprecedented damage and loss of life. The resulting litigation will cause change in public policy.

Will we have done our part to preserve the information necessary for communities to make wise land use decisions?

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SURVEY DATA COLLECTION ASSOCIATED WITH AN AML EMERGENCY PROGRAM

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ABSTRACT

Unplanned sag subsidence affects structures of all kinds throughout the coal mining regions of the world. The writers have been involved with investigating and monitoring sag subsidence events in the state of Illinois since 1980 and have found that surveying can provide important data yielding insight on the behavior of the subsidence event. Detailed survey information facilitates subsidence research of ground movements, aids in evaluating structural response and is useful in determining the optimum time for structural repair. Survey data quality is generally limited by factors such as monument design, monument spacing, frequency of measurement, quality of survey equipment, and proper survey technique. The main problem encountered in establishing techniques for the monitoring of a sag subsidence event is the trade-off necessary between physical constraints and time constraints. Since Illinois Department of Natural Resources- Abandoned Mined Lands Reclamation Division (AMLRD) personnel typically become involved early in the development of a subsidence event, we have the unique opportunity to investigate early ground movements as well as the ability to continue monitoring the ground movements through completion. This paper is meant to provide an overview to the survey techniques utilized by the AMLRD in those investigations designed to collect long term ground movement data associated with coal mine subsidence.

INTRODUCTION

The use of precision level surveys as means of monitoring structural damage resulting from unplanned coal mine sag subsidence has been an important part of the Illinois AML Emergency Program since its inception nearly 25 years ago. As our understanding of sag type subsidence evolved so did our survey technique. We know that at onset, large and rapid ground movements over a definable area are common to subsidence. Further, subsidence related ground movements are by nature continuous and continuously decreasing in rate through time. Based on empirical estimates, nearly 40 to 60 percent of the total ground movement typically occurs within the first few days following the onset of subsidence movements. Therefore, the elapsed time between the onset of subsidence and the first response by qualified investigators represents a significant magnitude of movement that goes unmeasured, and in many instances, is lost. The primary concern of the AMLRD is to protect the public from mine related problems that constitute an immediate threat to the public health, safety, or general welfare (from Public Law 95-87). Because we typically become involved early in the development of a subsidence event, we have the unique opportunity to investigate early ground movements as well as the ability to continue monitoring the ground movements through completion. As the AMLRD has become more responsive to the needs of the public, greater expectations have been placed on the program to provide the expertise that would otherwise be generally unavailable to the property owner or

public entities such as local government. The collection and analysis of survey data, along with other information, has enabled the personnel of the AMLRD to develop a better understanding of the behavior of subsidence events, how they vary regionally, and to utilize this information to the benefit of the public.

Throughout the last 20 years the investigators have constantly sought to improve the cost effectiveness, efficiency, and integrity of the data that is collected at subsidence events. During the early 1980's when the Illinois emergency program was first developing, our involvement at a site would have been limited from a few months up to a year. Survey information was collected with the intent to measure only large magnitude ground movements. Therefore survey monuments were considered to be temporary and were chosen based on ease and speed of installation. It was determined that by making slight modifications in our initial surveying practices, that we could substantially improve both the overall quality and extend the longevity of the survey net. As data was collected on various projects, the technique was refined to improve the overall effectiveness of the process.

The main problem encountered in establishing techniques for the monitoring of a sag subsidence event is the trade-off necessary between physical constraints and time constraints. These are interdependent and a change in one affects the performance of the other. Some examples of physical constraints include survey equipment quality, monument design, monument location, and survey technique. In addition to physical constraints, time constraints present complications in dealing with the dynamic movements characteristic of subsidence events. Locating, installing, and surveying of monuments for subsidence investigation would be straightforward, if not for time constraints. Monuments could be surveyed using high quality equipment, under optimum surveying conditions (wind, temperature, humidity and available light) with a predetermined number of equipment setups all designed to keep error to an absolute minimum while providing the maximum amount of data.

The procedures we have developed have been designed to address time related problems associated with the collection of survey data. In the early stages of a subsidence event, it is difficult to establish and collect survey information of the same quantity and quality, as can be collected 6 months into an event. Another complication is related to settlement rate and longevity of a subsidence event. Some subsidence events are continuing to settle more than a decade after onset. The challenge in monitoring these types of problems is maintaining monument integrity. Loss of monuments due to damage becomes increasingly problematic when monitoring subsidence ground movements lasting a decade or longer. Thus, when measuring subsidence related ground movements, it is necessary for the investigator to adjust procedures to accommodate the different challenges inherent with subsidence to ensure quality data throughout the monitoring period. These procedures provide a baseline that is often supplemented with other measurements for the purpose of investigating certain characteristics of a subsidence event.

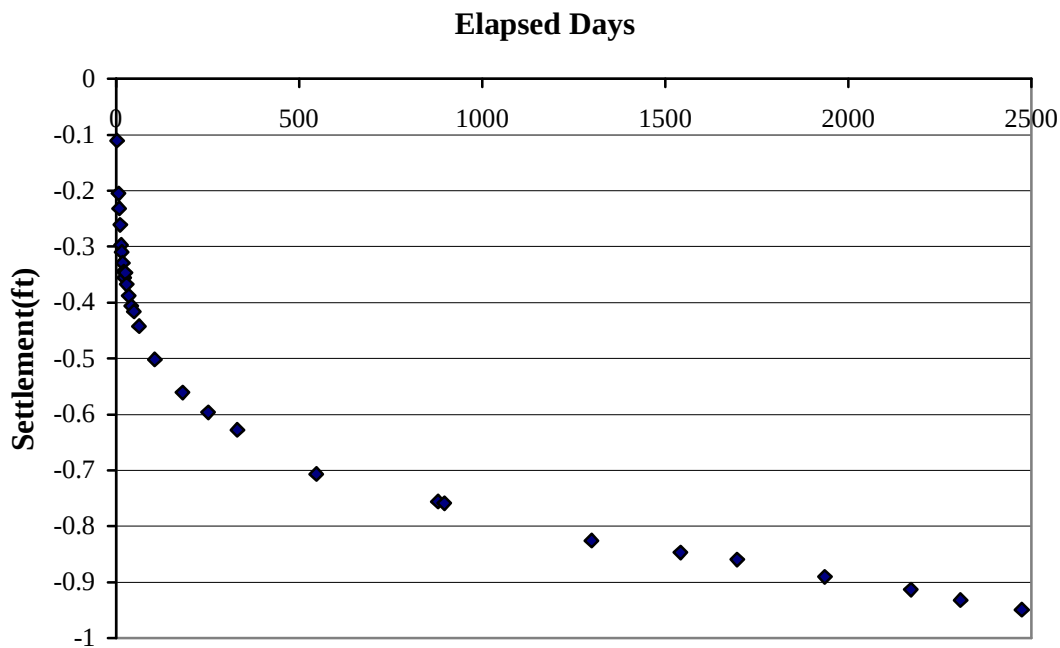
GENERAL TECHNIQUES

Once subsidence begins, the ground drops continuously until movements cease. In the early stages, large and rapid settlements along with differential movements, commonly characterize a subsidence event. This places a challenge on the survey techniques that are necessary to collect a snapshot of the settlements. As the subsidence event gets older, the rate of movement decreases until differential movements during the course of a single survey have little

effect on data integrity. Toward the end of the event, the magnitude of subsidence is sufficiently small so that it becomes very difficult to differentiate subsidence related ground movement from measurement error or soil effects. Varying aspects of the survey such as monument design, layout, timing, and procedures accommodates these differing conditions.

Generally, we have found that surveys using 2nd order or better equipment yield the best value for investigation and analysis. For obvious reasons, a first order instrument yields the greatest precision in surveys. However the requirements in maintaining 1st Order precision surveys increase the time and cost necessary to conduct a full survey. The increased precision is more than offset by the error introduced by the ground movements which take place during the early stages of an event. In other words, the error introduced by the subsidence ground movement may yield 2nd Order or lower error results even using 1st order equipment and techniques. The net result is a less accurate survey. The higher the order of the survey though, the more useful the data, especially in the latter stages of an event when settlements rates are small and approaching zero. We employ equipment and techniques that are consistent with 2nd order survey requirements. The AMLRD uses both a Wild NA2002 (2nd order instrument) and a Wild NA 3003 (1st Order instrument) digital level for surveying. We have found that the use of either instrument with a second order staff in conjunction with our survey techniques consistently yields accuracy approaching 1st order.

Figure A illustrates the settlement of a monument through time and is typical to many events monitored by the AMLRD. From the figure it can be seen that during the initial stages of the event, survey measurements were taken frequently when settlement rates were large. Plotting the elevations in this manner allows the researcher to confirm that the rate of settlement is diminishing. Estimates of future settlement can thus be made and the time between successive surveys gradually increased until they are taken on an annual basis.



Sag Type Subsidence: Time vs. Settlement

Figure A

NETWORK DEVELOPMENT

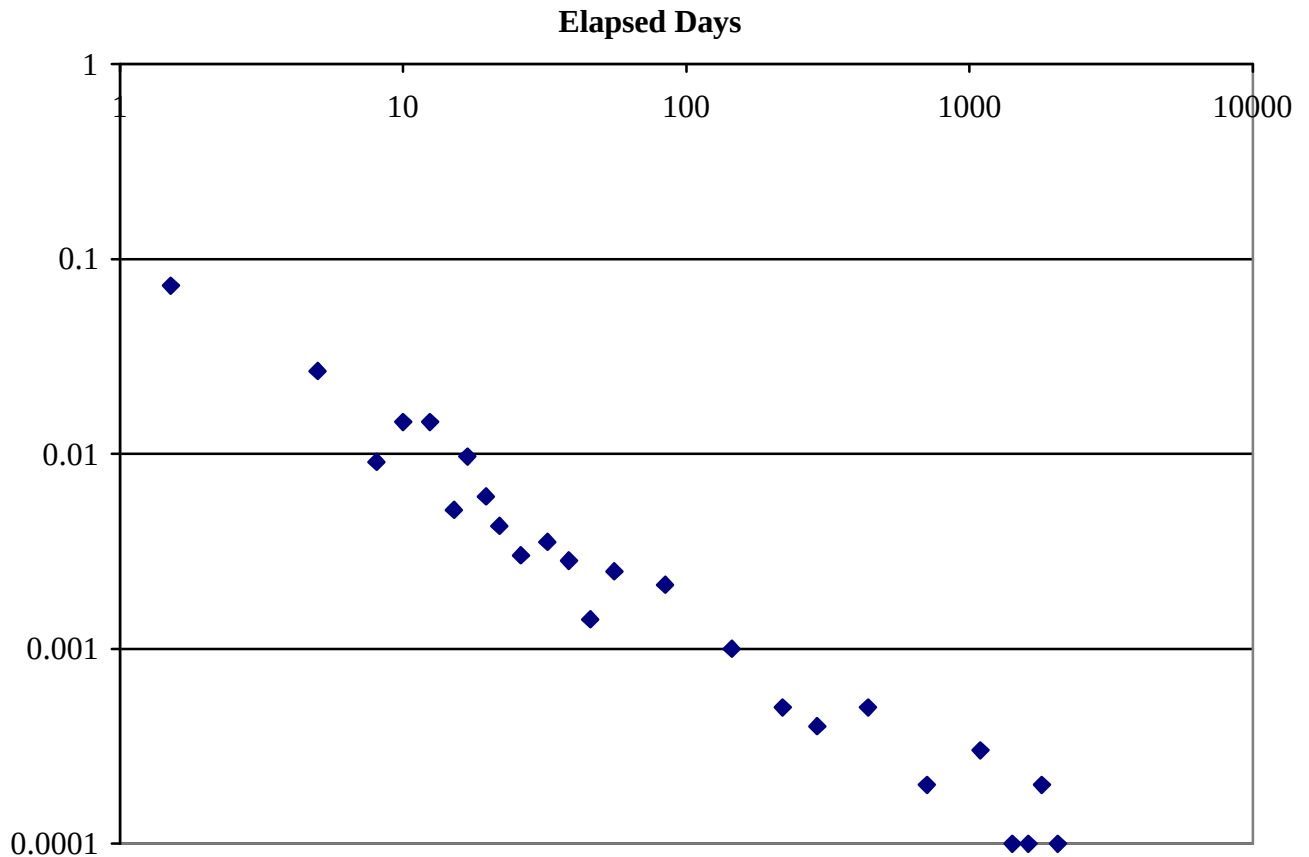
During the early stages of a subsidence event, ground movements within the sag can be sufficiently large in magnitude and rate, whereby measurable change in surface elevation can occur within a few hours. As the ground drops, there is a change in shape. In order to characterize the shape of the ground surface, it is necessary to measure all the points collectively, as close as possible to the same point in time. In order to determine the rate of settlement, it is necessary to measure all the points as frequently as possible. These competing tasks are difficult to accomplish and can be additionally complicated if the subsidence event is large, requiring stationing the leveling instrument within the subsiding area, and requiring a substantial amount of time to complete a survey. The amount of error resulting from the instrument settling during a survey can be significant and is indicated in the value calculated for the Standard Error of Closure. These problems are typical of many subsidence events in Illinois.

There are different approaches that can be applied to address the problems described above but they involve a trade off between measuring the shape of subsidence and the rate of subsidence. One solution would be to forego measuring the shape of the subsidence movements and concentrate solely on the rate of movement. This could easily be accomplished by measuring one point at or near the center of the event until settlement rates have negligible impact on survey accuracy. Such an approach has obvious shortcomings since the large movements that occur early in the event can be detrimental to structures. These movements also tell us the most about the shape of the event. For these reasons, it is beneficial to conduct a survey that includes a sufficient number of points to describe the shape of ground movement and to acknowledge that closure error may be greater than would be considered acceptable in later surveys. This error is proportionately a small percentage of the measured movement and is insignificant in the overall analysis. Knowing the source of potential error, however, gives us the opportunity to minimize the magnitude. This is accomplished by controlling the survey technique and physical characteristics of the monuments.

When establishing a survey network early in the development of a subsidence event, it is worthwhile to design a network that meets immediate data objectives and is expandable for long-term objectives. Ideally, monuments would be positioned so that instrument stationing maximizes the speed of surveying the network, thereby minimizing the error subsiding ground introduces on the instrument. Usually increasing the density of monuments through time and choosing locations that keep the number of required setups to a minimum can accomplish this. Additionally the instrument can be stationed as far as possible from the center of the event where settlement rates are largest. Typically, our first few surveys of a subsidence event are designed to minimize the amount of time the instrument is within the event. Although this may require an additional setup or two, it is a small tradeoff to maintain closure integrity. However, too many setups can increase the time to complete a survey and introduce error associated with the settlement of the instrument while within the limits of the sag.

Figure B shows a plot of survey data that illustrates the rate of settlement typical to many events. After about a week to ten days, settlement rates have decreased to a manageable level. Since each event behaves uniquely, this plot is only considered representative of expected decline in settlement rate. It does, however, provide a guideline, in the absence of any specific survey data, on when to adjust survey procedures.

When first establishing a survey network for a new event, we attempt to define the limits of the subsidence event. We then utilize this information to determine the best location of the survey lines to achieve our desired cross-section profiles. We have found that level survey data is most useful when monuments are established in a ‘plus’ pattern where the lines intersect near the center of a sag. This pattern allows us to construct cross-sections of the subsidence event along



Settlement Rate Example

Figure B

which we can calculate the maximum settlement, slope and curvature and apply it to critical structures affected by the event. A temporary monument line will usually be established expediently. If it is at all possible, we attempt to incorporate our initial temporary monuments coincident with or parallel to our final profiles.

MONUMENTS

Monument design can be divided into two types, temporary and permanent. Temporary monuments tend to be those that are convenient to install but provide information that is useful for a limited time. In general, measurement error increases through time when using a temporary type monument. Permanent monuments tend to provide meaningful data for long periods of time

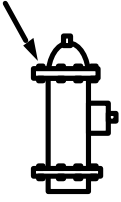
but may be more difficult and/or costly to install. Often it is necessary to install a combination of types and gradually replace or supplement temporary monuments with permanent monuments. It is desirable to keep the replacement of monuments to a minimum to ensure data integrity. Typically it is necessary to install a minimum number of monuments in order to roughly characterize the event. Additional monuments are sometimes added on a time permitting basis to more fully characterize and quantify ground and structural movements.

Several monument designs have been found to provide acceptable survey results. Temporary benchmarks, located outside the affected area, can include any of the following: drop-in anchors set into building foundations or power poles; fire hydrant cap bolts; large spikes driven into a wood utility poles; frost protected rebars; and property corner stakes. Temporary monuments located within the subsiding area may include those described above in addition to short wooden or plastic stakes, PK nails driven into concrete or asphalt surfaces, paint markings on a hard surface, or pencil marks on an interior floor. Figures C and D illustrate the design and functionality of temporary and permanent survey monuments.

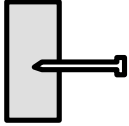
As the subsidence event develops and settlement rates decrease, there is more time for personnel to establish a permanent survey grid. During this time, the initial survey points are supplemented with more permanent monuments. Typically, frost protected re-bars are installed for the final bi-directional pattern across the event. Generally, these monuments would be placed at intervals of approximately 10% of the mine depth. We typically use intervals of 5, 7, or 10 meters (ranges 6- 15 % mine depth) depending on the characteristic of the event. The frost protected rebars are constructed as described in Figure D and can be installed relatively quickly and with little intrusiveness on the property owners. A single monument can be installed in less than 5 minutes with favorable soil conditions. When possible, the survey lines are extended completely through the subsidence event so that each line terminates outside the affected area. This aids in defining the boundary of an event and provides a means to check the quality of the survey data.

Permanent benchmarks are usually established during this time. The location of the benchmark is based on finding a convenient location at the surface, with a low probability of disturbance that also corresponds to the maximum available support at the mine level. We utilize multiple benchmarks surrounding an event to verify stability of all the benchmarks. Typically we install at least two benchmarks outside the affected area on opposing sides of the subsidence event. A third benchmark may be included, particularly if multiple events are being monitored in the same general vicinity, or if we suspect that the event may increase in size. We prefer to keep the distance between the benchmark and affected area to a minimum for several reasons. First, error increases with survey distance. Second, since many of the mines in Illinois are quite large, the nearest non-mined area may be several miles away from the project site. Finally, by keeping the survey distance to a minimum, we can survey the site more frequently and at a lower cost.

Benchmarks are typically constructed as either 5-foot frost protected rebars or 20-foot long, frost protected deep benchmarks. The deep benchmarks are constructed with a recessed and protected top as shown in Figure D. Other investigators have utilized monument constructions of similar types, but all are designed to minimize adverse soil effects and resist frost related movements. If a 20-foot benchmark is constructed, it is common practice to also install a 5-foot



Fire hydrant cap bolt - typically a bolt is selected in the top flange and described in the survey notes for reference and marked with paint. Demonstrates good long term integrity and average long term accuracy. Maximum lifespan - decades.



A large nail such as a 40d or 60d driven into a wood power pole. Demonstrates fair long term integrity and poor long term accuracy. Maximum lifespan - several years under favorable conditions.



Property corner stake- these are typically 1/2" rebars or 1/2" pipe. Demonstrates good long term integrity and fair long term accuracy. Maximum lifespan - decades.



Wood/Plastic stake - these are typically 1"x2" or 2" x 2" and made of pine, spruce, or oak if wood, 1/2" or 3/4" PVC pipe if plastic. Demonstrates poor long term integrity and poor long term accuracy. Maximum lifespan - 6 to 12 months.



PK nails - These are typically 1.5" to 2" long and are driven into pavement; generally asphalt or macadam. PK nails can yield extremely variable results and are significantly dependent on their environment and installation. Some may provide good results for more than a decade and others may not last 1 month. Demonstrates good long term integrity (with proper installation) and average long term accuracy. Maximum lifespan - months to decades.



Floor marks - These are marks which are made on floors, usually interior where other types of monuments may be unacceptable. Demonstrates average long term integrity and average long term accuracy. Maximum life span - years (with periodic maintenance)

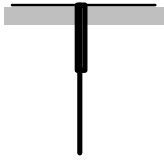


Paint marks - This can simply be a small paint spot which is sprayed on a road or other hard surface. It is very quick to install and can provide reasonable results during the early phases of a subsidence event. Demonstrates poor long term integrity and poor long term accuracy. Maximum lifespan - 6 to 12 months

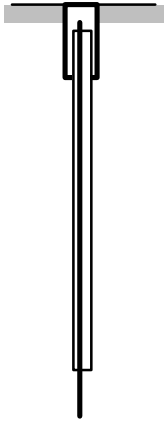
Temporary Survey Monument Types

Figure C

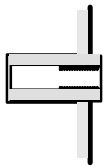
frost protected rebar beside it. Bauer and Van Rosendaal (1992) recommend founding all monuments within the same geological unit to minimize possible differential movements resulting from natural volumetric changes within soil. The five foot and twenty foot frost protected monuments are now used to measure differential movement within the soil that is unrelated to subsidence. We have found the 20 ft. rebars to be only slightly more stable than the 5 ft rebars, but more damage resistant due to their construction. In some instances, deeper monuments may be necessary based on the presence of multiple soil units.



Frost Protected rebars - These points are constructed of 5' rebars which are driven into the ground through a 24" long section of 3/4" CPVC pipe. The points can be installed quickly using a 1" soil sampler to make a hole, placing a precut length of CPVC into the hole and then driving a rebar down through the pipe and leaving it flush with the ground. Demonstrates excellent long term integrity and excellent long term accuracy. Maximum life span - decades.



Frost protected deep benchmarks - These points are constructed of a long steel pipe or rod which is driven into the soil inside a 2" PVC pipe which has been placed to a depth of 10 to 20 feet. The rod is driven several inches below the ground surface and the entire unit is encased in a section of 4" PVC and capped. This type of design is shielded from minor surface damage and most weather effects. Demonstrates excellent long term integrity and excellent long term accuracy. Maximum life span - decades.



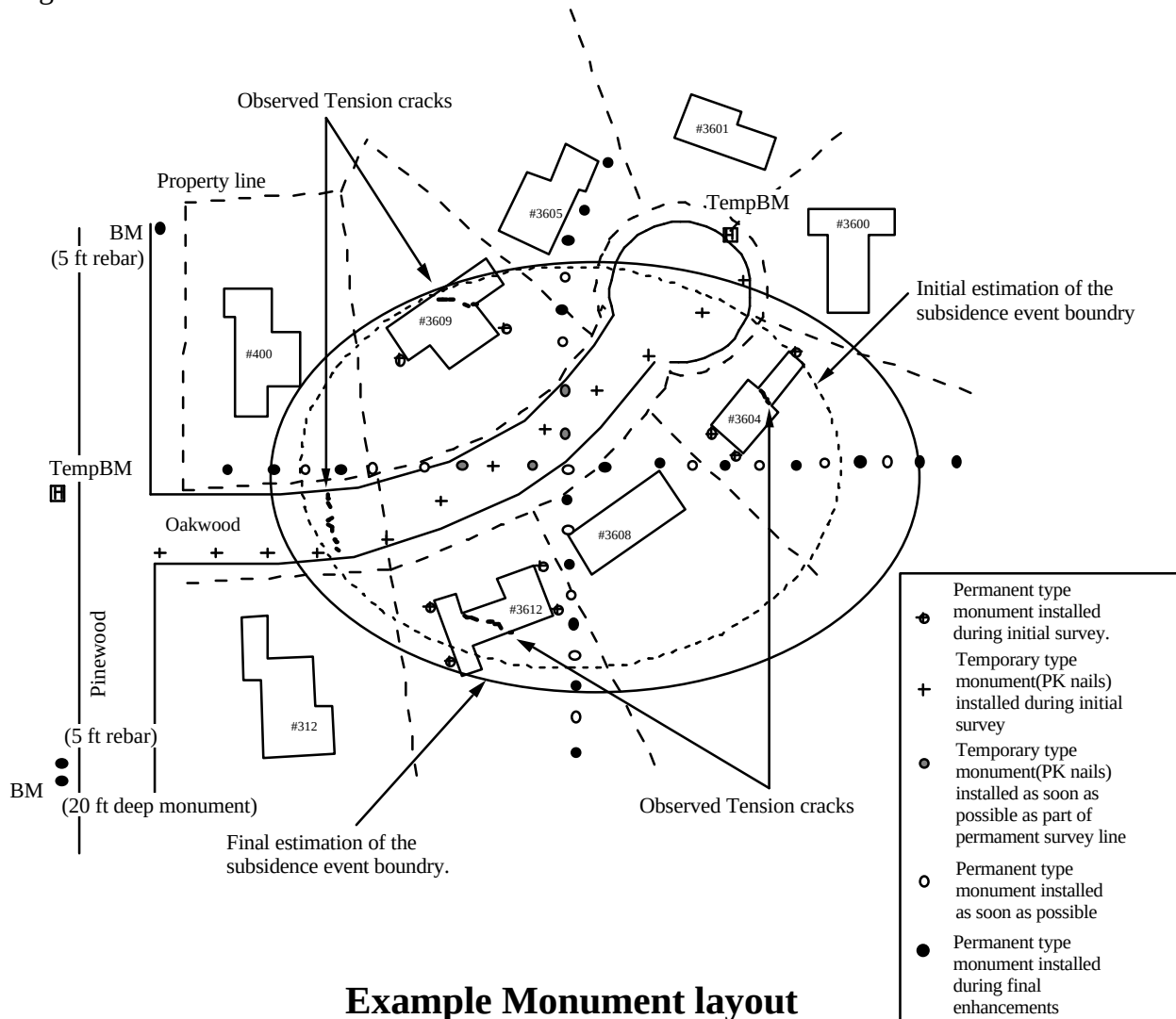
Drop-in anchor, typically 1/2" or 3/8"; Installed by drilling into power poles, light poles, foundations, ect and setting with a punch; this unit is used with a precision manufactured surveyors plug or shoulder bolt which is threaded in for surveying and then removed. The same plug or bolt is used in all dop-ins which have been set. Demonstrates good long term integrity and good long term accuracy when placed into deep founded structures. Maximum lifespan - decades.

Permanent Survey Monuments

Figure D

Figure E illustrates the monument layout for a typical subsidence event. Monuments are initially installed with concern for the following factors: 1) avoidance of subsurface utilities, 2) rate of ground movement, 3) number and location of structures within subsidence event, 4) maximum coverage of monitoring area, 5) minimum installation time, 6) minimum survey time and 7) facilitation of special research objectives. These objectives usually require several different monument designs. PK nails are installed up the road through the center of the subsidence event.

Drop-in anchors are placed into the foundations of critical structures. Fire hydrants on either side of the event are selected to serve as temporary benchmarks for the first few surveys. These monuments enable immediate monitoring and provide information on settlement during the early stages of the subsidence event.



Example Monument layout

Figure E

Once the underground utilities have been located and the first surveys have been completed and analyzed, the permanent monuments as shown in Figure E can be installed. In Figure E, two 5-foot frost protected monuments along with a 20-foot frost protected monument were installed to act as permanent benchmarks. A combination of frost protected rebars and PK nails are installed in the desired plus pattern that extends through the center of the subsidence event. Though not of a permanent design, PK nails are selected for use in the road surface due to lack of a better alternative. Often the size and shape of the event can be determined immediately on investigation. In such instances, having personnel installing permanent monuments while survey crews are measuring the temporary points can reduce the monument network installation

time. The survey crew can then include the new permanent monuments into the survey network as time permits.

COMPLETING THE NETWORK

Typically within the first fifteen to thirty days a majority of the ground movement has occurred. It is during this time that the rate of settlement decreases and field personnel are now able to refine the survey net by installing additional survey points. By this time a large percentage of the survey net has been established. Further, there has been time to inspect all structures and to prepare maps locating both monuments and structures within the subsidence event. Collectively, such information will be used in placing additional monuments. Modifications made both to the monument layout and survey techniques provide a more detailed and accurate view of subsidence movements and allow increased efficiency in data collection. Finally, adjustments are made in survey techniques that employ more stringent and standardized procedures like those that would be used if the ground were considered stable.

The first iteration of frost protected rebar installation involved placing monuments along straight sightlines on intervals that are approximately 10% of the mine depth. The data collected from measurement of these points is utilized to verify whether the existing points 1) are along an orthogonal line whose intersection is at or reasonably near the subsidence center, 2) extend through and beyond the affected area, and 3) adequately describes the event movements. We have found that smaller and sub-critical events typically require closer spacing of monuments. A judgment is made at this time concerning the need and placement of additional points.

Additional monuments may be installed at this time. Such points are usually installed to extend survey profiles, provide specific or detailed information, and to increase accuracy or speed of the survey. Survey lines may sometimes need to be extended because 1) there was insufficient time to place the necessary number of points, 2) the boundary was not chosen correctly, 3) the event is expanding in size, and/or 4) more detailed analysis of boundary conditions are desired. Besides extending monument lines, additional points may be needed to monitor the movement of a structure that is located off the survey lines. If not yet installed, permanent deep benchmarks are established outside the subsiding area at locations considered more stable.

Monument networks are maintained until they are no longer practical (loss of monuments through destruction) or needed (land use change). Some survey stations, particularly temporary points installed during the early phase of the event, may be abandoned at this time, especially if they are susceptible to damage, inconvenient to the property owner or are redundant. Critical monuments are replaced if damaged and additional monuments installed if warranted.

CONCLUSION

Each case presents unique challenges. The procedures outlined above are followed with necessary modifications made to address individual site conditions. A well planned, flexible subsidence monitoring network not only provides benefits to AML programs and researchers studying subsidence mechanics, but also generates real data on regional problems that is helpful in land-use planning and, ultimately, in protecting the public.

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TECHNICAL PAPER SESSION 2 PARTNERSHIP / POLICY

Title: [Federal-State Relations in the Mining Regulatory Arena:
Pursuing Productive Partnerships](#)

Author: [Gregory E. Conrad](#)*, Executive Director, Interstate Mining Compact Commission

Title: [A Team Approach To Evaluating State Abandoned Mine Reclamation Programs](#)

Author: [Ronald N. Sassaman](#)*, Environmental Protection Specialist, OSM - Denver Field Division

Title: [Eastern PA Partnerships Supported through the EPCAMR Regional Watershed Support Initiative \(RWSI\)](#)

Author: [Robert E. Hughes](#)*, Regional Coordinator, Eastern PA Coalition for Abandoned Mine Reclamation

Title: [San Juan County AML Partnerships](#)

Authors: [Loretta E. Pineda](#)*, Public Information Officer and **Dave Bucknam**, Director, Abandoned Mine Land Reclamation Program, Colorado Division of Minerals and Geology

FEDERAL-STATE RELATIONS IN THE MINING REGULATORY ARENA: PURSUING PRODUCTIVE PARTNERSHIPS

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I appreciate the invitation to participate in this year's Annual Conference of the National Association of Abandoned Mine Land Programs. I will be addressing the topic of pursuing productive partnerships in the context of state and federal regulation of mining **B** be it active operations or abandoned mine lands projects. My perspective will admittedly be as a state government regulator since my organization represents the natural resource and environmental protection interests of 20 Eastern, Midcontinent and Western member states. The Interstate Mining Compact Commission has served for over 30 years as a forum for action, discussion and information dissemination on any and all issues affecting minerals development within its respective member states. The Compact strives to act as a consensus builder, a strategy designer and implementer, and an effective advocate for the states' interests on mining matters. The states are represented by their Governors who serve as Commissioners and the Commission acts through various committees on which each of the member states are represented. Many of the states in attendance here today are members of the Compact and I appreciate your support and active involvement in our work. To the extent that you are unfamiliar with who we are and what we do, please do not hesitate to seek me out during or after the conference so that I can visit more with you. Our organization is open to all 50 states and I would be happy to discuss membership with those of you who are not yet members.

Now on to the matter at hand. Since the beginning of human existence, the earth's resources have played a vital role in the development of our society. Over time, rudimentary tools and weapons gave way to more sophisticated uses of the earth's resources, culminating in all of the necessities and luxuries that we use or enjoy today. All of humankind's advances have been tied to the development and utilization of the earth's resources, including energy, minerals, timber, and soils.

The industrial and agricultural revolutions that began in the 18th century and the scientific revolution of the 19th and 20th centuries provided the impetus for the rapid expansion and development of energy and mineral resources. The aspirations of the rapidly growing populations of developing nations, as well as the demand for necessities and luxuries consumed by the industrialized nations, require the continued availability of resources that are the basis of products and new wealth. We also have learned from past experience that these resources must be produced in a manner consistent with the protection of human health and safety and the environment.

While it may not be apparent to most Americans, it requires about 10 tons of nonfuel minerals, 76,000 cubic feet of natural gas, 25 barrels of oil and 4 tons of coal for every man, woman and child in the United States each year just to maintain our current standard of living. It is estimated that each American uses about 47,000 pounds of newly mined minerals per year. Energy from hydropower, nuclear power, wind power and other alternative energy technology is in addition to these numbers.

Obviously, these energy and mineral resources can only be produced where they have been deposited or made available by geological processes. Much of the undeveloped energy and mineral

resources occur on federal, state, and Native American lands located primarily in the western U.S. and Alaska. Significant undeveloped resources occur within the other states as well, as demonstrated by recent copper discoveries in New England and the revival of precious metals mining in the Carolinas in recent years. Construction and industrial minerals are being produced and utilized nationwide.

As we all know, development of resources often conflicts with other land uses. Earth- and nature-based religions and cultures of Native Americans may conflict with resource development on their lands. The proximity of resource lands to urban areas, national and state parks, wilderness areas, and developed recreation sites also affects their availability for development. Privately owned land is affected through local and regional zoning. The frequent separation of the surface and mineral estates, particularly in the case of private or fee ownership of the surface estate and the federal reservation of the mineral estate or mineral rights, have resulted in competing interests and often in litigation. Americans are concerned about the impact of resource development on the environment, including such areas as air and water quality, wildlife and endangered species.

A fairly recent article in *AMining Voice*, the magazine of the National Mining Association, commented as follows: "The most common multiple-use activities on federal land include private-sector industries such as mining, timber harvesting, water usage, oil and gas leases and grazing. Popular recreational uses are boating, hunting, fishing, mountain biking, camping, dirt biking and off-road driving. Government agencies also manage cultural resources, archeological sites, wild horse populations, real estate transactions, easements and rights-of-way. As more people use federal lands for recreation, multiple-use issues become more complicated." In all of these scenarios, the key is to balance the growing demands of the public for more recreational space with the more traditional uses of commodity extraction and mining.

As a result of the competing interests associated with multiple-use management, the making of informed, credible decisions at the state and federal executive and legislative levels is more important now than ever before. We have all likely faced the criticism that resource development decisions are being made by politicians and government officials who are influenced by the NIMTO syndrome (i.e. not in my term of office) as a result of pressure by the NIMBYs (not in my backyard) and the POTPEs (people opposed to practically everything) and the BANANAs (build absolutely nothing anywhere near anything). In commenting on this regulatory decision-making conundrum, a former state regulatory official and IMCC representative who now works for the Colorado School of Mines stated as follows:

Ideally, a regulatory program should foster the activity that it regulates in a manner that will optimally benefit the public (i.e. those engaged in the activity and the state's citizens) in a manner consistent with proper protection of public health and safety as well as protection of the environment. For such programs to become reality requires that legislators and officials of the executive branch of government act as true public servants **C** that they recognize their subservient role to the public and its best interests. Statutes and regulations adopted in the guise of regulating an activity but which in reality were designed to prevent such activities do not constitute a regulatory program; instead, they are confiscatory, denying the public the

benefits it deserves. Vociferous special interest groups on various sides of an issue too often exert all of the pressure they can muster to confuse decision makers with emotion and misinformation. Knowledge and integrity are the defenses against such pressures, and legislators and administrators possessing both will produce regulatory programs that can truly serve the public.

(AResource Development in Today's Environmental and Political Climate®, by Erling Brostuen, Energy and Minerals Field Institute, Colorado School of Mines, Environmental Geosciences, Vol. 4, No. 1, pp. 29 - 36.)

Where does this leave us? As regulatory authorities within our respective areas of jurisdiction and spheres of influence, we must make some sense out of the multiple-use management dilemma in our attempt to balance the use and protection of natural resources and the interaction between the mining industry, government and society. I would like to focus on one practical way of responding to this sometimes elusive regulatory quagmire: pursuing productive partnerships through intergovernmental cooperation, coordination and consensus-building. Then I want to conclude with a couple of perspectives about public education and regulatory reinvention.

As we might expect under regulatory programs that grow out of national environmental laws like the Surface Mining Control and Reclamation Act (SMCRA), the Clean Water Act (CWA) and the Resource Conservation and Recovery Act (RCRA), there is a fairly high level of interaction (some would say Afriction®) between the states and the federal government. Primarily this is based on a formula in these statutes whereby the states are authorized to take the lead for regulating in a particular area (i.e. water quality, surface coal mining operations, landfills) upon federal approval of a state plan or program. The federal government then accedes to an oversight role in which it monitors the progress of the states without interfering in day-to-day implementation matters.

A federal appeals court in Richmond recently had an opportunity to address Athe carefully designed balance that Congress established between the federal government and the states® in the context of a lawsuit brought by a citizens group challenging West Virginia's handling of permits related to mountaintop mining and valley fills. The court found that the effect of a citizen suit to require officials in a primacy state to comport with the federal provisions establishing the core standards for surface coal mining would end the exclusive state regulation and undermine the federalism established by the Surface Mining Act. The court went on to delineate the role of the states vis-a-vis the federal government under SMCRA:

While it is true that Congress's desire to implement minimum national standards for surface coal mining drives SMCRA, Congress did not pursue, although it could have, the direct regulation of surface coal mining as its preferred course to fulfill this desire. Nor did Congress invite the state to enforce federal law directly. By giving states exclusive regulatory control through enforcement of their own approved laws, Congress intended that the federal law establishing minimum national standards would Adrop out® as operative law and that the state laws would become the sole operative law. Thus, all of the federal provisions

establishing the minimum national standards are not directly operative in West Virginia so long as it remains a primacy state.

The reality of the situation, as we all know, is often quite different from the theoretical state primacy approach contained in the statutes. In the best of times, the federal/state interaction that occurs on an almost daily basis sometimes leads to duplication and confusion; in the worst of times, the tension that attends the intergovernmental balancing act can be almost debilitating. We have found that concerted efforts to foster intergovernmental cooperation, coordination and consensus-building have paid incredible dividends. Not only do we function more as partners than competitors (thus accomplishing more and avoiding duplication), but we also gain a measure of credibility and integrity among those we regulate and protect. In this regard, I wholeheartedly endorse recent remarks by Secretary of Interior Gale Norton where she emphasized the need for consultation, cooperation and coordination in order to achieve effective conservation. The four A's I have advocated over the years are very similar: cooperation, coordination and communication in order to achieve consensus, regardless of the issue.

Admittedly, there will always be those who believe that there is something incestuous and inappropriate about state and federal government agencies working too closely together. However, this tends to reflect a desire by some groups to be able to leverage one government agency against another, rather than a substantive argument against intergovernmental cooperation. Besides, we have seen that a federal agency can work closely with its state counterpart and still retain a significant and meaningful oversight authority. The 900 pound gorilla seems to be alive and well when needed.

Among the areas where IMCC has seen significant results from intergovernmental cooperation are coal remining, the design of a federal oversight program for state surface mining programs, the Clean Streams Initiative within the Office of Surface Mining, the Acid Drainage Technology Initiative, increased funding for states to reclaim abandoned mine lands, a state/federal initiative to review and improve coal data reporting requirements and forms, a state/tribal/federal effort to address mine placement of coal combustion wastes and, most recently, a state program benchmarking effort sponsored by IMCC. In each of these cases, the states have approached our federal counterpart (be it the Office of Surface Mining in the Interior Department, the U.S. Environmental Protection Agency, or the Mine Safety and Health Administration in the Labor Department) and suggested a cooperative approach for resolving shared issues or problems. The results to date have been remarkable and encouraging.

The work of an OSM/State team on federal oversight was recognized by former Vice President Gore's office with a Hammer Award for its efforts to reinvent the way we operate as governments. Pursuant to the new oversight approach, the states' performance in implementing their programs is evaluated based on an assessment of the success of their respective programs on-the-ground, rather than the mere bean-counting approach of the past.

The coal remining initiative has resulted in the promulgation of a final rule this year that removes a significant disincentive that has stood in the way of cleaning up abandoned coal mine sites that often contain acid mine drainage. These sites will likely never be approved for funding under the Abandoned Mine Land Fund, so remining is the only hope for remediation. In a related effort, the

Acid Drainage Technology Initiative has brought together the states, federal government and academia to identify proven technologies that will reduce or even eliminate the formation of acid pollutants associated with current and past mining practices.

Last year, IMCC initiated an intergovernmental forum on the mine placement of coal combustion wastes (CCW). This topic was recently addressed in EPA's 1999 Report to Congress and again in EPA's 2000 Regulatory Determination regarding CCW. The result of the forum was an agreement to pursue cooperative and coordinated discussions and actions regarding the regulation of mine placement of coal ash based on current state regulatory programs and perceived gaps that may exist. In April, I presented an overview at OSM's Technical Interactive Forum on Coal Combustion By-Products in Golden, Colorado where I reported on the significant progress we have made to date. Most promising of these efforts was our most recent state/federal meeting in April where EPA presented a draft report on *Minefill Regulatory Concerns* which assesses the potential gaps that exist in current state regulatory programs vis-a-vis EPA's analysis of federal regulatory requirements pursuant to subtitle D of RCRA. For the first time, the states have a clearer idea of where EPA is coming from and, based on our discussions with them, EPA has a better understanding of how our existing regulatory programs (both coal and noncoal) address these concerns. Next steps in the process call for the states to develop a more detailed analysis and presentation of how our existing SMCRA and RCRA state programs line up with EPA's concerns. The end outcome should be a bridging of the gap between where EPA and OSM believe we must go and how the states are either positioned to go there or can accommodate their concerns. In the final analysis, we hope to reach a consensus that avoids the need for unnecessary, duplicative national regulations and that recognizes the comprehensive state programs already in place for effectively regulating mine placement of CCW.

Another recent state/federal initiative that is showing signs of promise is an effort begun last summer by IMCC, MSHA, the Energy Information Administration in the Department of Energy and the Internal Revenue Service to review the potential for redesigning existing coal reporting forms that are used by state and federal agencies in an effort to ease the reporting burden on industry and to coordinate our individual collection efforts and responsibilities. We hope to agree on either a common reporting format, develop common reporting terms and protocols, or forge an agreement about which agency collects what information and data and how this can then be shared and relied upon by all other agencies. OSM has gathered all of the reporting forms together into a single document and provided an overview of the reporting requirements and accompanying statutory authorities. The states have prepared a matrix that analyzes these forms and requirements. OSM is currently pursuing the potential of coordinating the coal reporting form efforts as part of the Small Business Administration's One-Stop Compliance Quicksilver Initiative, which would provide additional funding for the project.

Another topic I want to touch on is IMCC's recent state program benchmarking initiative. Over the past year, IMCC has been working with OSM to advocate a prototype state program benchmarking workshop together with a seminar on current and emerging strategic and performance management techniques. IMCC believes that the future of state regulatory program improvement and enhancement **B** as anticipated by SMCRA **B** lies in this effective management tool, whereby states share their regulatory experience and expertise on a particular topic as a sort of benchmark by which other states and OSM can measure their respective programs and performance. The end product is

a means by which everyone benefits in terms of program improvement. Our recent prototype benchmarking workshop focused on probable hydrologic consequences (PHC-s) and cumulative hydrologic impact assessments (CHIA-s) and was held from March 12 - 14 in New Orleans. A total of 58 state and tribal representatives attended the workshop, 13 of whom served as either presenters or facilitators. A total of 22 persons from OSM also attended the workshop. The program received very high marks from the participants based on an evaluation form that was distributed to all attendees. Pursuant to a contract with OSM, IMCC was able to reimburse 50 state and tribal representatives for their travel expenses to attend the workshop.

The benchmarking workshop lasted two days and was followed on the third day by a seminar entitled **A**Interactive Working Session regarding Program Effectiveness; Redesigning Program Structures; and Aligning Resources to Achieve Program Outcomes/Results.® The seminar was conducted by Carl DeMaio of the Performance Institute, who had previously facilitated several sessions for stakeholders concerning the Interior Department-s Strategic Plan for FY 2003 and beyond. The seminar was also well received and provided participants with an opportunity to engage in several strategic planning exercises directed at the PHC/CHIA process. Based on the success of both the prototype benchmarking workshop and the strategic planning seminar, IMCC has submitted a proposal to OSM seeking funds for additional benchmarking opportunities and related seminars. Under the proposal, IMCC would sponsor two additional benchmarking sessions and/or seminars over the next two years. Funding would cover IMCC administrative expenses and travel for state and tribal participants. Among the topics that could be addressed at the workshops/seminars are bonding; water use and quality; subsidence; public participation and handling of citizen complaints; state self-audits; and performance measurement/management. In a related matter, IMCC has worked with OSM in coordinating a series of workshops on the development of performance measures for both the Title V and Title IV programs, both of which were held in August.

I would now like to address very specifically some of the challenges that I see facing the AML program in the coming months and years. Our most important initiative will be legislative action to amend Title IV of SMCRA, which is likely to see concerted attention in the 108th Congress convening in January of 2003. Several legislative attempts were made in the current Congress to address Title IV, most of which were motivated by the fact that the authority to collect the per ton fee levied on coal production, which serves as the funding mechanism for the AML Trust Fund, is set to expire on September 30, 2004. However, due to a variety of factors, no substantive amendments are expected in the 107th Congress. This puts the pressure on the next Congress, which must act or the fee collection authority will terminate.

It will be incumbent on the states, as the primary delivery mechanism for Title IV reclamation moneys, to be a key player in these legislative debates **B** as we have throughout the 107th Congress. Not only will the states need to continue their close working relationship with OSM and with Congressional staff, but we will need to forge effective partnerships with other interested and affected agencies and organizations. Among these are national and local citizen groups, the mining industry, and several federal agencies who are relatively new entrants to the AML remediation initiative due to recent congressional funding for their programs. These federal agencies include the Bureau of Land Management, the National Park Service, the Environmental Protection Agency and the U.S.

Army Corps of Engineers. Although these agencies have little to do with reauthorization of Title IV of SMCRA, they are competing for the same limited dollars as the states when it comes to AML remediation efforts. Thus, it will be important for the states to clarify the roles that are played by the states and the federal government under the various authorizing statutes and funding schemes. In particular, it will be critical for the states to emphasize the 25 years of experience and expertise that we have developed with the implementation of effective and efficient AML programs and why it is vital for the states to remain the primary delivery mechanism for these services in order to avoid duplication of effort and wasted resources.

Under the circumstances, there is probably no other state/federal initiative that is as dependent on the pursuit of productive partnerships than the future of the AML program. There are myriad interests, issues and considerations from a regulatory, policy and political perspective that must be reconciled and resolved before a final solution is reached. By working with all interested and affected parties, the states will be better positioned to advocate their views and protect their interests, with the overall objective of serving their constituents by assuring protection of public health and safety, environmental restoration, and economic development in the coalfields of America.

In each of the cases presented above, the key to success has been (or will continue to be) a coordinated effort based on a cooperative attitude focused on consensus solutions to common problems. This type of approach for implementation of regulatory responsibilities seems tailor-made for the area of multiple-use management and balancing resource use where industry, the government and society all have a stake in the eventual outcome. Instead of competing for jurisdiction and authority, thereby sending confusing and contradictory signals to our constituencies, we are able to implement programs of integrity and consistency and gain the public's trust and confidence in our decision-making and policy choices.

Our efforts in this regard will be complemented by some of the on-going efforts to reinvent government, and the way we operate as governments. One initiative in particular, labeled AA New Environmentalism®, holds great promise from my perspective. This initiative calls for new partnerships between citizens, the private sector, communities, and federal, state and local governments to achieve the next generation of environmental benefits. A New Environmentalism® identifies four basic principles for improving environmental policy and the environment itself: 1) nurture the creativity and problem-solving capacities of state and local officials and ensure accountability for environmental results; 2) encourage a more flexible performance and compliance-based management of the environment; 3) harness environmental entrepreneurship like A private stewardship® and A green business practice® with incentives; and 4) emphasize honesty, integrity and balance in environmental decision-making by acknowledging science as crucial to good decisions. Many of these goals are reflected in the above-described activities that are already taking place between the states and OSM and EPA. They are also contained in the Enlibra Principles adopted by the Western Governors' Association some years ago and that now serve as the basis for governmental action and decisions affecting the environment. Among other things, Enlibra encourages resolving environmental problems through consensus by employing the notion that people working together can create jobs and protect the environment. We will be looking for new and expanded opportunities like these in the future.

A final key component of the overall picture regarding balancing resource use and protection that I want to briefly touch on is education. IMCC has recently undertaken a minerals education program in an effort to play a role in the overall effort to inform the public about the importance of minerals and the impacts associated with their development. As Erling Brostuen has noted in his article on Resource Development: "People in today's society make little connection between commodities considered necessities and luxuries and the source of the materials that have gone into their manufacture. A collective ignorance is manifested in the continued portrayal of the extractive resource industries as irresponsible corporations and individuals intent on destroying the environment for monetary return. Many in our society do not or refuse to recognize that we are all consumers of natural resources and that the only reason such resources are extracted is to satisfy our demand for food, shelter, energy, automobiles, refrigerators, and the like. Society's understanding of the social, economic, and environmental benefits of the extractive industries to the community, state or region is unfortunately extremely limited." (Pages 33-34)

One of our objectives at IMCC is to inform and educate the public about natural resource development issues associated with mineral extraction, including our role as state regulators. We believe that an informed public will be better able to understand the need for minerals and the importance of attempting to balance the development of our mineral wealth with the protection of other resources like air, water and land. This process of education must begin at an early age and hence we are focusing on teaching teachers about mineral resources, since they are the key to the minds of tomorrow's decision makers and constituents. We have seen repeatedly that an investment of time, energy and money in the educational arena will pay dividends when the time comes for rational, informed decision making.

What are the challenges facing government, industry and society at large concerning multiple-use management in the mineral resource arena in the future? Among the issues we are working on, besides those mentioned above, are adequate funding for state AML reclamation grants; impacts from subsidence on dwellings and water supplies; mountaintop removal and valley fills; protection of significant historic and archeological properties; bonding for acid mine drainage and other long-term mining impacts; viewsheds associated with mining activity; blasting practices; effective handling of citizen complaints; and reforestation and other postmining land use opportunities. I am convinced that the productive partnerships I have discussed with you today contain lessons and options that are applicable to these new challenges. It will be incumbent upon us as regulators to choose the best and most promising approaches as we seek to balance the use of our abundant natural resources with the required protection and preservation. Much of this transcends political parties and Administrations and serves as an example of how we can best manage our resources, particularly where sustainable development is an overall goal. In the end, multiple use applied honestly and with integrity will ensure the responsible management of our natural resources, which will in turn supply the raw materials, energy, food and recreation for our ever-expanding society. And the partnerships we pursue and produce today will serve to advance these goals and will reap benefits well into the future.

A TEAM APPROACH TO EVALUATING STATE ABANDONED MINE RECLAMATION PROGRAMS

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ABSTRACT

The Surface Mining Control and Reclamation Act of 1977 (SMCRA or the Act) authorizes the Secretary of the Interior to approve and fund State and tribal abandoned mine land (AML) reclamation programs through the Office of Surface Mining (OSM). SMCRA also requires the Secretary, through OSM, to conduct activities necessary to ensure compliance with the Act. OSM's directive AML-22 describes the policies, procedures, and responsibilities OSM should follow to evaluate how States and Indian tribes administer their approved AML programs to ensure that they meet the requirements of SMCRA and the implementing Federal regulations. AML-22 also provides considerable flexibility for structuring and carrying-out those evaluations.

OSM's Denver Field Division (DFD) is responsible for evaluating the Colorado Inactive Mine Reclamation Program and the Utah Abandoned Mine Reclamation Program. Since 1996, the "Colorado-Utah AML Review Team" (our team) has been conducting those evaluations annually on OSM's behalf. Our members include representatives of the Colorado and Utah Programs and DFD. We decide what topics to review, conduct the reviews, make findings and recommendations, and complete evaluation reports.

In evaluation year 2001, we evaluated three performance measures for each State program. Those measures evaluated: Whether completed reclamation met project goals; if the States' project ranking and selection processes evolved to meet their programs' changing needs, and if so, how; and, if the States obligate their grant funds in a timely manner. We concluded that both Programs' reclamation met project goals and the States' obligation rates were satisfactory. We also found that the Programs' changing needs prompted refinements in one ranking and selection process while prompting the need for an AML plan amendment to recognize changes in the other.

INTRODUCTION TO EVALUATING AML PROGRAMS

Section 102(h) of SMCRA says one purpose of the law is to "promote the reclamation of mined areas left without adequate reclamation prior to the enactment of [SMCRA] and which continue, in their unreclaimed condition, to substantially degrade the quality of the environment, prevent or damage the beneficial use of land or water resources, or endanger the health or safety of the public * * *." Title IV of SMCRA created the Abandoned Mine Reclamation Fund (the Fund). Active coal mine operators pay fees on each ton of coal they produce, and those fees comprise the Fund. SMCRA authorized the Secretary of the Interior to approve programs to reclaim abandoned coal and noncoal mines in States that have approved programs to regulate active coal mining ("primacy states") as one means of fulfilling the purpose of section 102(h). In the Supplemental Appropriations Act of 1987, Congress gave the Secretary authority to approve three tribal AML programs. To date, the Secretary approved 23 State and 3 tribal AML programs under SMCRA. The Colorado Inactive Mine Reclamation Program has been operating

since its approval on June 11, 1982. Utah's Abandoned Mine Reclamation Program has been operating since its June 3, 1983, approval.

OSM awards grants from the Fund to Indian tribes and States to pay their AML programs' administration and reclamation costs. The Abandoned Mine Reclamation Act of 1990 amended SMCRA to, among other things, expand provisions for noncoal abandoned mine reclamation under title IV and to authorize funding of projects to address acid mine drainage, to assist communities impacted by past mining and processing, and to address the need for activities or public facilities in States impacted by the mining industry. The Energy Policy Act of 1992 extended collection of the fees on coal production to September 30, 2004.

Events of the early to mid-1990's laid the groundwork for our approach to evaluating AML programs. The Government Performance and Results Act (August 3, 1993) and reductions in Federal spending at the time required OSM to look at different ways of accomplishing its mission and measuring performance. One result was OSM's "environmental restoration business line" that encompasses Federal, State and tribal AML reclamation programs funded under SMCRA. Its goal is to cooperate with States and tribes to reclaim abandoned mine lands while measuring performance toward achieving that goal. A reorganization that followed in mid-1995 significantly reduced OSM's resources. The reorganization also transferred responsibility for evaluating the Colorado and Utah AML programs to the newly created Denver Field Division in the Western Regional Coordinating Center. OSM adopted use of self-directed teams to carry out many of its functions in response to these new challenges. Another change in operating procedures occurred on November 20, 1995, when OSM put Directive AML-22 into effect.

Directive AML-22 describes OSM's policies, procedures, and responsibilities for evaluating State and tribal AML programs under SMCRA. AML-22 calls these evaluations "enhancement and performance reviews." Those reviews evaluate and help States and Indian tribes administer, implement, and maintain their approved reclamation programs to ensure that they meet the requirements of SMCRA and the implementing regulations. OSM previously called this activity "oversight." AML-22 establishes Programmatic Agreements (PA's) as the basis for the commitment OSM, States, and Indian tribes share toward achieving their common goal of successful AML reclamation. As such, PA's establish the framework for annual AML program evaluations and are to be developed in cooperation with States and tribes. They include "principles of excellence" that evaluators can use as guidelines for conducting enhancement and performance reviews. PA's describe what aspect of programs to review, how to measure performance under each principle ("performance measures"), the logistics of conducting reviews, and how findings and recommendations will be made. They should emphasize on-the-ground results and consider each program's unique character. AML-22 suggests several principles of excellence and performance measures. While OSM is responsible for evaluating AML programs under the directive, AML-22 provides flexibility for doing so.

DESCRIPTION OF OUR TEAM AND EVALUATION PROCESS

Using a team to evaluate SMCRA-funded AML programs is not unique. An informal review of annual evaluation reports dating from 1998 through 2001 posted on OSM's website (<http://osmre.gov/report01.htm>, for 2001) showed that, of 26 AML programs evaluated, teams apparently conducted parts or all of at least 10 State and tribal program evaluations during those four years. The actual number may be higher given the possibility that some reports did not describe team involvement in the evaluations. In many cases, OSM appears to have developed

performance agreements or work plans in cooperation with States or tribes but performed the subsequent evaluation(s) itself. Where teams were noted, many appeared to be “ad hoc” teams assembled for a one-time review of a specific topic or topics. Some teams included personnel from States or Indian Tribes and OSM. Our use of a standing team to plan and perform evaluations in their entirety under a multi-year performance agreement is less common and distinguishes our approach from most others’.

OSM formed the “Colorado-Utah AML Review Team” in January 1996. We report to the OSM-DFD chief. Our State and Federal members jointly attended team training that Vantage Human Resources, Inc., of Lakewood, Colorado, presented in 1997. Originally, team members included two representatives from the Utah program, one from Colorado’s program, and four staff members of OSM-DFD. One OSM-DFD member served as the team leader. Membership changed in the team’s second, third, and fourth years, but we retained four members for the last two years. Presently, team members include the administrator of the Utah Program, the supervisor of the Colorado Program, one OSM grants specialist, and one OSM environmental specialist. Our Utah and Colorado members are the only original members still on the team. We discuss whether or not to rotate the team leader role at the beginning of each evaluation year. Some of our evaluations require assistance from specialists on the State Programs’ staffs. Occasionally, our State members function as team members and topic specialists during our reviews. This approach makes our roles and interaction more complex and challenges each member’s objectivity.

Our team signed its first Performance Agreement on May 2, 1996. That PA included: A statement of its purpose; descriptions of member responsibilities; three principles of excellence and a total of 17 performance measures (called “performance elements” at that time); and members’ signatures. (See Attachment 1 for a description of the original three principles of excellence and the performance measures.) The PA also included each measure to be evaluated in the first and second years for the respective principles. It described each principle and performance measure, background information pertinent to the review, the review populations and samples, how the reviews were to be conducted and reported, and the review schedules. Our first PA initially covered the 1996 and 1997 evaluations. We completed the first annual summary evaluation reports in November 1996.

The Performance Agreement changed over time just as our team changed. AML-22 encourages OSM to tailor its evaluations to the needs and unique character of each program. It also encourages conducting evaluations that provide meaningful feedback to States and tribes. In 1998, we revised our Agreement to extend through the 2002 evaluation year. At that time, we also made significant changes to the principles of excellence and performance measures to reflect those topics of greatest interest and benefit to Colorado, Utah, and OSM. Though the current Agreement spans five years, we review it annually to make any necessary changes. We completed enhancement and performance review reports and summary evaluation reports each year through 2001 to date. Despite the numerous content changes, the PA’s overall format remains relatively unchanged. Attachment 1 describes the changes we made to the principles of excellence and performance measures. It also shows the principles of excellence and performance measures we evaluated since our team was formed. We will change the PA again after it expires on September 30, 2002.

Our team holds meetings once or twice each evaluation year in addition to our field and office reviews. We meet at the beginning of each evaluation year to update the Performance Agreement, principles of excellence, and performance measures. At that time, we also discuss

evaluation samples, decide if we will need extra help, and schedule field and office reviews. We schedule meetings and field evaluations months in advance or risk not being able to convene our members on short notice. Changing our plans later in the year can be difficult. On the other hand, meeting and jointly evaluating on-the-ground reclamation enables us to benefit from our different perspectives and combined knowledge. We interact informally throughout the year by telephone, electronic mail, and during office visits that coincide with other business.

Office reviews usually focus on activities that influence the States' ability to effectively administer their programs and conduct on-the-ground reclamation. Such evaluations involved grants, contracting, project ranking and selection, and others as shown in Attachment 1. When possible, we schedule office reviews to avoid interrupting the States' construction season and to ensure that staff specialists will be available if needed.

Our OSM members write evaluation reports based on the team's observations and reviews. All team members review and comment on our reports. Enhancement and performance review reports present our findings and recommendations in great detail. Those reports, in turn, provide the factual support for summary annual evaluation reports. The team leader sends summary annual reports to OSM headquarters in Washington, D.C., where they are posted on OSM's website. We decided to not combine our annual summary evaluation reports for the Colorado and Utah programs with evaluations of the respective States' coal regulatory programs operated under title V of SMCRA.

The observations, findings and recommendations we make provide quick feedback to our State members in their roles as managers of the Colorado and Utah Programs. We have the responsibility and authority to make recommendations to the State AML programs and to OSM. However, we do not have authority as a team to require the States to implement our recommendations. We develop our findings and recommendations through consensus. That helps our recommendations survive the transition from our reports to the State programs' planning. It is incumbent on us as team members to encourage correction of problems if recommended but the ultimate responsibility for resolving them rests with us in our individual roles as State and OSM employees. We realize our team has not been fully "tested" on its ability to reach consensus on contentious issues. So far, we have not yet encountered an issue that was so problematic we could not reach consensus on it. On the other hand, that might be the strongest evidence yet of the Colorado and Utah AML programs' overall success.

SUMMARY OF OUR 2001 EVALUATIONS

We reviewed the same principles of excellence and performance measures for the Colorado and Utah programs in the 2001 evaluation year.

Principle of excellence 1 was "the State's on-the-ground reclamation is successful." Our reviews of performance measure (a) (our "1(a)" review) determined if reclamation met project goals. The review populations included projects funded for construction in 1998, 1999, and 2000. The review samples included two coal and nine noncoal projects in one State and two coal and three noncoal projects in the other. Reclamation of all projects was complete. We compared the States' reclamation to their project specifications and other documentation for each project visited. We determined if projects complied with conditions resulting from interagency consultation (if evident) on issues involving threatened and endangered species, cultural resources and other values and if they improved overall site conditions compared to pre-reclamation conditions. Overall, though, we focused on whether reclamation continued to abate

the original hazards. We looked for specific reclaimed hazards or other aspects of reclamation while empirically evaluating overall site conditions. If we found problems, we discussed them and decided if they were hazardous or not and if maintenance was needed to correct them.

Our 1(a) evaluations found that projects we visited in both States met their respective goals. We also observed that the Programs' reclamation protected wildlife habitat and species by constructing gated closures and by reestablishing riparian vegetation. We also noted where the Programs avoided disturbing historically significant structures or preserved it during the course of reclamation. Only one gated closure on a mine opening in one State required maintenance and a second required monitoring, both due to vandalism. In the other State, we found only one mine closure that needed maintenance and two others where continued monitoring was advisable. We recommended that the respective Programs perform the necessary maintenance and monitoring, which they are planning.

Principle of excellence 2 was "the State AML programs' procedures are efficient and effective." Reviewing performance measure (a) (our "2(a)" review) looked at whether each States' project ranking and selection evolved to meet the their Programs' changing needs, and if so, how it evolved. The review populations included all coal and noncoal projects funded for reclamation in grants OSM awarded to the States since the Secretary approved their Programs. Our review samples included 13 projects funded for reclamation in one State's 1998, 1999, and 2000 grants and 38 projects funded in the same years' grants for the other State. We looked at how the States' existing processes ranked coal and noncoal projects they selected for reclamation under those grants. If selected projects did not rank high compared to others, we examined the reasons why the Programs selected them. We also looked at whether the Programs believed their existing processes let them select those projects most in need of funding or whether they considered other factors to do so. Experience in Colorado and Utah shows that a number of factors have become obvious in the course of project ranking and selection, particularly with respect to noncoal hazards. Factors such as shifts in population centers, changes in access resulting from increasing road density, and diverse and dispersed outdoor recreation have an increasing influence on the degree to which abandoned mines, especially noncoal mines, pose hazards to public health and safety.

We found that one State followed its approved process to rank and select the sample projects we reviewed. We also found that this State generally addresses its most hazardous problems before it considers other less hazardous sites. While the Program followed the State's approved process, we found that it perceived a need to improve the process to make it more objective for selecting noncoal projects. The Program developed a Geographic Information Systems (GIS)-based "noncoal planning process" within the overall framework of its approved process to make its noncoal project selections more objective and quantifiable. The process generates composite maps that enable the Program to preliminarily select noncoal projects almost at a glance and target areas most in need of abatement with greater confidence. In viewing composites generated by the time of our evaluation, we noted that the new process substantially validated the Program's past, more "intuitive" selections of noncoal projects it reclaimed.

In the second State, our 2(a) evaluation found that the Program followed part of the ranking and selection process described in its approved plan but did not follow other parts of the process that its experience showed to be impractical. We concluded that the State's formal ranking and selection process has not changed to meet the Program's needs. On the other hand, we found that the informal process the Program used gave subjective consideration to changing

factors (such as those mentioned above) that influence the degree to which abandoned mines are hazardous. The Program prioritized all 38 sample projects. However, we were unable to determine if those projects addressed the most hazardous problems in the State that existed at the time the Program selected them or how they compared to each other because they were not objectively ranked. The Program believes its informal process meets its needs and works well being based on subjective, professional judgment. It also believes an “objective ranking” process would, in most cases, support the projects it selects under the “subjective judgment” process it uses. At the same time, the Program recognizes the need to amend its plan to describe the process it will follow. We recommended that the State revise its plan to describe the criteria it will use to rank and identify projects as required by 30 CFR 884.13. To do so, the State decided to revise an AML plan amendment currently pending with OSM.

The third principle of excellence was “the State must have systems to properly manage AML funds.” Our review of performance measure (f) (our “3(f)” review) determined if Colorado and Utah obligate their SMCRA grant funds in a timely manner. The review populations included all active AML grants OSM awarded to the States in the 1998, 1999, and 2000 Federal fiscal years. We began by determining how the States obligate their funds within their respective accounting systems. We met with Program and other staff responsible for tracking contractual obligations using AML grant funds that OSM awards to the States. In addition, we reviewed and discussed administrative costs, major purchases, contracting costs and samples of actual obligations. We found both States’ obligation rates to be timely and acceptable. One State’s obligation rate was 97.22 percent at the end of fiscal year 2000; at the time of our review, it was 97.8 percent. The other State’s obligation rate was 86.08 percent at the end of fiscal year 2000 and 88.4 percent at the time of our review. Our evaluations concluded that obligation rates are a valid measure of how States spend grant funds though some administrative factors affect how AML programs and OSM perceive obligation rates. We did not recommend any changes in how the States obligate their grant funds as a result of our evaluations.

ATTACHMENT 1

PERFORMANCE AGREEMENT PRINCIPLES OF EXCELLENCE AND PERFORMANCE MEASURES

1996 & 1997 PERFORMANCE AGREEMENTS – PRINCIPLES OF EXCELLENCE & PERFORMANCE MEASURES	YEAR & STATE EVALUATED
1: The State's on-the-ground reclamation is successful.	
a: Does completed reclamation meet the goals of the project?	UT: '96 thru '97; CO: '97
b: Is reclamation successful on a long-term basis?	CO: '96; UT: '97
2: The State must have an approved reclamation plan that meets the requirements of Federal laws and regulations and must conduct reclamation in accordance with its plan.	
a: Does the current plan meet the requirements of SMCRA, the regulations and other applicable laws? Does the State AML program work cooperatively with OSM to establish a schedule and make necessary changes to the plan?	CO: '96 thru '97 UT: '96 thru '97
b: Does the State AML program comply with OSM Directive AML-1 (AML Inventory?)	
c: Does the State AML program comply with its plan for project ranking and selection?	
d: Does the State AML program follow the reclamation requirements of the plan?	
e: Are the State contracting procedures being followed?	CO: '97; UT: '97
f: Does the State AML program perform the AVS check as required on the successful bidder at the time of contract award?	CO: '97; UT: '97
g: Does the State AML program comply with NEPA as required?	
3. The State must have systems in place to ensure accountability and responsibility for spending AML funds and a process to assure that such systems are working.	
a: Are drawdowns and disbursements of monies accomplished in accordance with requirements for Federal funds?	
b: Is State AML program income accounted for properly?	
c: Are grant applications and reports submitted timely?	
d: Are State procedures for property procurement, management and disposal of property followed?	
e: Do the state internal control systems work?	
f: Are audits conducted by the State in accordance with the Federal Single Audit Act of 1984? Does the State cooperate with OSM in audit resolution?	
g: Do State AML program managers have adequate financial information to manage the projects and the program?	UT: '96 thru '97; CO: 1997
h: Are the costs of State AML program activities appropriately documented and supported?	

ATTACHMENT 1 (cont'd)

'98, '99, 2000, 2001, 2002 PERFORMANCE AGREEMENTS - PRINCIPLES OF EXCELLENCE & PERFORMANCE MEASURES	YEAR & STATE EVALUATED
1: The State's on-the-ground reclamation is successful	
a: Does completed reclamation meet the goals of the project?	CO: '99, 2001 UT: '99, 2001
b: Is reclamation successful on a long-term basis?	CO: '98, 2000, 2002 UT: '98, 2000, 2002
c: Do the State's monitoring and maintenance procedures effectively ensure successful reclamation? <i>(new performance measure added for future evaluation, but not scheduled for review in 2002)</i>	
2: The State AML program procedures are efficient and effective.	
a: Has the State's project ranking and selection evolved to meet the State program's changing needs? If so, how? <i>(revised and replaced the '98 version in 2001, which read, "Is the State process for project ranking and selection still valid?" That '98 version replaced the '96-'97 version of 2(a) and revised the '96-'97 version of 2(c))</i>	CO: 2001; UT: 2001
b: Can the State's contracting procedures be improved to be more responsive to program needs? <i>(revised and replaced former 2(e) in '98)</i>	CO: '99; UT: '99
c: Is the State's Authorization to Proceed submittal, and OSM's response, efficient in allowing the State to proceed with construction as planned? <i>(revised and replaced former 2(g) in '98)</i>	CO: '98; UT: '98
<i>*(performance measures 2(b), (d), and (f) from the 1996-'97 Agreement were deleted in '98)</i>	
3. The State must have systems to properly manage AML funds <i>(revised and replaced former principle 3 in '98)</i>	
a: Is State AML program income accounted for properly? <i>(formerly 3(b) in '97)</i>	
b: Can the grant application and report procedures be improved? <i>(revised and replaced former 3(c) in '98)</i>	
c: Are State procedures for property procurement, management and disposal of property effective? <i>(revised and replaced former 3(d) in '98)</i>	
d: Do State AML Program managers have adequate financial information to manage the projects and the program? <i>(revised and replaced former 3(g) in '98)</i>	CO: '98
e: Are the costs of State AML program activities appropriately documented and supported? <i>(formerly 3(h) in '97)</i>	CO: '99 -2000; UT: '99 – 2000
f: Is the State obligating its grant funds in a timely manner? <i>(new performance measure added for 2001)</i>	CO: 2001; UT: 2001
g: Do the State's procedures for managing set-aside funds support the intent of SMCRA? <i>(new performance measure added for 2002)</i>	CO: 2002; UT: 2002
<i>*(performance measures 3(a), (e), and (f) from the '96-'97 Agreement were deleted in '98)</i>	

REFERENCES

- Abandoned Mine Reclamation Act of 1990; P.L. 101-508 (November 5, 1990)
- Annual Summary Evaluation Report of the Colorado-Utah Abandoned Mine Land Review Team for the Colorado Inactive Mine Reclamation Program for Evaluation Year 2002 (November 20, 2001)
- Annual Summary Evaluation Report of the Colorado-Utah Abandoned Mine Land Review Team for the Utah Abandoned Mine Reclamation Program for Evaluation Year 2002 (November 20, 2001)
- Colorado Inactive Mine Reclamation Plan (June 11, 1982)
- Colorado Inactive Mine Reclamation Program 2001 Enhancement and Performance Review Reports (1(a), September 5, 2001; 2(a), October 25, 2001; 3(f), September 18, 2001)
- Colorado-Utah AML Review Team Performance Agreement (rev. 1/7/02)
- Energy Policy Act of 1992; P.L. 102-486 (October 24, 1992)
- Evaluation of State and Tribal Abandoned Mine Land Programs, OSM Directive AML-22 and 22-1, Transmittal Nos. 840 and 872, respectively (November 20, 1995, and October 6, 1997, respectively)
- Government Performance and Results Act; P.L. 103-62 (August 3, 1993)
- Supplemental Appropriations Act, 1987; P.L. 100-71 (July 11, 1987)
- Surface Mining Control and Reclamation Act, as amended; P.L. 95-97; (August 3, 1977)
- Utah Abandoned Mine Reclamation Plan (June 3, 1983)
- Utah Abandoned Mine Reclamation Program 2001 Enhancement and Performance Review Reports (1(a), September 5, 2002; 2(a), September 24, 2001; 3(f), September 18, 2001)

EPCAMR: BUILDING COALITIONS THROUGH PARTNERSHIPS IN THE EASTERN PA COALFIELDS

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ABSTRACT

PA has a \$15 billion AML problem with over 280,000 acres of AML and 3500 stream miles impacted by AMD. The public has little knowledge of reclamation or remediation techniques available to treat AMD and reclaim AML. EPCAMR provides nearly 60 watershed organizations alone, in Eastern PA, continued support, technical assistance, grant writing assistance, equipment, monitoring and education programs, legal assistance, funding for assessments or implementation of pilot-scale AMD treatment systems.

For the last four years EPCAMR, in partnership with the Western PA Coalition for Abandoned Mine Reclamation (WPCAMR) and funding from the PA DEP-Office of Mineral Resources Management (PA DEP-MRM), to administer a small, but, successful mini-grants program, called the EPCAMR RWSI. The goal of the program is to help new groups organize and assist experienced groups in their efforts to restore watersheds impacted by AMD/AML, through sustainable community-led watershed partnerships, and related reclamation/remediation projects. Robert E. Hughes, EPCAMR Regional Coordinator developed the Eastern PA program, in conjunction with the WPCAMR Regional Coordinator from scratch in 1997, based on the needs of local groups working on AMD/AML issues.

Examples of the types of watershed improvement projects funded have included: Land Reclamation Projects, Water Monitoring, Organizational Support, Education, Design & Engineering, Implementation of Abatement Measures, Teacher Workshops, Conferences, and Community Meetings. Grants are awarded up to \$5000 each, requiring a 20% local match, contributed either in donated services, other grants, or cash.

EPCAMR Regional Coordinator will discuss how EPCAMR leveraged \$50,000 from the PA DEP-MRM and turned it into \$380,000 to complete 11 projects in 2001-2002. Over the last 4 years, EPCAMR has completed 49 projects, through building successful partnerships, with only \$200,000 from the PA DEP-MRM and turned it into nearly \$2 Million in matching funds by "Inviting the Public IN" to work on watershed reclamation/remediation projects.

16 County Conservation Districts in Eastern PA support EPCAMR. EPCAMR provides technical assistance to over 60 organizations throughout the region. EPCAMR has maintained a diverse board membership over the last 6 years. The regional non-profit organization is made up of community watershed organizations, Anthracite coal operators, the Anthracite Region Independent Power Producers Association, the PA Anthracite Council, Co-Generation facilities, conservancy groups, and other regional non-profits.

ABANDONED MINE RECLAMATION & AMD REMEDIATION

EPCAMR provides the following services to groups:

- Grant Writing Assistance, Administration, Coordination
- Project Technical Assistance related to Passive Treatment Designs & Engineering for the Abatement of AMD
- State-wide Conference Coordination on AMD/AMLR
- Teacher Training and Water Quality Monitoring Workshops
- Watershed Assessments, Comprehensive Reclamation Plans
- Scholarships and Grant Funding
- Education and Outreach Opportunities, Media Events; and
- AMD/AMR Field Tours in the Anthracite Coal Fields

EPCAMR REGIONAL WATERSHED SUPPORT INITIATIVE GRANT PG

The goal of the EPCAMR RWSI Grant PG is to restore watersheds impacted by AMD & AML through the development of sustainable community-led watershed organizations, coalitions, partnerships, environmental action, and related reclamation, remediation, and environmental education projects. The PG has been a cooperative effort between EPCAMR, WPCAMR, PA DEP Bureau of Mineral Resource Management, and the PA DEP Bureau of Watershed Management-Section 319 PG for the last 4 years.

MEETING THE COMMUNITY NEEDS OF WATERSHEDS IMPACTED BY AMD/AML

EPCAMR funds the following type of community projects in the region:

- Water Quality Improvement/Land Reclamation Projects
- Water Monitoring or Sampling
- Organizational Support–legal fees, public meeting facility rentals, part-time personnel, office supplies, equipment purchases, etc.
- Student & Teacher Training Workshops
- Watershed Conferences, Meetings, Forums

- Implementation of AMD Abatement Measures –Passive Treatment Systems, i.e., Diversion Wells, OLCs, ALDs, OLDs, Wetlands, SAPS; and
- Project Development –Design & Engineering

EPCAMR RWSI PG

EPCAMR Criteria for supporting reclamation and remediation projects are as follows:

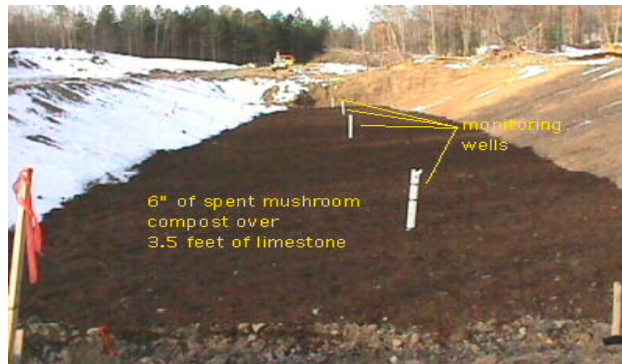
- Up to \$5000 maximum for individual grants available
- Minimum of 20% local match is required
 - in-kind services, volunteer time, donated professional services, other grants, or cash match
- Projects need to be completed within 1 year
- Diverse partnerships are encouraged to achieve integration of all parties interested in AMR
- Projects must involve abandoned mine reclamation, AMD remediation, watershed restoration, or education & outreach within the local communities affected
- Simple 4 Page Grant Application including a Budget Sheet; and
- Regional Coordinator Available to Help Prepare Applications

LIST OF PROJECT SUPPORTED UNDER THE EPCAMR RWSI PG IN 2001-02

- Shamokin Creek Restoration Alliance’s Carbon Run Watershed AMD SAPS Construction of (Site 42)
- Lackawanna River Corridor Association’s Legget’s Creek Greenway/Rail Trail Corridor AML Restoration
- Schuylkill Headwaters Association’s Rhoersville AML Pit Stream Restoration & Relocation Project
- Huber Breaker Preservation Society Formation & Restoration
- Schuylkill County Conservation District’s AMD/AML Bear Creek Watershed Awareness Festival
- Wyoming Valley Watershed Coalition’s Streamside AMD/AML Cleanup
- Hicks Creek Watershed Association Formation
- Wildlands Conservancy’s Luasanne Tunnel Aerobic Wetlands Construction
- Earth Conservancy’s Abandoned Mine Reclamation Brochure
- Coordination of the 4th Annual State-wide Conference on AMD/AMR
- Luzerne Conservation District’s 2-Day Teacher Training Workshop/Field Tour on AMD/AMR

CARBON RUN WATERSHED AMD SAPS CONSTRUCTION OF (SITE 42)

SCRA and the Northumberland County Conservation District placed 60 T of mushroom compost to the Carbon Run (Site 42) Successive Alkalinity Producing System (SAPS) Vertical Flow Wetlands Treatment System in the Shamokin Creek Watershed. SCRA volunteers assisted in the spreading of the compost evenly and members of the Northwest Cadets Juvenile Probation Center assisted in rock moving and placement. SCRA fabricated and installed a new influent pipe that passed the pre-treated AMD over a larger, more evenly distributed surface area reducing the previous problems of concentrated flows to a single area within the SAPS. Site 42 is used as an educational facility, with signs posted explaining how the AMD is treated using the SAPS, for

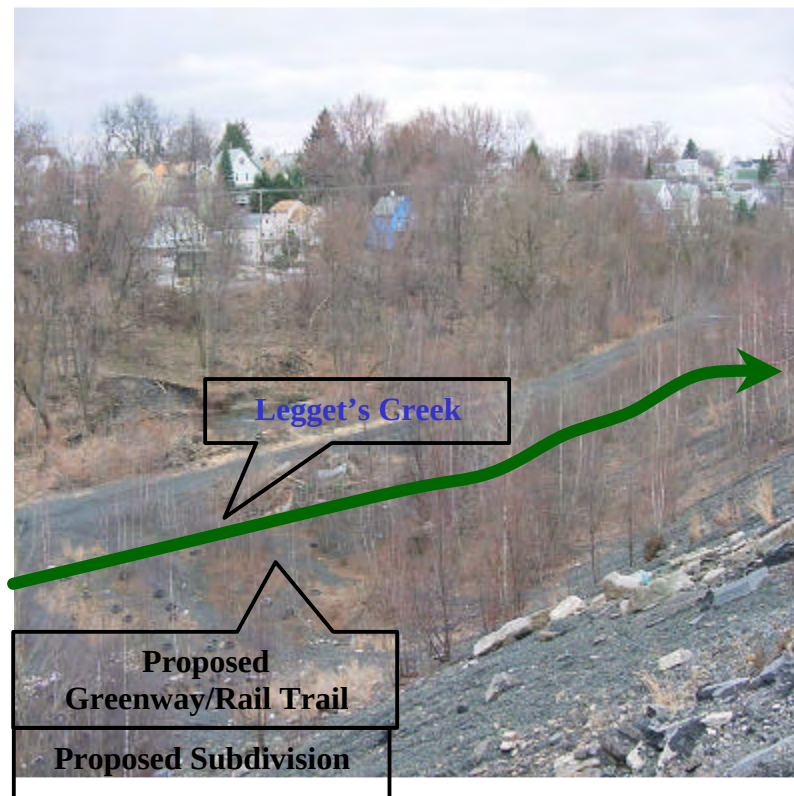


Site 42 SAPS

tours of local high schools, community groups, and Bucknell University college students.

LACKAWANNA RIVER CORRIDOR ASSOCIATION'S LEGGET'S CREEK GREENWAY/RAIL TRAIL CORRIDOR AML RESTORATION

The project area consumes a 40 acre land reclamation project in N. Scranton along a ½ mi. reach of Legget's Creek; Lackawanna River's 4th largest tributary. LRCA is working with LVC, City of Scranton, Marvine/Dutch Gap Little League, LSEC, and the Polish National Union to provide volunteers for the planting of the greenway and LL&E plans to develop a 68-lot single-family moderate-income subdivision on the former AML site. LRCA purchased additional topsoil amendments and blended it with composted woodchips from the Lackawanna County Recycling Ctr to amend the soil along the Leggett's Creek and to create planting pits for trees and shrubs purchased with a USFS grant.



Legget's Creek Greenway/Rail Trail Corridor

**SCHUYLKILL HEADWATERS ASSOCIATION'S RHOERSVILLE AML STRIPPING
PIT STREA, RESTORATION & RELOCATION**



1st Photo-AMD in the Pit; 2nd-Anthracite Bottom Rock Syncline; 3rd-Area Where Stream Flows into the Pit Prior to Project; 4th-Pipe Installed to Divert Water; 5th-SHA member stands in the newly constructed stream diversion channel; 6th-Newly restored stream channel flowing away from the Rhoersville Stripping Pit

RHOERSVILLE AML STRIPPING PIT STREA, RESTORATION & RELOCATION

Schuylkill Headwaters Association addressed a major NPS problem at an AML site in the Heckschersville Valley, known as the Rhoersville AML Stripping Pit. A major headwater tributary to the W. Branch of the Schuylkill River flowed directly into the pit and into the underground mine workings before surfacing as AMD at the Oak Hill Outflow, which flows at ~10-15,000 gpm within a ½ mile from the point at which the water is lost. SHA, Reading Anthracite Company, Schuylkill County Conservation District, EPCAMR, ICI Explosives USA, PA DEP Pottsville DMO, Minersville Water Authority installed pipes across a haul road and relocated the stream that was flowing into the pit restoring a 800' stream channel to divert the flow from entering the Rhoersville Pit. Flows have been reduced at the Oak Hill Outflow, allowing dissolved iron, manganese, and aluminum to precipitate out more quickly, and there are now plans to construct a sizable wetlands to treat the AMD in the vicinity of the Oak Hill Outflow in the Village of Duncott. SHA and the PA DEP BAMR continue to monitor the outflow.



Oak Hill AMD Outflow to the West Branch of the Schuylkill River

FORMATION OF THE HUBER BREAKER PRESERVATION SOCIETY & AML RESTORATION

HBPS developed and produced 2/4 quarterly newsletters and a full-color brochure to highlight potential projects around the Huber Breaker. A 6.5 acre AML site surrounds the largest standing functional Anthracite Coal Breaker in the Wyoming Valley. Plans are to restore the Huber Breaker into a museum and historic visitor center. The Huber Breaker, as a tourist attraction ties into the Delaware & Lehigh National Heritage Corridor Trail System. HBPS has also acquired a computer system through EPCAMR to help them in building the internal capacity of the organization through membership drives, grant writing, and managing newsletter mailing lists and databases. HBPS provides tours to many groups to sell them on the vision that they see for the Breaker while raising funds for its restoration at the same time.



Huber Breaker

WYOMING VALLEY WATERSHED COALITION'S STREAMSIDE AMD/AML CLEANUP

Thanks to 305 volunteers...4 streams, and a 6-acre AML site along a 15-mile corridor along the Susquehanna River were cleaned up within 4 months. 8 Tons of trash and other debris, 10.5 Tons of tires (1056 tires)-May 2002. 3 Tons of trash and 3 Tons of white goods. 2 Tons of tires (200 tires)-August 2002. EPCAMR funded the disposal of the trash, white goods, & tires; The PA Environmental Council produced a quarterly newsletter and a website for outreach and notification of projects was created (www.wvwc.org). Partners in the Cleanups were the Luzerne Conservation District, Nanticoke Conservation Club, EPCAMR, PEC, Wyoming Valley Sanitary Authority, Earth Conservancy, PA DEP, Hicks Creek Watershed Association, PA Gas & Energy, PA Power & Light, Wilkes University, Luzerne County Community College, Plymouth Twp., Larksville and Plymouth Boros.



Abandoned Tire Piles in the 6 acre AML Pit Which EPCAMR hopes to reclaim into a community playground and recreation area in Plymouth Township

175 Wilkes University Freshman Students, LCD, Plymouth Twp., EPCAMR, and children from the Avondale Hill Residential Community in Plymouth Twp. assisted with the cleanup of the AML Site in August 2002



WYOMING VALLEY WATERSHED COALITION'S STREAMSIDE AMD/AML CLEANUP



Garbage and Debris Litter the 6 acre AML Site, but that didn't stop Hayley Hughes from getting rid of the tires in the rain one by one.



118 Tires were removed from the Honey Pot Outfall in Nanticoke, however these kids who also participated in the cleanup came up with the name Stinky Potty Outfall instead

FORMATION OF THE HICKS CREEK WATERSHED ASSOCIATION

HCWA raises community awareness of issues facing the watershed through monthly newsletters and cleanups. A 60 acre AML culm bank fire was just recently extinguished by the federal OSM. Many of the community members came to the HCWA for answers to questions about the culm bank fire and about the recent restoration efforts in the watershed. 6 Tons of trash was removed from the watershed in April of 2002. A full color organizational brochure was printed to distribute to the public to keep them up to speed on watershed activities and environmental action projects. Water testing kits were purchased to assist HCWA in developing a volunteer stream monitoring PG. Legal fees to support the group in its approval from the IRS

to become a 501©(3) non-profit organization were also a part of the RWSI Grant. EPCAMR provided the office supply funds as well for postage and mailing costs to allow the HCWA to reach the members within the watershed in its first few years without having to worry about raising the organizational funds up front. EPCAMR and the Luzerne Conservation District also assisted the group in preparing a watershed assessment grant that was recently funded by the PA DEP Growing Greener Grants PG.



The 60-acre “Black Desert” Culm Bank Fire and volunteers along with EPCAMR Coordinator (green shirt) and the PA DEP Secretary, Dave Hess (blue jacket) and the “Oven Rollers” during the cleanup in April 2002

WILDLANDS CONSERVANCY’S LUASANNE TUNNEL AEROBIC WETLANDS CONSTRUCTION AND REMEDIATION SYSTEM

WC will construct a 1.5 acre aerobic vertical flow wetlands complex on Lehigh Gorge State Park property to treat the Luasanne Tunnel AMD (~ 4600 gpm) which flows into the Nesquehoning Creek and then onto the Lehigh River. Water monitoring will be conducted to gauge the success of the wetlands and tours will be conducted to educate the public. The project hit a snag this summer when the PA Historic Museum Commission found significant cultural resources and the wetlands design had to be modified by the PA DEP BAMR. Partners in the project include the PA DEP BAMR, EPCAMR, PA DEP BMR, PA DCNR, PA DEP BWM-Section 319 PG, Carbon County Conservation District, C&S Railroad, Lehigh River Stocking Association, Ducks Unlimited, and Parkland HS Lehigh River Watch Education PG. EPCAMR funded the final portion of the grant funds that were needed to complete the construction of the aerobic wetlands treatment system.



Luasanne AMD Tunnel

EARTH CONSERVANCY'S ABANDONED MINE RECLAMATION BROCHURE

EC produced a full-color informational brochure on AML and reclamation in the Wyoming Valley. Various methods of abandoned mine reclamation are discussed, impacts on the local communities, economic, social, and environmental benefits are presented. Examples of reclamation projects are showcased in the brochure from throughout the Wyoming Valley in northeastern PA. Since 1992, EC has reclaimed over 800 acres of AML in partnership with the PA DEP-BAMR, PA DEP, US DOI-OSM, and EPCAMR.



The Avondale Hill Stripping Pit (left) and the Wadesville Active Stripping Pit Operation (right) are just two examples of the effects of past mining practices and future reclamation

COORDINATION OF PA'S 4th ANNUAL STATE-WIDE CONFERENCE ON AMD/AMR

EPCAMR provided funds to the PA Organization for Watersheds and Rivers to offset the facility rental costs of the 2-day event held at the Penn-Stater Conference Ctr, State College, PA. POWR handled the Conference registration and was a member of the planning committee. Around 200 people were in attendance. 45 Exhibitors. 24 speakers. The EPCAMR Regional Coordinator served as Chair of the 2002 Conference. Co-sponsors and the Planning Committee included WPCAMR, WPC, PA DEP-BMR, PA DEP-BWM-Section 319, PA DEP OPPCA, WPWPP, EPA, OSM, CVI, KBA, SRBC, CC, and the LCD. A local bluegrass band from the Southern Anthracite Coalfields in Dauphin County, the "Wiconisco Creek Pickers" entertained the attendees. St. Vincent's College, using recycled iron oxide pigment from AMD to give away free t-shirts to all who attended the Conference, conducted a tie-dye t-shirt workshop. Finally, an AMD In A Jar Contest for Best Looking AMD from Across PA was held to lighten up the last session of the Conference on the second day.

COORDINATION OF PA'S 4th ANNUAL STATE-WIDE CONFERENCE ON AMD/AMR



EPCAMR Display at the 2002 PA AMD/AMR Conference and CVI, EPCAMR, WPCAMR representative field questions during a panel session

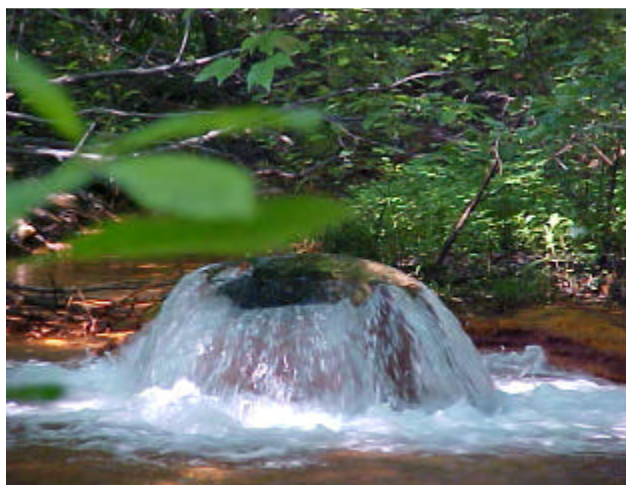
COORDINATION OF PA'S 4th ANNUAL STATE-WIDE CONFERENCE ON AMD/AMR

AMD Tye-Dye T-shirt, AMD in a Jar Across PA Judging, and the "Crick Pickers"



LUZERNE CONSERVATION DISTRICT'S 2-DAY TEACHER TRAINING WORKSHOP/FIELD TOUR IN LUZERNE COUNTY ON AMD/AMR

The LCD Environmental Ed. Coordinator and EPCAMR conducted a countywide teacher-training program in Luzerne County. 12 public school districts involved. 9/12 are directly impacted by AMD/AML. The Luzerne Intermediate Unit # 18 approved ACT 48 continuing education credits for the workshop for 12 credit hours. 24 teachers anticipated to attend; LCD to run the workshop twice before Summer 03'. A Field Tour of AMD sites, AML reclamation sites, reclaimed AML Projects and AMD remediation projects, an electroshocking survey of an AMD impacted stream, bug ID, water monitoring, and introduction to an array of community resource groups are a part of the workshop as well. Handouts, curriculum guides, Powerpoint presentations on AMD/AML, and fact sheets and brochures will be handed out at the workshop free of charge to all teachers who participate.



Solomons Creek AMD Borehole & Avondale Hill AML Stripping Pit are two stops on the AMD/AML Field Tour at the Teacher Training Workshop in Luzerne County

LEVERAGING FUNDS UNDER THE EPCAMR RWSI GRANT PG

EPCAMR awarded \$45,000 in grants to 12 projects in the region. Over \$380,000 in local matching funds was generated from the projects in just one year. Nearly 50 new partnerships in the Eastern PA Coalfields supportive of abandoned mine reclamation, AMD remediation, and watershed restoration efforts were formed with the assistance of the EPCAMR Regional Coordinator. 50 Projects were funded over the last 5 years under the EPCAMR RWSI Grant PG which turned \$200,000 over 4 years into almost \$2,000,000 in local matching funds. EPCAMR is hoping to continue administering the PG for a 5th year and is waiting for a commitment from PA DEP-MRM and is working with the WPCAMR to gain support for another year of funding due to its overwhelming success and the continued growing need for assistance by groups across PA who request financial assistance from EPCAMR and WPCAMR throughout the year.



**BUILDING PARTNERSHIPS IN EASTERN PA UNDER THE EPCAMR
REGIONAL WATERSHED SUPPORT INITIATIVE GRANT PG**



**NRCS, Columbia County Conservation District, Catawissa Creek Restoration Association, Wildlands Conservancy, EPCAMR, Schuylkill County Conservation District, Friends of the Nescopeck Creek, PA DEP BAMR, PA DEP DMO, PA DEP BWM
Congressman Kanjorski's Office, NCAMR**



Reclaim Abandoned Mine Lands Today,
For A Cleaner Environment Tomorrow



SAN JUAN COUNTY AML PARTNERSHIPS

Loretta Pineda, Public Information Officer,
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ABSTRACT

The recent interest in abandoned mine problems from many diverse agencies and groups is requiring even more effective collaboration. The secret of successful abandoned mine reclamation projects is to locate interested groups, learn to communicate, and find common ground. In San Juan County there were many challenges and opportunities for abandoned mine land reclamation work. Challenges included local participation and anxiety over problems that threatened the community's image, endangered its historical and cultural values, and jeopardized its economic well being. The opportunities were found in the interest, technical expertise, and funding support from state and federal agencies. The ability of different sectors, organizations, and individuals to collaborate was realized. Together their time, assets, and commitment have tackled the most difficult abandoned mine land issues. Through joint work, many groups accomplished long-term objectives that would have been impossible to achieve individually and have strengthened the abandoned mine program in Colorado.

The Colorado Inactive Mine Reclamation Program (IMP) has addressed AML issues - hazards, water quality, and historic preservation - in San Juan County with a multitude of partners. In some cases the IMP has taken the lead, in some it has been a major participant, and in still others it has been quietly in the background helping facilitate activities. These partnerships, tailored to specific activities, are synergistic and have helped make the AML efforts in the county accepted and successful. With some background for perspective, here is how we make this countywide AML effort work.

This is one of the most rugged counties in Colorado. Lying in the heart of the San Juan Mountains which range to over 14,000 feet high, there are few level spots in the county. Vistas are dominated by this alpine terrain along with evidence of past mining activity. Such evidence is considered an asset to the economy and a drawing card for tourism. Snow avalanche paths on the mountain sides are more numerous and of greater visual impact than most of the easily visible mining scars.

Even though mines stopped producing decades ago, San Juan County's economy is still driven by their presence. At 387 square miles, this one of the smallest counties in the state. Its year-round population of 558 is supported by the tourism industry rather than mining. Though the mining is gone, a vivid community spirit lives on today.

HISTORY

Gold was discovered here in 1860, and after negotiations with Chief Ouray of the Ute Tribe, the country was opened for settlement. The Town of Silverton was platted in 1874, and by 1875, the population had doubled. The mountains were filled with gold and silver, and mines with names such as the Silver Lake, the Iowa, the Royal Tiger, and the Gold Prince produced millions. Otto Mears, "Pathfinder of the San Juans," built his famous "Rainbow Route" - one of three railroads that carried ore to the smelters in Silverton from the high camps. Mining reached

its peak between 1900 and 1912, and the population of San Juan County peaked at 5,000. Over 30 mills and two smelters had been built by the turn of the century. Hundreds of millions of dollars of gold and silver were extracted from the mines. Silverton was the metropolis of the district, and by 1902, had a complete water and sewer system, telephone service, and a municipally owned electric power company.

Production history began in San Juan County in 1873 and by 1908 over \$45 million in precious, mainly silver, and base metals had been produced. The last mine, Sunnyside Gold closed in 1991. Reclamation there is underway.

AML ISSUES

But these mines that provide a livelihood to the sparse population of Silverton, also left their mark along the landscape and threaten water quality in the Animas River, which drains the district. In 1980 the Colorado inventory noted 405 mine openings in the county.

To address AML problems statewide, Colorado's AML program realized that it could only be successful if it had the support of the various communities involved: landowners, mining industry, the environmental interests, historic preservation groups, local government, and land management agencies. One of the first things some of the miners with small older mines noted was that "there are no abandoned mines; only idle or inactive mines waiting to be reopened." Committed to a voluntary program and knowing that we needed the support of miners and landowners, we immediately adopted the idea into our program name. We have been the "Inactive Mine Reclamation Program" since 1980 and have worked hard to obtain and retain the trust and support of "abandoned" mine owners. This also led to the organization of our still functioning Inactive Mine Program Advisory Council. It is composed of representatives from coal mining, hardrock mining, environmental interests, local government, academia, mineral collectors, historical interests, and land management agencies.

INVENTORY

During the summer of 1980, we had 14 people combing the mineralized areas of Colorado to collect information about the extent and nature of the AML problem. Detailed information about 8,656 hazardous mine openings was collected that summer. It was the perfect job for the field teams – mostly recent graduates of natural resource and environmental programs. Imagine, someone paying you to wander around in some of the most scenic parts of Colorado to practice using your newly acquired skills and knowledge. That original "reconnaissance" inventory would provide the basis for Colorado's Inactive Mine Reclamation Plan and guidance for addressing the legacy of pre-law mining problems in the State. Subsequent investigations have led us to estimate that 23,000 hazardous mine features exist in the State; about 22,000 of them at hardrock mines.

In San Juan County, our reconnaissance inventory centered on the major mining districts. The Silverton, Howardsville, Eureka-Animas Forks districts as well as more remote areas such as Arrastra Basin were visited and studied in the field. The county is very scenic and extremely popular with campers, hikers, and 4-wheelers. Many come to explore and photograph the rustic old mines as well as for the scenic beauty. An advertisement for a local commercial campground exhorts visitors to "pan for gold, go for a jeep ride, visit ghosts towns or old abandoned mines." Some areas are remote and accessible only by foot trails through rugged

terrain, and many mine openings are located on steep mountainsides, inaccessible to all but the most determined climbers. The most common mining method used in the county was tunneling into steep mountain or valley walls along mineralized faults or fractures. Comparatively few shafts were used. Only 38 shafts were encountered during the 1980 field season. Fifteen open stopes were also recorded. There were 352 adits or horizontal mine openings examined. Most of these were considered hazardous because of the ease of accessibility and possible connections with vertical workings. Several had significant discharges of acid mine water draining into local streams. Over 300 mine dumps were also evaluated in this initial study.

The reconnaissance inventory covered all the more accessible and historic mines which attract visitors and could be used as a basis for determining priorities of those hazardous mine areas in need of reclamation or safeguarding. In fact, when an updated estimate of inactive and abandoned non-coal mine problems was prepared for the Western Governors' Association Mine Waste Task Force in 1991, San Juan County was shown to have an estimated 500 hazardous mine openings – up from the 405 visited and recorded in 1980.

SAFEGUARDING

With this inventory in hand Colorado soon began the business of actually reclaiming and safeguarding sites. As the law required, Colorado first addressed hazardous coal mine features, then environmental problems associated with coal mines, and finally hazardous hardrock mine features. San Juan County has no coal mines so it wasn't until several years into the program that safeguards began being placed on the hardrock mine openings there. The first project was completed in the Red Mountain Pass area in late 1988.

Since the program first began receiving funds to do on the ground reclamation in 1982 we have safeguarded 6,127 hazardous mine features statewide. In San Juan County, six projects have been completed with 257 extremely hazardous mine openings safeguarded. The close proximity of mine openings to Silverton and their accessibility have also provided an excellent laboratory for OSM's National Technical Training Program's AML Design Workshop for Dangerous Openings. Three of these field oriented workshops conducted by Colorado and OSM AML staff have been held in Silverton.

Closures techniques include the use of precast concrete panels, steel grating, polyurethane foam, bulkhead seals, and backfilling. Because of the interest in preserving the historical character of the mines, the San Juan Board of County Commissioners reviews all closure proposals before work takes place. Closures methods are regularly modified to help stabilize remaining mining structures. Although the sites are at high elevations, some bat habitat has been identified by the Division of Wildlife and is accommodated with grated closures that allow bats' ingress and egress. Local interest in the IMP activities is high as evidenced by the cost sharing of many landowners, the cooperation of mining companies, and the involvement of local contractors.

HAZARDOUS OPENINGS SAFEGUARDED

Project name	# of shafts & stopes	# of adits	Cost	Date Completed
Red Mountain	20	7	\$ 71,333	1988
San Juan	57	19	335,729	1990
Ouray	17	15	108,979	1990

Silverton	10	22	52,200	1996
Mineral Creek	8	46	100,970	1997
Adelaide	4	32	94,916	2000
Maid of the Mist	21	18	150,000	Scheduled for 2002
Totals to date	116	141	914,127	

WATERSHED RESTORATION

Along with safeguarding hazardous mine openings, the IMP has become involved in other problems at inactive mines. Mining related nonpoint source pollution in Colorado is widespread and diverse. There are 605 miles of stream in Colorado that are affected by heavy metal contamination. Sediment resulting from past mining and milling activities contributes to the contamination of additional waters and streams.

In Colorado, most of the mining related nonpoint source pollution results from inactive metal mines. These mine sites present some of the most difficult challenges to water quality improvement in Colorado, and the nation. This is due to the nature of the pollutants, and also to the difficult administrative and legal challenges involved with controlling the sources of pollutants. Without intervention, most of these sites will not be naturally reclaimed. Many of these sites are “orphan sites”, or are owned by individuals who were not involved in either the mining activities that created these water quality problems, or the financial benefit from the mining. In addition to these complicating factors, it is important to recognize that the majority of the hardrock inactive mining sites are found in remote locations, at high altitudes, and with a minimal infrastructure of roads and power.

San Juan County comprises the upper Animas River watershed - one of the most heavily mineralized and mining impacted areas in the state. Seventy-one miles, a high percentage of all stream miles in San Juan County, are impacted by past mining activity. Heavy metals and acid mine drainage have destroyed the biological integrity of many reaches in the watershed.

In order to address non-point source pollution from mining activity, in-depth studies are necessary to analyze the impacts from specific sites and sources and to determine the potential for improving water quality. Four reclamation feasibility reports have been prepared by Division of Minerals & Geology staff for use as a guidance document by the Animas River Stakeholders Group (ARSG) in prioritizing and planning water quality reclamation projects at mine sites in the watershed. Using this information the ARSG has prioritized 33 mine adits and 32 waste piles for remediation. The IMP has also prepared additional site specific feasibility reports for some of these priority sites.

The ultimate goal of this work is to improve the water quality and fisheries of the Animas River downstream of Silverton by reclaiming abandoned mine sites upstream of the town. Because the IMP funding for these water quality projects is restricted by SMCRA, we focus on providing technical assistance and support to the primary project sponsors.

PROJECTS COMPLETED WITH 319 FUNDS

Project Site	Products	Project Date	Project Sponsor/ Funding Source
Mineral Creek/	High and Low flow samples	1997	CDPHE, DMG/ 319

Project Site	Products	Project Date	Project Sponsor/ Funding Source
Targeting and Characterization	taken. Detailed loading analysis report		Funds
Cement Creek/ Targeting and Characterization	High and Low flow samples taken. Detailed loading analysis report	1998	DMG/319 Funds
Lower Animas Targeting and Characterization	High and Low flow samples taken. Detailed loading analysis report	1998	DMG/319 Funds
Upper Animas Targeting and Characterization	High and Low flow samples taken. Detailed loading analysis report	1999	DMG/319 Funds
Mineral Creek	Remove mine waste from drainages and revegetate.	1999-2001	San Juan RC& D/ 319 Funds
Silver Wing Mine	Construct biological treatment system for acid mine drainage	1999-2001	Landowner/ 319 Funds
Mammoth Tunnel	Construct settling pond treatment facility for acid mine drainage	1999	Landowner/ 319 Funds

PROJECTS COMPLETED WITH OTHER FUNDING SOURCES

Project Site	Products	Project Date	Project Sponsor/ Funding Source
MRRC Mine	Removed mine waste from stream. Constructed ALD to treat mine drainage	1994	Landowner
Joe and Johns Adit	Opened mine portal to capture and quantify mine drainage.	1998	BLM/ BLM Funds
Galena Queen	Constructed upland diversion ditches.	1998	DMG/ OSM Funds
Forest Queen	Passive mine drainage treatment system	1999	BLM
Mayday/ Lackawanna	Hydrologic controls and mill tailings removal	2000	BLM
16 major mine sites	Hydrologic mine seals, mine and mill waste removal, hydrologic controls at waste piles	1991-1999	Sunnyside Gold Corp.
Gold King	Hydrologic controls for mine workings and mine waste	1998	Gold King Mines Corp.

MINING HERITAGE

Across the state, people in the public and private sectors work hard to retain Colorado's unique historic character. In the course of developing and implementing the safeguarding and watershed restoration activities at abandoned or inactive mines the program considers the historic and cultural resource aspects of each project. The program has provided documentation of the area's existing historic mining resources, assisted with stabilization of historic properties, worked with the local community to promote an awareness of mining history, and encouraged tourism to Colorado's mining communities.

The people of San Juan County, like many Coloradoans are increasingly aware of mining's historic significance and are expressing a commitment to its preservation. San Juan County, the Town of Silverton and the San Juan County Historical Society have developed cooperative efforts that contribute to the success of their mission to advance heritage tourism in San Juan County and preserve the unique mining resources.

One special project that IMP worked on in cooperation with several partners was the stabilization of Old Hundred Mine Boarding House and Tramway Terminal. This property represents one of the few remaining sites typical of the tramway-dependent mining systems of the San Juan district. The two buildings are perched 2000 feet above Cunningham Gulch up Galena Mountain on the face of a steep cliff, in one of the West's most rugged, weather-beaten and inaccessible mining districts. The Boarding House and Tramhouse provide one of the better-preserved examples of the remarkable resourcefulness, perseverance, and inventiveness that miners would resort to for the removal of valuable ores and are a model of the technology typical of the San Juans. The Old Hundred Tourist Mine operation in the valley bottom is visited annually by thousands of tourists, students and historians seeking clues to the patterns of Western culture and industry and to the legacy of mining in Colorado.

The roof of the boarding house was partially collapsed and caused some damage to the second-story floor. The roof of the tramhouse is completely collapsed. Severe weather damage and marmots who enjoyed chewing on the wooden portions of the two buildings damaged the remaining intact lumber inside the structures. The boardwalk which once linked the boarding and tramhouses was no longer in place, and may have been swept away by avalanches. Some of the tin siding was missing from both buildings, and there were no remaining doors or glass in the windows. The stabilization work is done in conjunction with the safeguarding of hazardous open adits.

The Colorado Division of Minerals and Geology, in conjunction with the San Juan County Historical Society, were awarded a State Historic Preservation grant to devise a construction plan to stabilize the remaining buildings of the Old Hundred Boarding House and Tramhouse. The BLM also provided matching funds. In the summer of 2000 the Old Hundred Boarding House was stabilized with a new tin roof and other portions of the old boarding house were reinforced. The San Juan Historical Society plans to stabilize the tramhouse during the summer of 2002.

CONCLUSION -- MAKING IT WORK

The ability to work together in San Juan County and leverage assets—human, economic, and civic—has created a unique model that deserves duplicating. The Colorado IMP has found unusual partners and new participants to contribute to the state's abandoned mine reclamation problems. We firmly believe that this is the future of abandoned mine land reclamation. Developing strong connections to the local community and working with a variety of groups to leverage funding has enabled the IMP to establish credibility, respond to local needs, and fulfill the goals of the abandoned mine land reclamation program as established under the Surface Mining Control and Reclamation Act.

Here is a partial listing of the many partners who have contributed to the abandoned mine land reclamation effort. Many other silent partners also participated.

Federal – provide funding and technical expertise

Office of Surface Mining, Bureau of Land Management, U. S. Forest Service, Environmental Protection Agency, U.S. Geological Survey, Bureau of Reclamation.

State – provide funding, technical expertise and in-kind services

Colorado Division of Minerals and Geology; Colorado Dept of Health, Water Quality and Hazardous Waste Divisions; Division of Wildlife; Colorado Geological Survey; Colorado Division of Water Resources; Department of Local Affairs; Department of Transportation; Scenic by Ways Commission; Colorado State Historical Society; Colorado State Historic Preservation Fund; Youth in Natural Resources; Western Governors' Association.

Local – provide funding, technical expertise, in-kind services and spirit

San Juan County, Upper Animas Stakeholders Group, Sunnyside Gold, San Juan Historical Society, Klinke & Lew; Red Mountain Task Force, Town of Silverton, San Juan Resource Conservation Development Council, Silver Wing Co, Inc.; Salem Minerals; Gold King Mining Co.; Echo Bay Mining,

REFERENCES

“Colorado Inactive Mine Reclamation Plan, Inactive Coal and Metal Mines of Colorado.”

Department of Natural Resources, Mined Land Reclamation Division. 1982. Volume II Reclamation Feasibility Reports: Animas River Below Eureka, Upper Animas River Basin, Mineral Creek, Animas River Below Eureka. 1997-2001 Colorado Division of Minerals and Geology.

**TECHNICAL PAPER SESSION 3
ACID MINE DRAINAGE - PART 1**

Title: [Acid Mine Drainage Abatement in the Lower Rock Creek Watershed – McCreary County, Kentucky](#)

Author: [Mark B. Carew](#)*, Registered Geologist, Kentucky Division of Abandoned Mine Lands

Title: [The Tonoma Passive Mine Drainage Treatment Project](#)

Authors: [Eric Cavazza](#)*, Design Section Chief and **Richard L. Beam***, P.G., Licensed Professional Geologist, Pennsylvania DEP Bureau of Abandoned Mine Reclamation

Title: [The Role of AMD in the Treatment of Other Problem Waters](#)

Author: [Jan C. Allbright](#)*, President, Arizona Wetlands Research Foundation

Title: [Spenceville Mine Closure](#)

Authors: [Daniel Wanket](#)*, Project Manager, GEI Consultants, Inc.; **Alberto Pujol***, PE, Project Manager, GEI Consultants, Inc.; and **William Walker***, PhD, Senior Geochemist, Vice President, Walker & Associates

ACID MINE DRAINAGE ABATEMENT IN THE LOWER ROCK CREEK WATERSHED – McCREARY COUNTY, KENTUCKY

Mark B. Carew, Kentucky Division of Abandoned Mine Lands, 2521 Lawrenceburg Road,
Frankfort, Kentucky 40601

ABSTRACT

Rock Creek above White Oak Junction is a beautiful boulder strewn stream designated as a Kentucky Wild River and is the premier mountain trout stream in Kentucky. Below White Oak Junction acid mine drainage (AMD) from over 40 coal mine portals and eight pyrite-rich refuse dumps has decimated aquatic life and rendered the stream virtually lifeless. The Rock Creek Task Force, a group of 12 state and federal agencies and conservation organizations, was formed to find solutions to the degraded water quality in the lower Rock Creek Watershed. Funding was provided by several of the Task Force partners including an EPA 319 Clean Water Action Plan grant, an Appalachian Clean Streams Initiative grant, a PRIDE grant from NOAA, KYAML's annual grant, and a USGS cost share agreement.

In 1998 a biological and water-monitoring program began in the lower Rock Creek watershed. Acid loading was calculated and in spring of 2000 dosing of selected tributaries with sand-sized limestone particles began. Within two months the flow out of Rock Creek into the Big South Fork of the Cumberland River changed from net acidic to net alkaline. After four months similar results were obtained in White Oak Creek, a major source of AMD to Rock Creek.

In the fall of 2000 construction began on a reclamation project targeting several of the worst AMD sites in the lower Rock Creek watershed. Pyrite-rich refuse was removed from the banks of Rock Creek. Open limestone channels were installed routing AMD through the limestone before discharging into the stream, and a modified vertical flow wetland was installed at a site with limited distance between the AMD source and the receiving stream. Dosing with limestone sand continued monthly with permanent dosing stations being established farther upstream in the impacted tributaries.

Water monitoring results continue to be encouraging with reductions in acidity and dissolved metals in the affected streams. Fish sampling has revealed that fish populations are already being re-established in once lifeless sections of White Oak Creek and lower Rock Creek. Macro-invertebrate sampling indicates that species diversity and numbers are also improving.

INTRODUCTION

Study Area Description

Rock Creek originates in Pickett State Park, Tennessee, traverses 21 miles in McCreary County, Kentucky and empties into the Big South Fork of the Cumberland River within the Big South Fork National River and Recreation Area, which is administered by the National Park Service. Rock Creek lies mostly within lands managed by the U.S. Department of Agriculture Forest Service (Fig. 1). Rock Creek is a beautiful boulder strewn stream designated as a

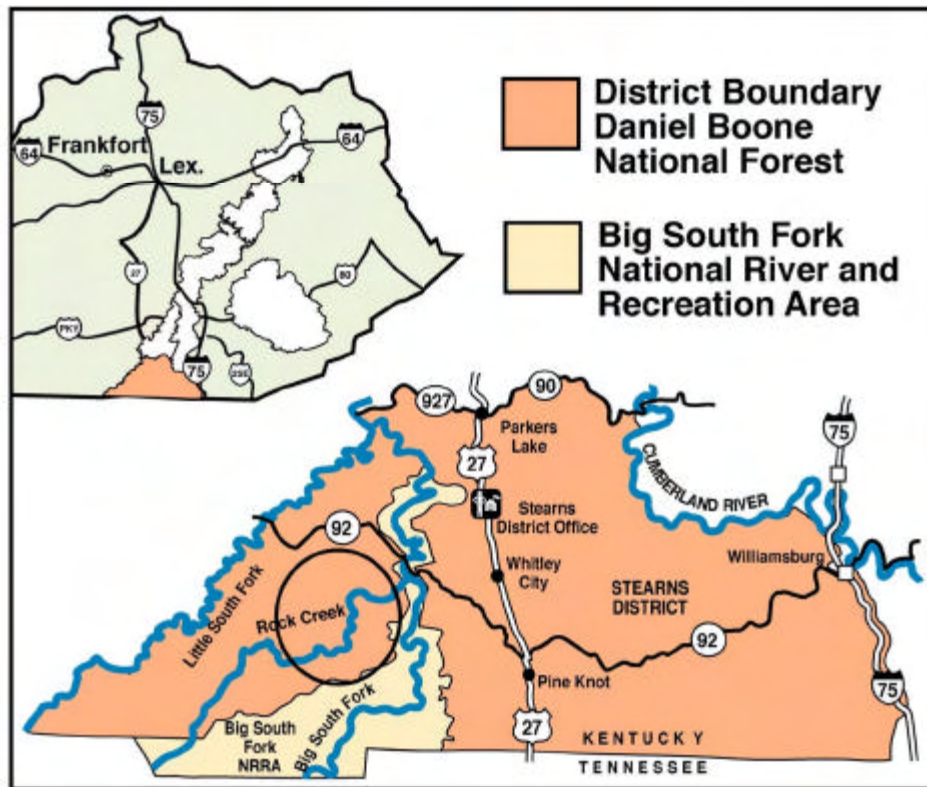


Figure 1. Study area (USFS, 2002).

Kentucky Wild River from the Kentucky State line to White Oak Junction. Rock Creek above White Oak Junction is the premier mountain trout stream in Kentucky. Below White Oak Junction acid mine drainage (AMD) from over 40 coal mine portals and eight pyrite-rich refuse dumps has decimated aquatic life and rendered the stream virtually lifeless (Fig. 2). The impacted area of the Rock Creek watershed includes White Oak Creek from Cabin Branch downstream to the confluence with Rock Creek at White Oak Junction, as well as Rock Creek from White Oak Junction to the confluence with the Big South Fork. All tributaries to White Oak Creek and this portion of Rock Creek are included. The project is located within the impacted area specifically in Cabin Branch, Cooperative North Portal, and Jones Branch of White Oak Creek, and in Roberts Hollow, Paint Cliff, Poplar Spring Hollow, Koger Fork, and the mouth of Water Tank Hollow on Rock Creek.

Land-use Activities

Underground coal mining began in the project area in the first decade of the 20th century and continued through the 1960's. Several small towns were built supporting the mining and lumber industries of the area. Several of the towns including Yamacraw, Fidelity, and Co-Operative no longer exist. With the exception of the railroad right of way, owned by the K & T Railroad Company, and a few small private in-holdings, the project area is managed by the United States Forest Service. Rock Creek is a major recreational attraction and is visited by thousands yearly. Fishing, hunting, hiking, backpacking, and camping are just a few of the interests pursued by visitors.

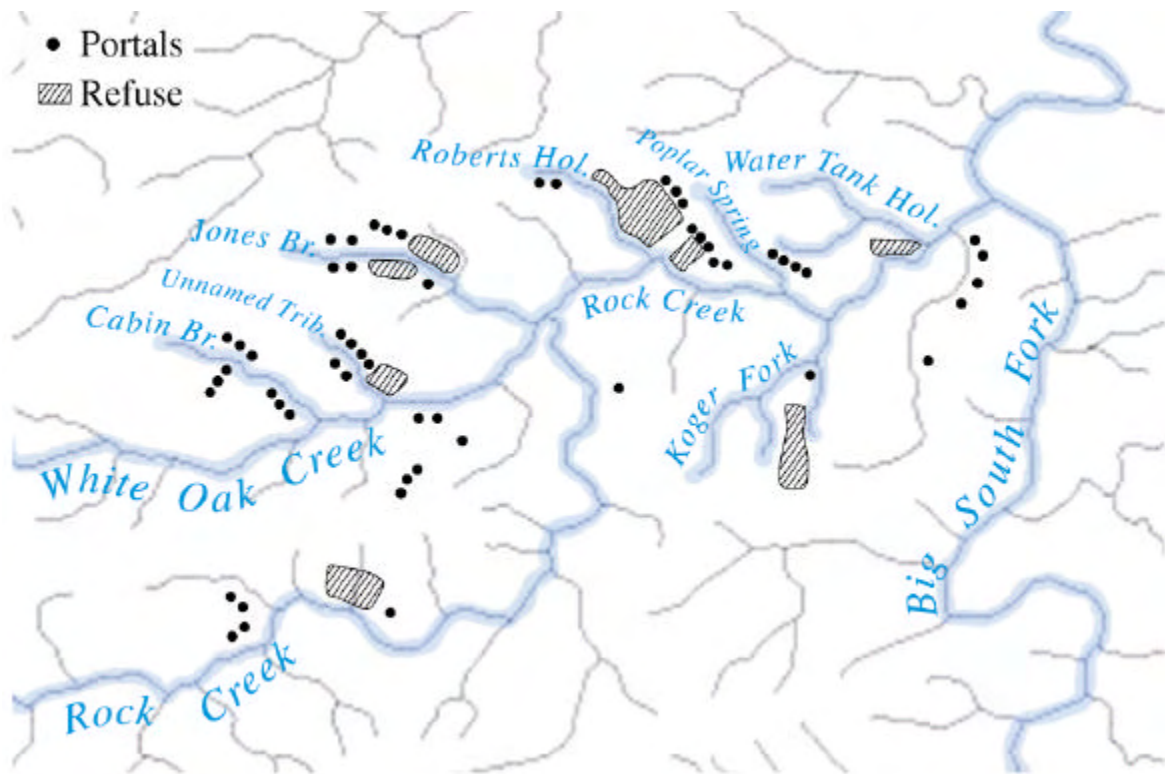


Figure 2. Lower Rock Creek Watershed portals and refuse fill locations.

Project Description

This project addresses several AMD sources in the Rock Creek watershed. The Rock Creek Task Force, a group of 12 state and federal agencies and conservation organizations, was formed to find solutions to the degraded water quality in the lower Rock Creek watershed. Members of the task force include: the Kentucky Division of Abandoned Mine Lands (AML), Kentucky Division of Water (DOW), federal Office of Surface Mining (OSM), Kentucky Department of Fish and Wildlife Resources (KDFWR), National Park Service (NPS), United States Forest Service (USFS), Trout Unlimited (TU), Kentucky Department for Surface Mining Reclamation and Enforcement (DSMRE), United States Geological Survey (USGS), United States Army Corps of Engineers (COE), United States Fish and Wildlife Service (USFWS), and the United States Natural Resources Conservation Service (NRCS). Funding was provided by several of the task force partners including an Environmental Protection Agency (EPA) 319 Clean Water Action Plan (CWAP) grant, an Appalachian Clean Streams Initiative (ACSI) grant, a Personal Responsibility In a Desirable Environment (PRIDE) grant from the National Oceanic and Atmospheric Administration (NOAA), KYAML's annual grant, and a USGS cost share agreement.

The overall plan was developed by the Kentucky Division of Abandoned Mine Lands with the partnership and assistance of the above agencies and organizations. The goal of the Rock Creek Project is to show a demonstrable reduction in sediment and acidity entering Rock Creek and to return the land where the coal processing refuse dumps are located to a vegetated state compatible with the surrounding land.

Construction activities to attain these goals included removal of the acid forming material from the banks of Rock Creek at the 3-acre Water Tank Hollow refuse site and at the Paint Cliff coal load out sites. The acid forming material was treated and placed in a compacted fill at the Roberts Hollow refuse site. Open limestone channels were constructed at the Cabin Branch site, the Co-op North site, the Roberts Hollow site, the Paint Cliff site, the Poplar Spring site, and the Water Tank Hollow site. A modified vertical flow system was constructed at the Paint Cliff site. Limestone sand application sites were developed on Cabin Branch, Jones Branch, Roberts Hollow, Poplar Spring Hollow, and Koger Fork.

METHODS

Data collection and methodology included a water monitoring program conducted by the United States Geological Survey (USGS) on a cost share basis with AML and a biological monitoring program conducted by AML, USFS and KDFWR personnel (Fig. 3). Soil and refuse analysis including computer modeling utilizing the Revised Universal Soil Loss Equation (RUSLE) was conducted by AML. Reclamation techniques were chosen after analysis of water chemistry, soil and refuse testing and site specific conditions.

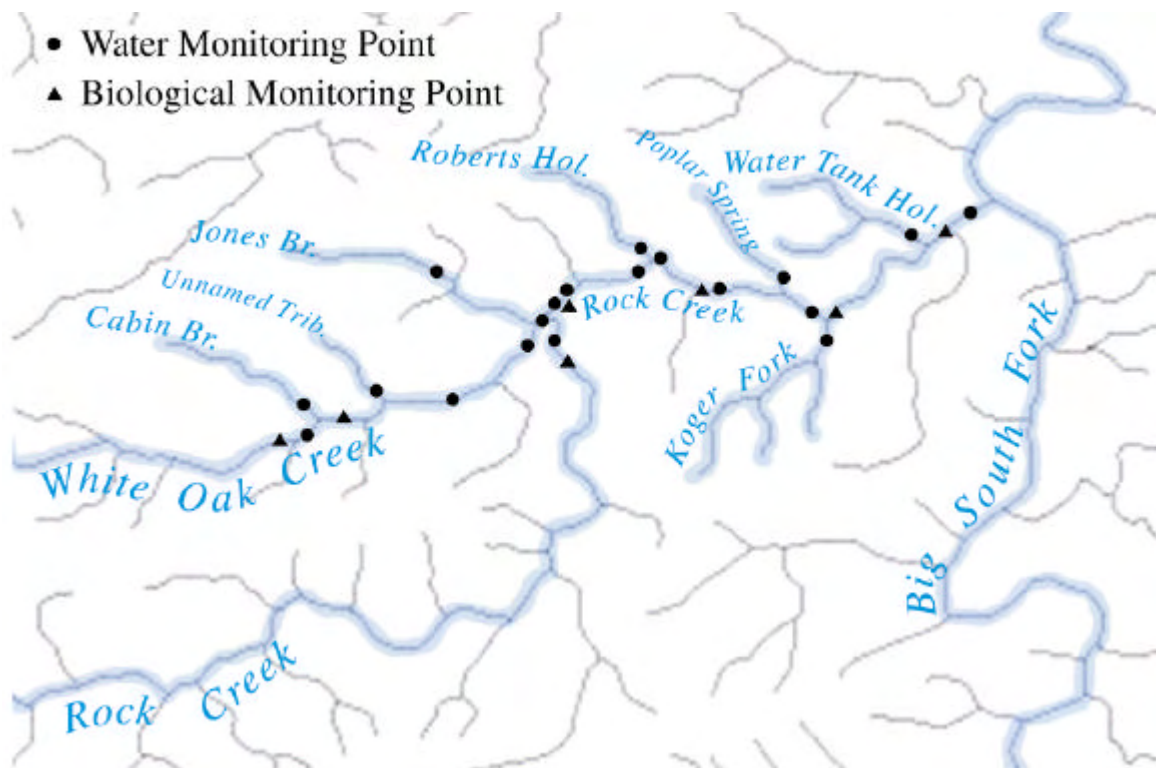


Figure 3. Water and biological monitoring sites in the lower Rock Creek watershed.

MONITORING

Water Monitoring

DSMRE personnel collected water quality data for 41 portals and seeps in the study area in the spring of 1995. The portals were sampled for pH, specific conductance, dissolved oxygen, and discharge in the field; alkalinity, acidity, total dissolved solids, total, dissolved, and ferrous iron, total and dissolved manganese, total aluminum, and sulfate were analyzed in the lab. Loading was calculated and passive treatment options were explored using the water chemistry for each portal discharge.

In the fall of 1998 a monitoring program was started monitoring the main stem of Rock Creek and the mouths of the main tributaries contributing acid mine drainage to the lower Rock Creek watershed. The parameters tested were the same as for the portals with the exception of dissolved oxygen and ferrous iron. Dissolved aluminum and total calcium were added as test parameters. The mouths of the tributaries and the main stem of Rock Creek were chosen as monitoring points to include all of the acid drainage sources and any natural buffering which may occur within the watershed. The sites were monitored monthly, for a period of eighteen months before construction activities began, to collect background data. The sites were monitored monthly during construction of the project and monthly thereafter to demonstrate project success.

All sample collection, preservation, and analysis were conducted in accordance with “Standard Methods for the Examination of Water and Wastewater” and/or “U.S. Geological Survey Protocol for the Collection and Processing of Surface-Water Samples for the Subsequent Determination of Inorganic Constituents in Filtered Water” – U.S. Geological Survey Open-File Report 94-539. Discharge was measured by current velocity meter or by the “bucket and stopwatch” method where possible. Conductivity and pH were measured using calibrated pH and conductivity meters.

Biological Monitoring

Aquatic macroinvertebrates were collected spring and fall by a series of three surber samples per station, along with one triangular kick-net sweep to cover all habitat types in the sample area. All whole samples were picked in the field, stored in 70% ethanol, and returned to the USFS Winchester office or AML Frankfort office for sorting and identification to the lowest possible taxon. After sorting and identification, the data was evaluated using the modified Hilsenhoff Biotic Index (HBI) (Lenat, 1993) to determine the overall pollution tolerance of the macroinvertebrate community and the degree to which the habitat is impaired. Other metrics used includes the Total Number of Individuals, Ephemeroptera/Plecoptera/Trichoptera Richness (EPT), and Percent Dominant Taxon.

Fish were collected in early summer by the use of a Smith-Root model 12A battery powered backpack electrofishing device. Fish collected were identified in the field when possible, with voucher specimens being returned to the lab for positive identification. Identification was to the lowest possible taxon. Type specimens were preserved in 10% buffered formalin for 1-2 weeks, then rinsed and transferred to 70% ethanol for long-term preservation and storage. After final identification the data was evaluated using the Index of Biotic Integrity (IBI) to determine the overall structure and health of the piscid community as an indicator of

aquatic habitat health. Also, Catch Per Unit of Effort (CPUE) of shocking time was considered as a measure of relative abundance.

Biological monitoring stations were used for both fish and macroinvertebrate sampling. Site selection criteria included ease of repositioning, and the ability to determine the effects of AMD treatments within the project area on the main stem of Rock Creek. All sites except for the control sites RC-00 and WC-01 are downstream from the AMD impacted tributaries.

Macroinvertebrate samples were collected, processed, and the resulting data analyzed by USFS personnel. Fish samples were collected, processed, and analyzed by KDFWR personnel. Biologists from DOW and AML assisted in collection, processing, and identification of both macroinvertebrates and fish.

Soil and Refuse Analysis

The Revised Universal Soil Loss Equation (RUSLE) was used to calculate soil loss from the project area before, and after, reclamation was completed. This provided a means of estimating the reduction in sediment entering Rock Creek from the Water Tank Hollow site after completion of the project. The annual acid load reduction into Rock Creek from the Water Tank Hollow refuse site was calculated using the acidity data from the refuse analysis in combination with the reduction in quantity of refuse washing into Rock Creek annually from the Water Tank Hollow refuse site as calculated by RUSLE.

The coal processing refuse was sampled at various locations in the project area. Any areas that had noticeably different soil properties were sampled and analyzed as separate samples. The soil/refuse samples were analyzed for soil water pH, buffer pH, available phosphorus, available potassium, and potential acidity.

ACID MINE DRAINAGE ABATEMENT TECHNOLOGIES INSTALLED

Limestone Sand Treatment

During testing of a self-feeding rotary drum stream neutralization system that ground limestone aggregate into a slurry, Zurbuch (1989) found that undissolved sand-sized limestone particles continued to be reactive in stream sediments and significantly reduced acidity. Further research into the use of limestone fines as a method to treat streams acidified by acid deposition corroborated Zurbuch's rotary drum results (Ivahnenko et al., 1988).

Sand-sized limestone may be directly dumped into acid mine drainage impacted streams at various locations in watersheds. The limestone sand is picked up by the stream flow and redistributed downstream, neutralizing the acid as the stream moves the limestone as bed load. The limestone sand in the streambed reacts with acid in the stream, causing neutralization. Coating of limestone sand particles with iron oxides can occur, but the agitation and scouring of the limestone in the streambed keep fresh surfaces available for reaction.

Water monitoring was conducted to determine the acid load being contributed by each tributary to the lower Rock Creek watershed. In the spring of 2000 a pilot project was started dosing the lower Rock Creek watershed monthly with limestone sand. The purpose of the pilot project was to determine the stream response to dosing at the calculated rates. Existing culvert outlets from the main tributaries into White Oak Creek and Rock Creek were used as dosing

sites. If the pilot project proved successful permanent-dosing stations would be constructed in the main tributaries.

Direct application of limestone sand to treat acidified streams is the least expensive method of treatment available based on the cost per ton of acid neutralized (Zurbuch, 1996; Zurbuch et al., 1996). Limestone sand dosing does not require the large capital investment or the operation and maintenance costs of mechanical stream dosing systems.

The annual cost to treat the acid load in the lower Rock Creek watershed with limestone sand after construction of all application sites and after the first year of dosing when rates are doubled was calculated to be \$15,000. The Division of Abandoned Mine Lands, as part of its annual grants from the Office of Surface Mining, budgets for the continued dosing of the lower Rock Creek watershed with limestone sand into the foreseeable future. It is anticipated that at some time in the future the United States Forest Service will assume the responsibility for dosing the lower Rock Creek watershed. If and when this occurs AML will relinquish responsibility for the dosing to the USFS.

Refuse Removal and Treatment

The Rock Creek Clean Water Action Plan Project involved the removal of 25,000 cubic yards of highly acidic coal mine refuse from the banks of Rock Creek near Water Tank Hollow and from the Paint Cliff coal load out site. The refuse was a significant source of sedimentation and acid mine drainage (AMD) into Rock Creek, as well as a visual blight to the surrounding forested area. The refuse was loaded and hauled to an existing refuse area in Roberts Hollow. The refuse was placed in six-inch to eight-inch lifts near the toe of the existing refuse fill. Foundation benches were excavated and an agricultural limestone barrier was placed prior to placement of the refuse. Agricultural limestone was incorporated into each lift. The rate of 20 tons of agricultural limestone per 100 cubic yards of refuse was used. The rate of limestone mixed with the refuse was determined by soil tests. Suitable borrow material for soil cover on the refuse was found in the fill area and was placed two feet thick on top of the final lift of refuse. The area filled had sparse vegetation and revegetation efforts following placement of the fill has improved the vegetative cover on the site, reducing the sediment load to the stream. The refuse fill area was seeded with a mix of acid tolerant warm and cool season grasses and legumes.

Open Limestone Channels

Open limestone channels (OLCs) were installed at the Cabin Branch portal discharge site, Co-op North portal discharge site, Roberts Hollow refuse fill site, Paint Cliff portal and refuse fill sites, Poplar Spring Hollow portal site, and the Water Tank Hollow refuse removal site. A limestone channel 500 feet in length was constructed at the Cabin Branch portal discharge. The portal discharge was diverted into the OLC before flowing into Cabin Branch. At the Co-op North portal the mine drainage was diverted into a 500 foot long OLC before discharging into White Oak Creek. A limestone channel 1000 feet in length was constructed immediately above the refuse fill area at the Roberts Hollow site. A limestone channel 800 feet in length was installed in the natural drain on the southeast side of the Roberts Hollow fill area. The limestone channels in Roberts Hollow intercept acidic water from the upper slopes of the refuse fill area, diverting acidic water away from the new fill, and provide treatment to the water before

discharging into the main tributary and Rock Creek. An OLC 130 feet in length was installed at the mouth of Poplar Spring Hollow. At the Paint Cliff site an OLC was installed to intercept and carry water from the toe of the refuse fill and from a deep mine discharge to a sediment basin before entering a vertical flow system. Acid seeps were intercepted by another OLC before discharging into Rock Creek.

At the Water Tank Hollow site a natural drainage feature was encountered during excavation of the coal mine refuse from the banks of Rock Creek. An open limestone channel was installed in the steep natural drain encountered during excavation of the refuse. Acid seeps were encountered near the toe of the slope after removal of the refuse from the Water Tank Hollow site. An open limestone channel was installed along the toe of the slope picking up the acid water and directing it through the limestone before discharging into Rock Creek.

The open limestone channels were lined with a few inches of limestone sand before placement of the crushed limestone. The crushed limestone was four to nine inches in size except for high flow areas. In high flow areas the crushed limestone was nine to eighteen inches in size.

Diverting AMD into open channels or ditches lined with limestone rock increases alkalinity in the acid water through limestone dissolution (Ziemkiewicz et al., 1994). Past assumptions have held that limestone coated with iron and/or aluminum hydroxides (armored limestone) ceased to dissolve, but experiments show that coated limestone continues to dissolve at reduced rates, as low as 20% of the rate of unarmored limestone (Pearson and McDonnell 1975). Studies have demonstrated that the rate of dissolution for armored limestone in the field may be higher than found in previous laboratory studies (Ziemkiewicz et al., 1997). Field experiments show considerable reductions in acidity by treatment with OLCs (Ziemkiewicz et al., 1994). Another problem is that precipitates tend to settle into and plug the voids in limestone beds forcing water to move over rather than through the limestone. While both armoring and plugging are caused by the precipitation of metal hydroxides, they are two different problems. Maintaining a high flushing rate through the limestone bed can minimize plugging of voids. Armoring, however, occurs regardless of the water velocity. Channel gradient and channel lengths are design factors that can be varied for optimum performance. Optimum performance is attained on slopes exceeding 20%, where precipitates are washed from limestone surfaces and kept in suspension by high flow velocities (Skousen et al. 1998). Dissolved metals sorb onto the surfaces of the precipitates in suspension, further reducing the amount of dissolved metals in the water. By adjusting the length of OLCs to account for reduced dissolution rates from armoring, and maintaining steep gradients, open limestone channels may be designed and constructed for long term treatment of AMD. Diverting AMD through OLCs before and/or after treatment with other passive systems can maximize treatment and metal removal.

Vertical Flow Systems

Vertical flow systems were conceived as a way to overcome the alkalinity generation limitations of an anoxic limestone drain and the large area requirements for compost wetlands. The vertical flow system consists of a treatment cell with a limestone under-drain topped with an organic substrate and standing water. The water flows vertically through the organic substrate that strips the oxygen from the water, making it anoxic. The water then passes through the limestone, which dissolves, increasing alkalinity. The water is discharged through a pipe with an air trap to prevent oxygen from entering the treatment cell. Highly acidic water can be treated by

passing the water through a series of treatment cells. A settling pond and an aerobic wetland where metals are oxidized and precipitated typically follow the treatment cells.

Problems associated with vertical flow systems include plugging of the pipes with aluminum precipitate, which must be periodically flushed when aluminum loading is high, and precipitation of metals in the organic substrate which may clog, preventing flow into the limestone under-drain.

A modified vertical flow system eliminating the use of pipes in the bottom of the treatment cell and eliminating the standpipe to control water levels and exclude atmospheric oxygen was installed at the Paint Cliff site (Fig. 4). The treatment cell was designed to be self-flushing. This site has high aluminum concentrations, ranging from 12 mg/l to 83 mg/l pre-construction. Iron concentrations are also high, ranging from 20 mg/l to 274 mg/l pre-construction. The modified design includes a treatment cell followed by a second cell (Fig. 5). A smooth wall 36-inch pipe installed at the bottom of the treatment cell connects the treatment cell to the second cell. Because of the direct connection between the treatment cell and the second cell via the 36-inch pipe, the spillway of the second cell controls the water level of the treatment cell. The positive slope on the treatment cell and the 36-inch outlet pipe towards the second cell encourages flow of aluminum precipitates from the treatment cell into the second cell. The second cell is excavated deeper than the bottom of the 36-inch pipe to provide storage for any precipitates flushed into it. With adequate freeboard in the treatment cell, as precipitate begins to clog the limestone bed, the water level rises in the treatment cell increasing head and flushing the precipitate into the second cell. The elimination of small diameter pipes and the flow-through design of the treatment cell should minimize clogging with precipitates.

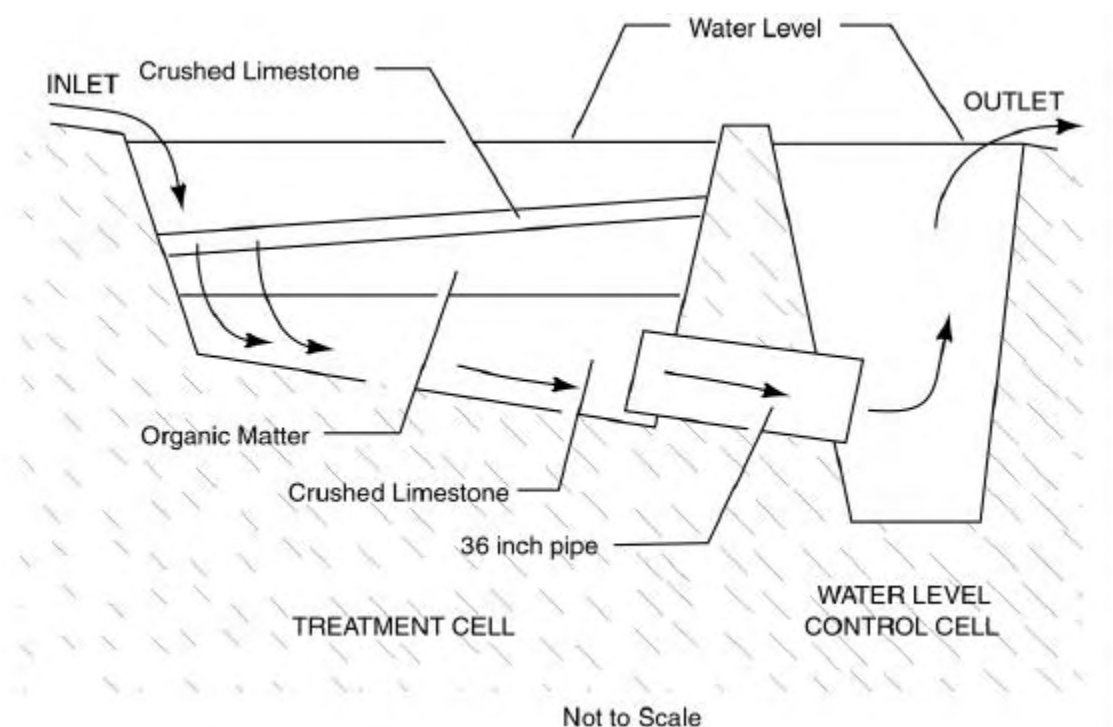


Figure 4. Modified Vertical Flow System detail.



Figure 5. Paint Cliff Vertical Flow System components.

RESULTS

Limestone Sand Dosing

In the spring of 2000 a pilot project began, dosing White Oak Creek and Rock Creek monthly with limestone sand at the mouths of each tributary that were a significant source of AMD. The rate was determined by acid loading calculations. Limestone sand was added at double the calculated rate. The pilot project continued with monthly dosing until the fall of 2001 when it ended due to low flow conditions. After two months of dosing, water quality at the mouth of Rock Creek changed from net acidic to net alkaline (Fig. 6). After four months of dosing, water quality at the mouth of White Oak Creek changed from net acidic to net alkaline (Fig. 7). Based on the positive results of the pilot project the decision was made to build permanent dosing stations in the main tributaries and continue with monthly dosing. Monthly dosing resumed in late winter with the increase in base flow. The rate of dosing continued to be double the calculated rate for the first year, and was reduced to the calculated rate thereafter. Dosing at double the calculated rate for the first year results in accumulation of one-year's worth of neutralization potential in the streambed. After two months of dosing the net acid load from Rock Creek into the Big South Fork of the Cumberland River was reduced from a monthly average of 110 metric tons (121 US tons) per month before dosing to a monthly average of 0.063 metric tons (0.069 US tons) per month (Fig. 8). After four months of dosing the net acid load entering Rock Creek from White Oak Creek, for the months having flow, was reduced from an average of 13 metric tons (14 US tons) per month before dosing to an average of 0.015 metric tons (0.017 US tons) per month (Fig. 9).

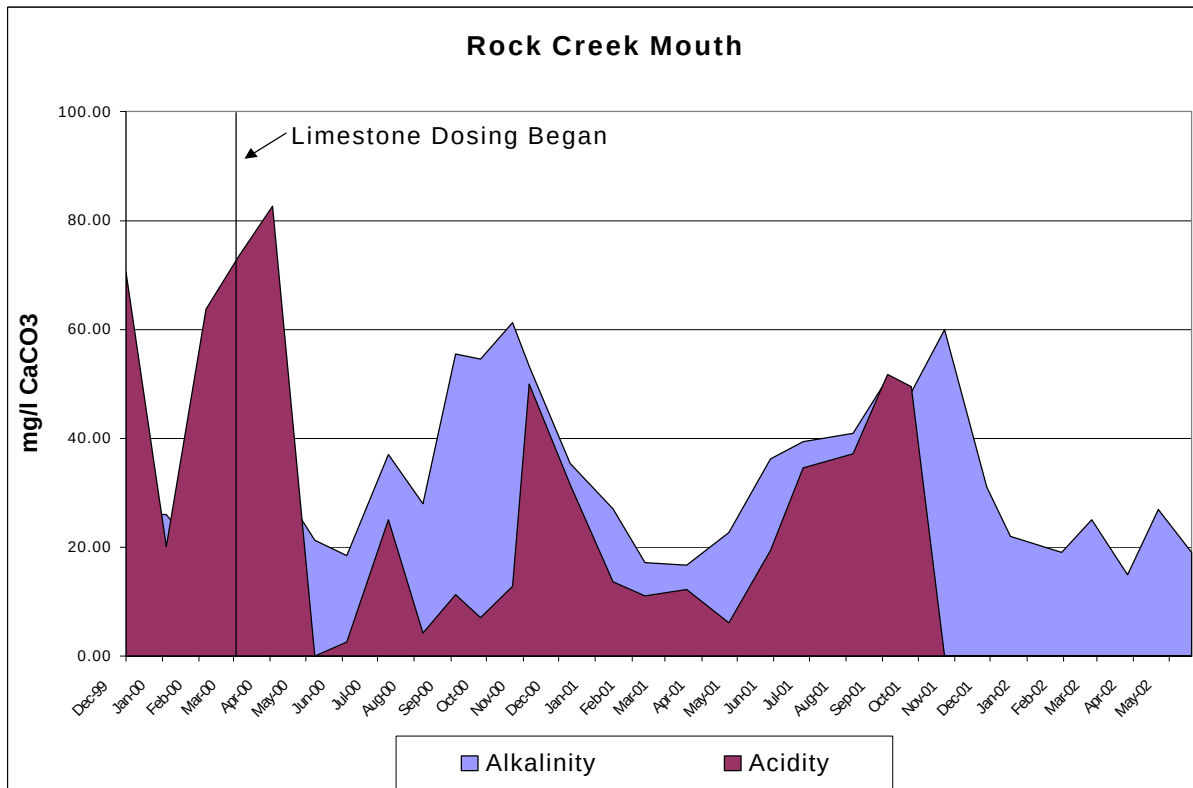


Figure 6. Rock Creek Acidity and Alkalinity

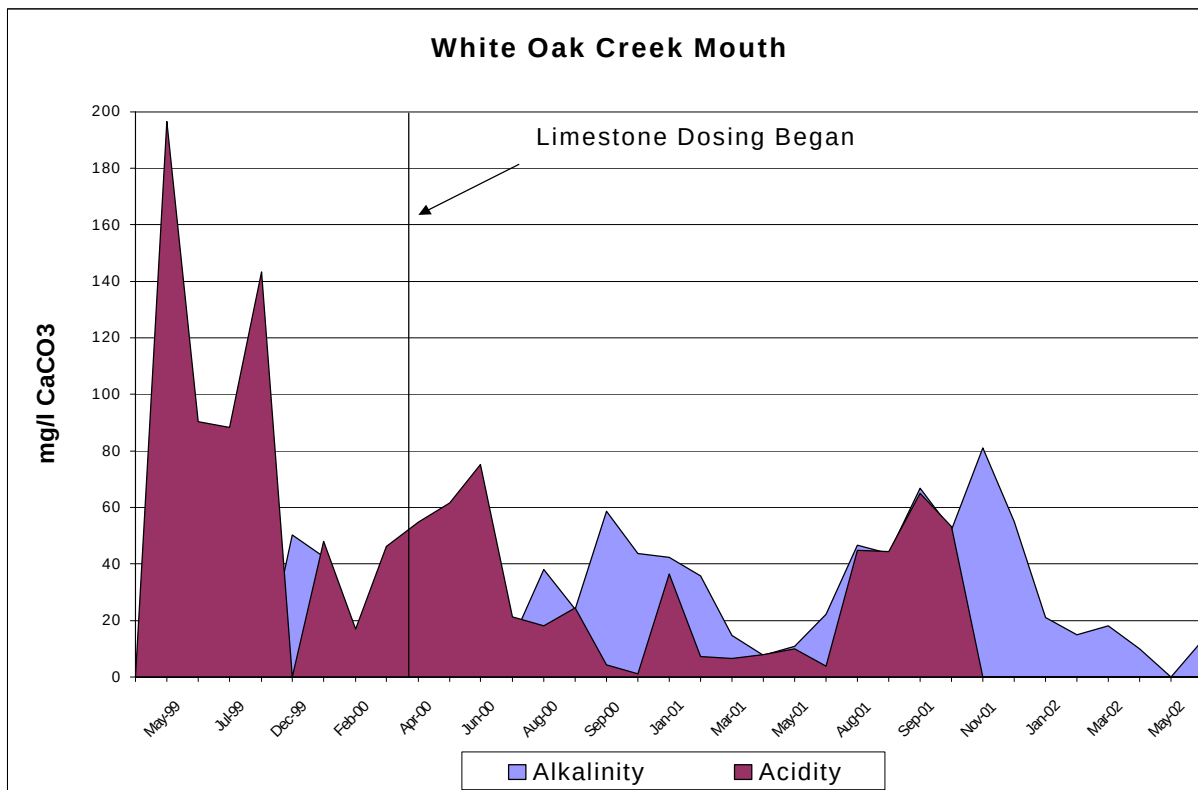


Figure 7. White Oak Creek Acidity and Alkalinity

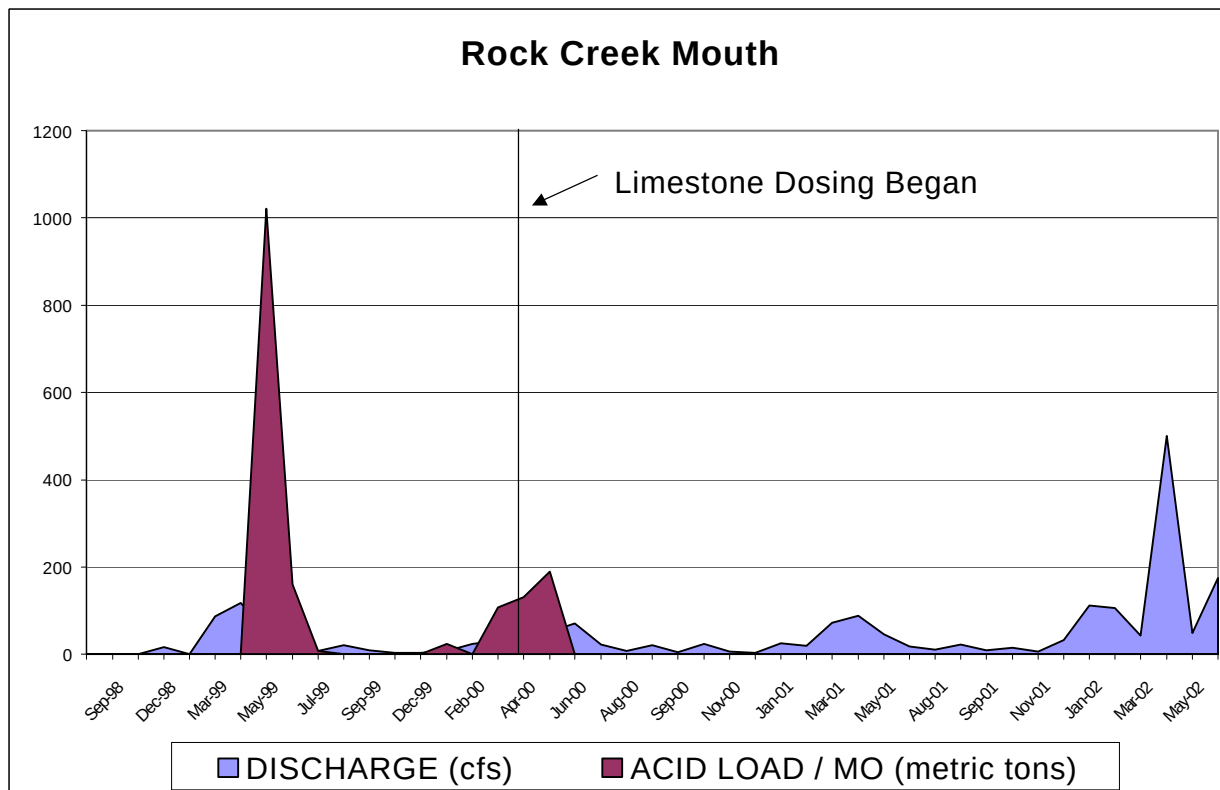


Figure 8. Rock Creek acid load

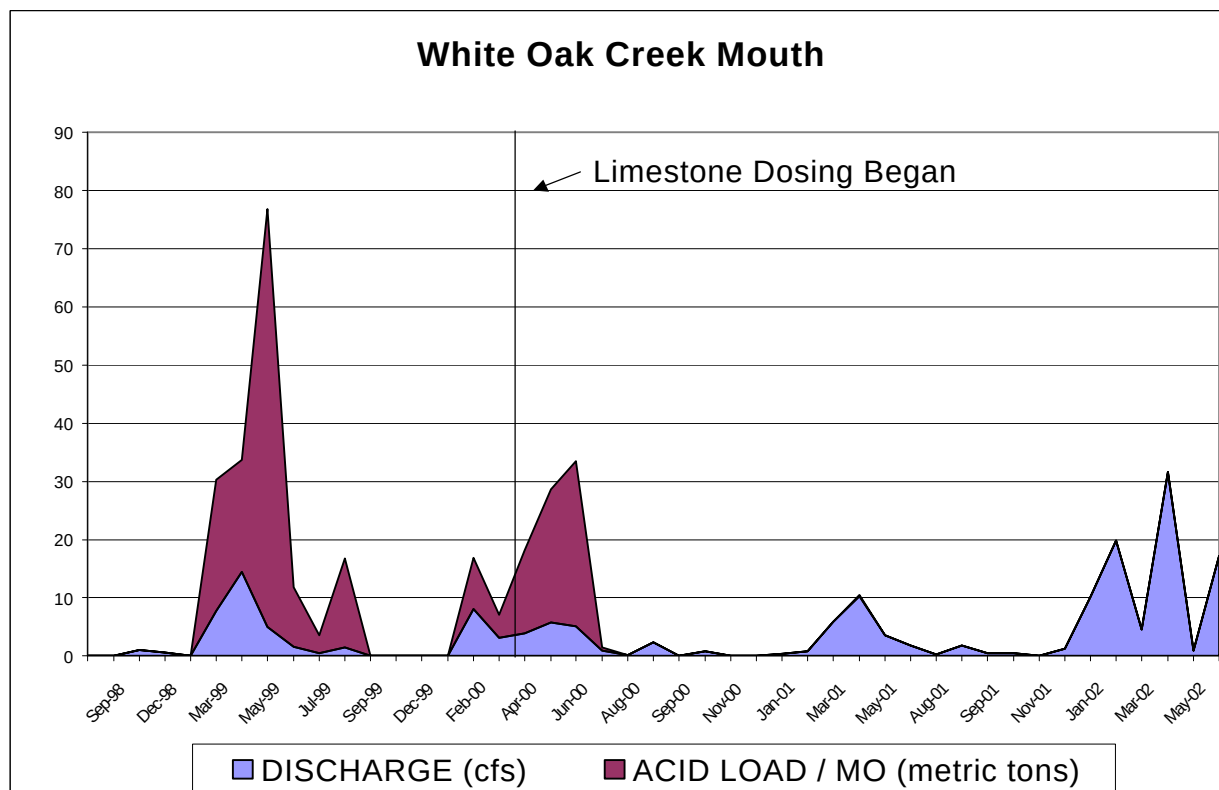


Figure 9. White Oak Creek acid load

Refuse Removal and Treatment

The Water Tank Hollow site was a 3-acre coal processing refuse disposal site on the north bank of Rock Creek (Fig. 10). This project involved the removal of 20,000 cubic yards of highly acidic coal mine refuse from the Water Tank Hollow site and the removal of 5,000 cubic yards of refuse from the Paint Cliff site. The refuse was hauled to an existing sparsely vegetated fill area in Roberts Hollow, treated with agricultural limestone at rates determined by soil testing, and placed in compacted lifts (Fig. 11). The computer programs SEDCAD4 and RUSLE were used to calculate the soil/refuse loss from the Water Tank Hollow refuse site each year. It was calculated that the annual soil/refuse loss was about 500 tons per year. The refuse was sampled and found to have a potential acidity of 165 tons CaCO_3 per kiloton of refuse. Removal of the refuse from the Water Tank Hollow site resulted in a reduction of 82.5 tons of acidity per year from the direct washing of the refuse into the stream. The actual acid load reduction is higher due to the formation of sulfur salts in the refuse and subsequent dissolution and runoff of acid into the stream during precipitation events. It was not possible to directly monitor the acid runoff at this site due to the nonpoint source nature of the three acres of acidic refuse located on the north bank of Rock Creek.

After removal of the refuse from the Water Tank Hollow and Paint Cliff sites the slopes were graded to a smooth uniform configuration. After placement of the fill at Roberts Hollow two feet of soil cover was placed over the refuse. Agricultural limestone was added to the sites and tracked in with a bulldozer. The sites were fertilized, seeded, mulched, and netted. The sites were revegetated with a mix of warm and cool season grasses, legumes, and trees compatible with the surrounding vegetation (Figs. 12, 13)



Figure 10. Water Tank Hollow Refuse Area before reclamation.



Figure 11. Roberts Hollow Refuse Fill Area before reclamation.



Figure 12. Water Tank Hollow Refuse Area after reclamation.



Figure 13. Roberts Hollow Refuse Fill Area after reclamation.

Open Limestone Channels

Open limestone channels were installed at Cabin Branch, Co-op North portal, Roberts Hollow, Paint Cliff, Poplar Spring, and Water Tank Hollow. At the Co-op North portal and an unnamed tributary in Roberts Hollow OLCs were the only treatment technique used. Before and after installation data is available for these two sites enabling an assessment of the efficacy of this treatment technique at these sites.

At the Co-op North portal site pH ranged from 2.8 to 6.1 before installation of the 500 foot long OLC and ranged from 6.7 to 7.6 after construction of the OLC (Fig. 14). Acidity levels decreased and alkalinity increased (Fig. 15). The monthly average acid load prior to construction of the OLC was 1.2 metric tons (1.3 US tons) and the monthly average acid load post construction was zero (Fig. 16). Computer modeling of the proposed 500 foot OLC at the Co-op North portal indicated that the monthly acid load reduction would range from 12% to 91%. The actual acid load reduction to date is 100%.

The unnamed tributary in Roberts Hollow has a drainage area of 0.11 square miles. The tributary receives drainage from a coal processing refuse fill and deep mine portals located in Roberts Hollow. Flow in the tributary is intermittent with no flow during dry months. An open limestone channel (OLC) 800 feet in length was installed in the natural drain. Water monitoring was conducted near the mouth of the tributary before and after construction of the OLC.

The pH values ranged from 2.7 to 4.9 for the 13 sampling dates that had flow prior to construction of the OLC. The pH values ranged from 4.9 to 7.9 for the 13 sampling dates having flow after installation of the OLC (Fig.17).

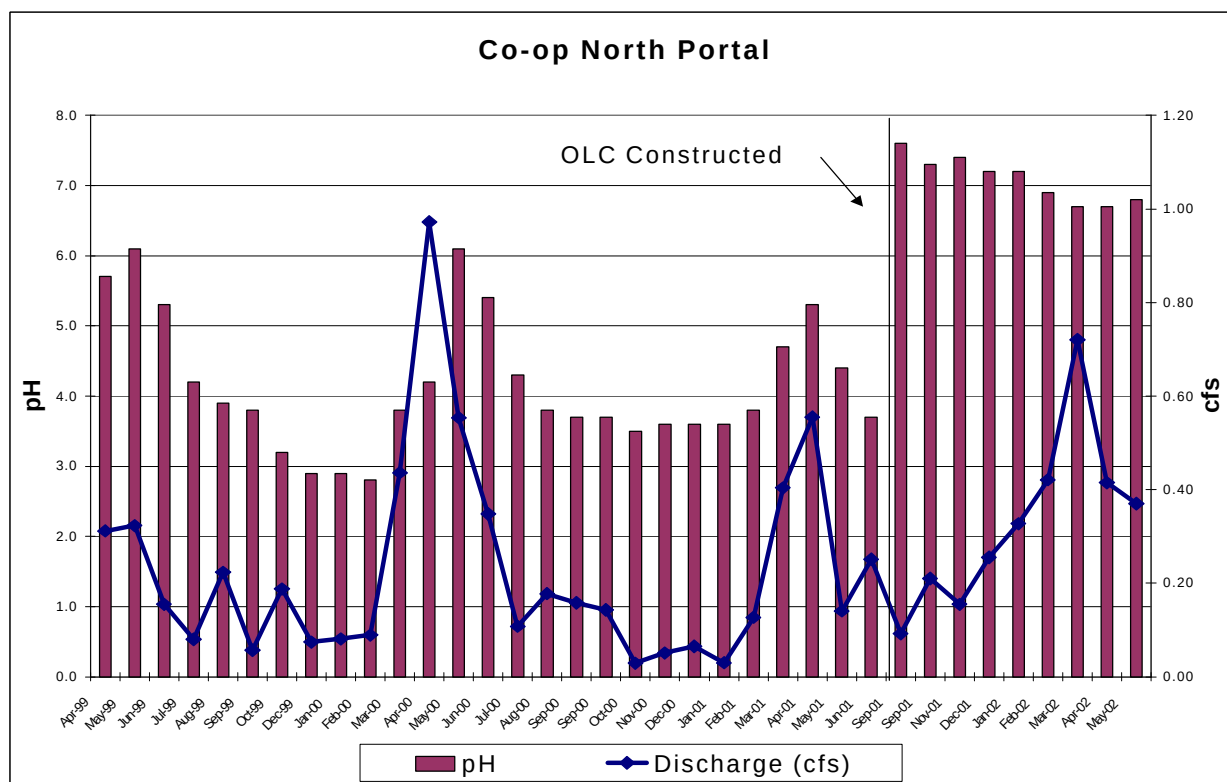


Figure 14. Co-op North drainage pH and discharge.

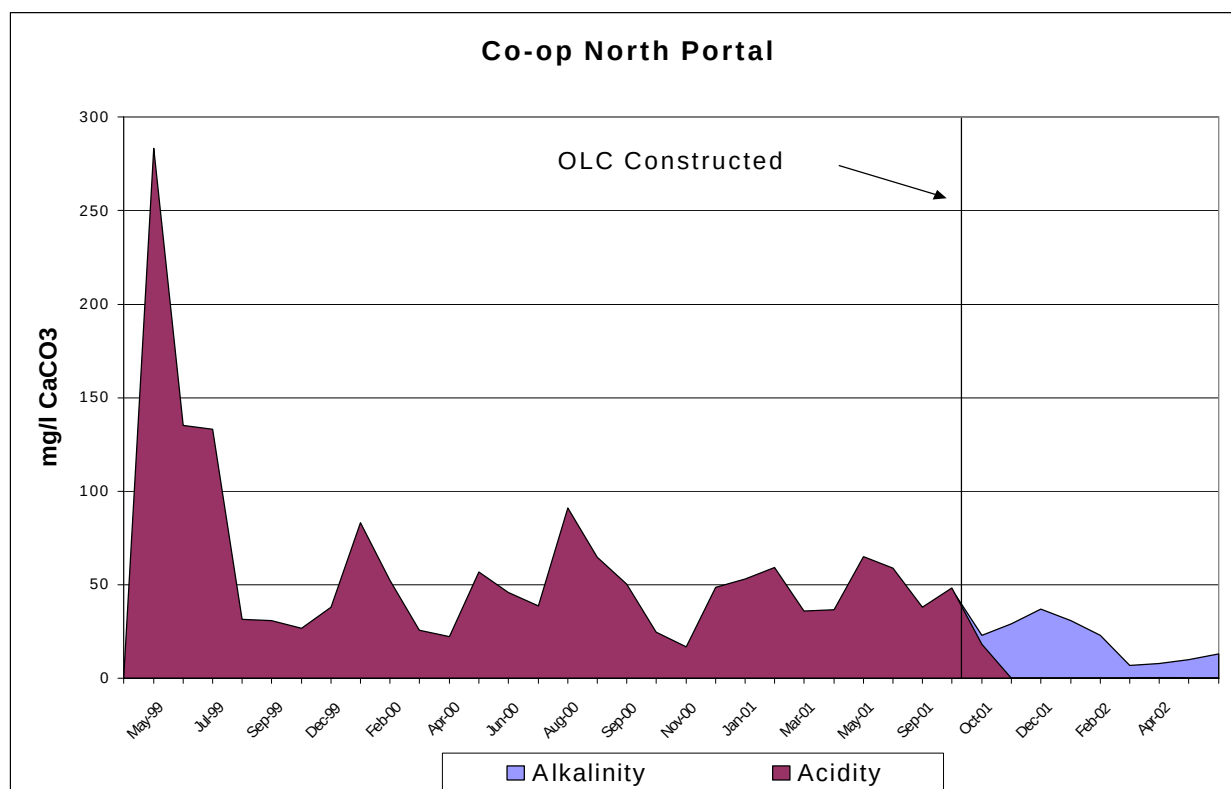


Figure 15. Co-op North drainage acidity and alkalinity.

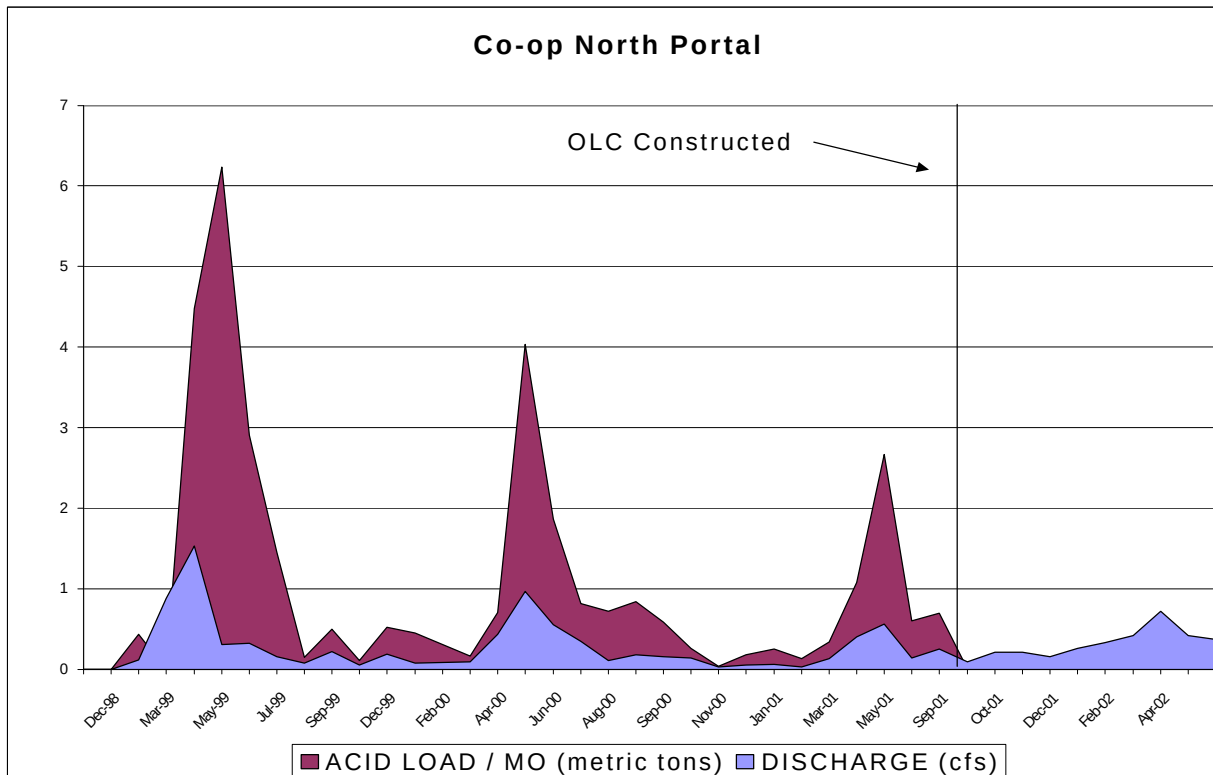


Figure 16. Co-op North discharge acid load.

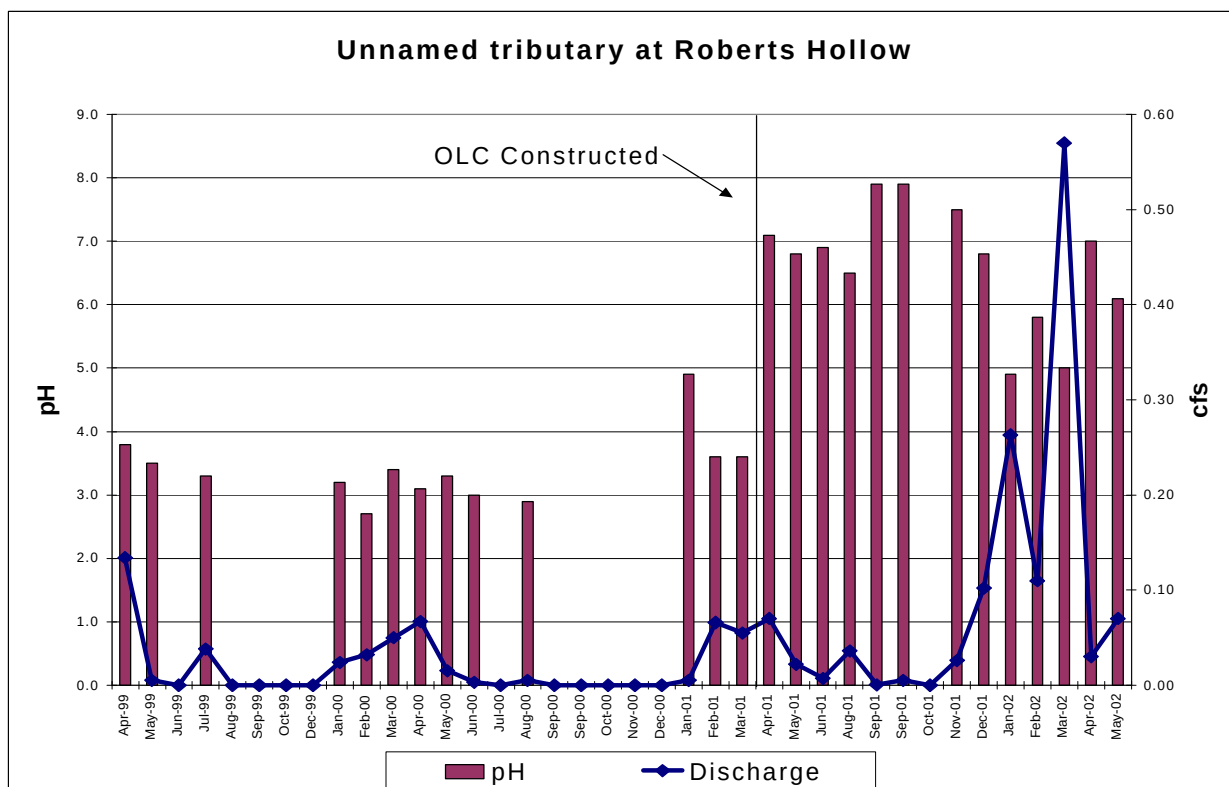


Figure 17. Unnamed tributary at Roberts Hollow pH and discharge.

Acidity decreased from an average of 182 mg/l CaCO₃ pre-construction to an average of 38 mg/l CaCO₃ after installation of the OLC. Alkalinity increased from 0 to an average of 54 mg/l CaCO₃ after installation of the OLC. Net acidity was reduced 99% from an average of 182 mg/l CaCO₃ to an average of 2 mg/l CaCO₃ post construction. The tributary was net acidic until installation of the OLC when it became net alkaline for 10 of the 13 sampling periods post construction (Fig. 18). Net acid loading was near zero post construction (Fig. 19).

Vertical Flow System

A modified vertical flow system was constructed at the Paint Cliff site. The system receives AMD from a pyrite rich refuse fill and a deep mine discharge. The system has a direct connection between the treatment cell and a second cell via a 36-inch smooth wall pipe installed at the bottom of the treatment cell. The water elevation in the second cell controls the water elevation in the treatment cell. This setup eliminates the standpipe normally used for water elevation control. After a few months of use the spillway on the cell controlling the water elevation in the treatment cell had to be lowered to prevent flow from exiting the emergency spillway of the treatment cell. As precipitates accumulated in the treatment cell more head was required to drive the water through the system. After lowering the spillway of the second cell the water elevation of the treatment cell was about a foot higher than the adjusted water elevation in the second cell. This adjustment eliminated flow out of the emergency spillway in the treatment cell except during high flow events in late winter and early spring. The system is undersized to handle the entire flow during high flow events. An increase of freeboard in the treatment cell may allow it to handle larger flows with the increase in head.

An open limestone channel 100 feet in length intercepts the AMD before discharging into the sediment basin. Flow proceeds from the sediment basin into the treatment cell. Water is discharged from the vertical flow system into an OLC 100 feet in length. The water then flows through 500 feet of low gradient limestone lined ditch before discharging into Rock Creek. The last 500 feet of ditch was installed along the highway and does not function as treatment due to clogging with precipitates. The water quality data is for the entire treatment system and not just the vertical flow treatment cell.

The pH values ranged from 2.4 to 3.9 for the 16 sampling dates that had flow prior to construction of the vertical flow system. The pH values ranged from 4.8 to 6.2 for the 17 sampling dates after installation of the vertical flow system (Fig.20).

Acidity decreased from an average of 677 mg/l CaCO₃ to an average of 25 mg/l CaCO₃ after installation of the vertical flow system. Alkalinity increased from 0 to an average of 8 mg/l CaCO₃ after installation of the OLC. Net acidity was reduced 96% from an average of 677 mg/l CaCO₃ to an average of 26 mg/l CaCO₃ post construction. The discharge was net acidic until installation of the vertical flow system when it became net alkaline for 10 of the 17 sampling periods post construction (Fig. 21). Net acid loading was near zero post construction with the exception of the September 25, 2001 sampling date when flow increased after a low flow period (Fig. 22).

This design has been in place for over a year and a half and has reduced acidity levels by more than 96% with no clogging problems to date. If the design proves to be successful over a long period of time it may be suitable for installation in high acid, high metal load conditions as found in the lower Rock Creek watershed.

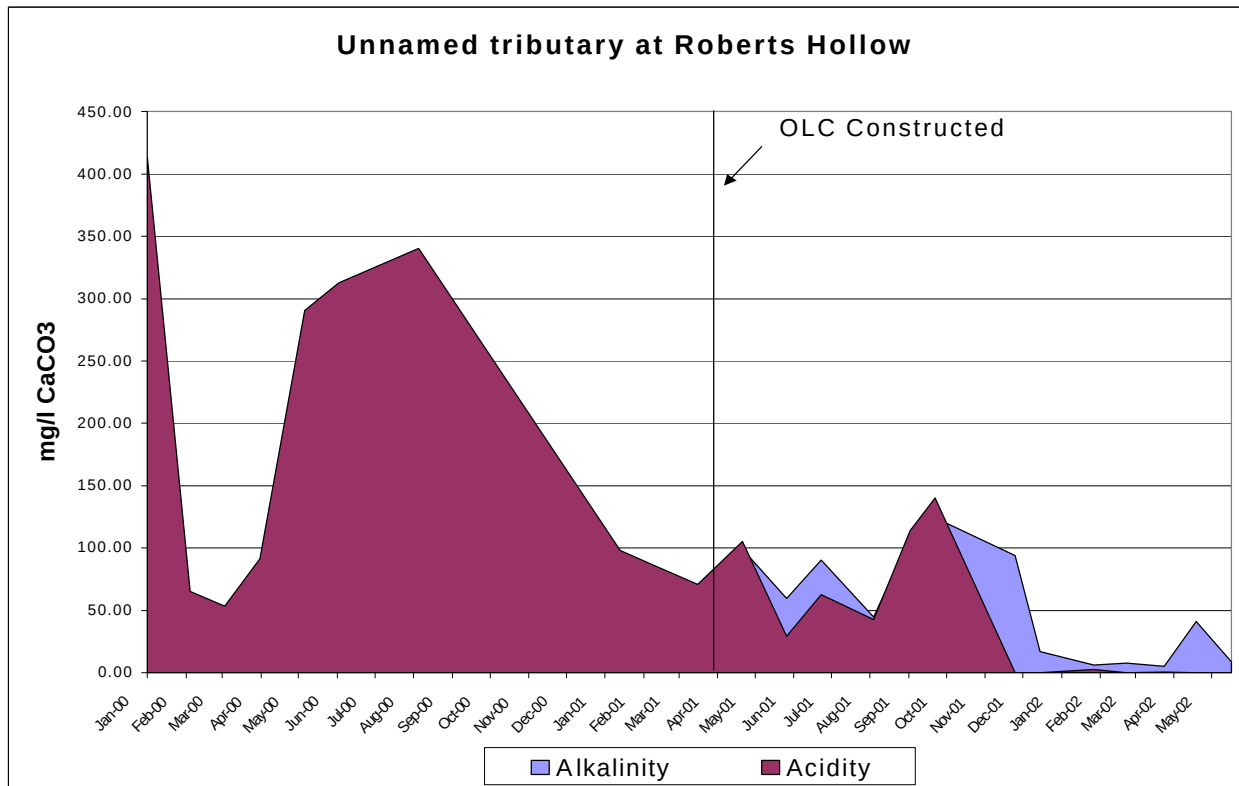


Figure 18. Unnamed tributary at Roberts Hollow acidity and alkalinity.

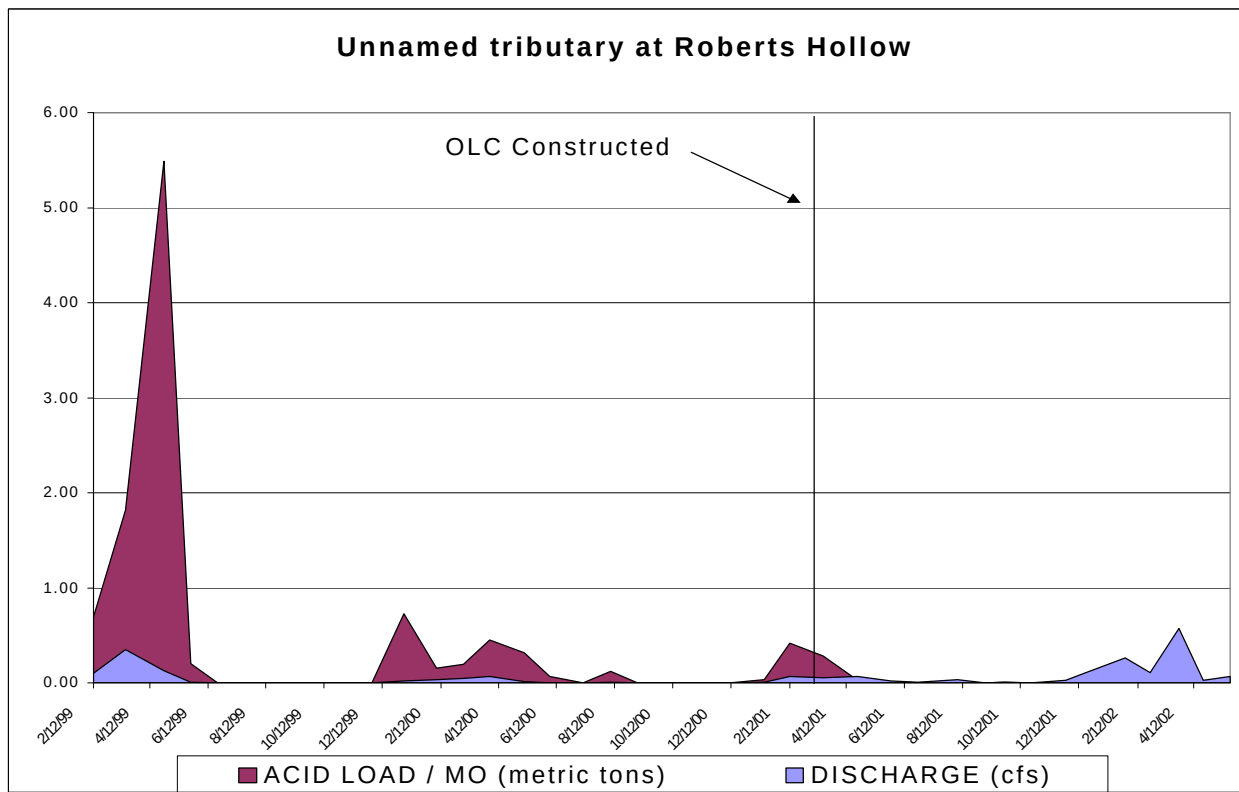


Figure 19. Unnamed tributary at Roberts Hollow acid load.

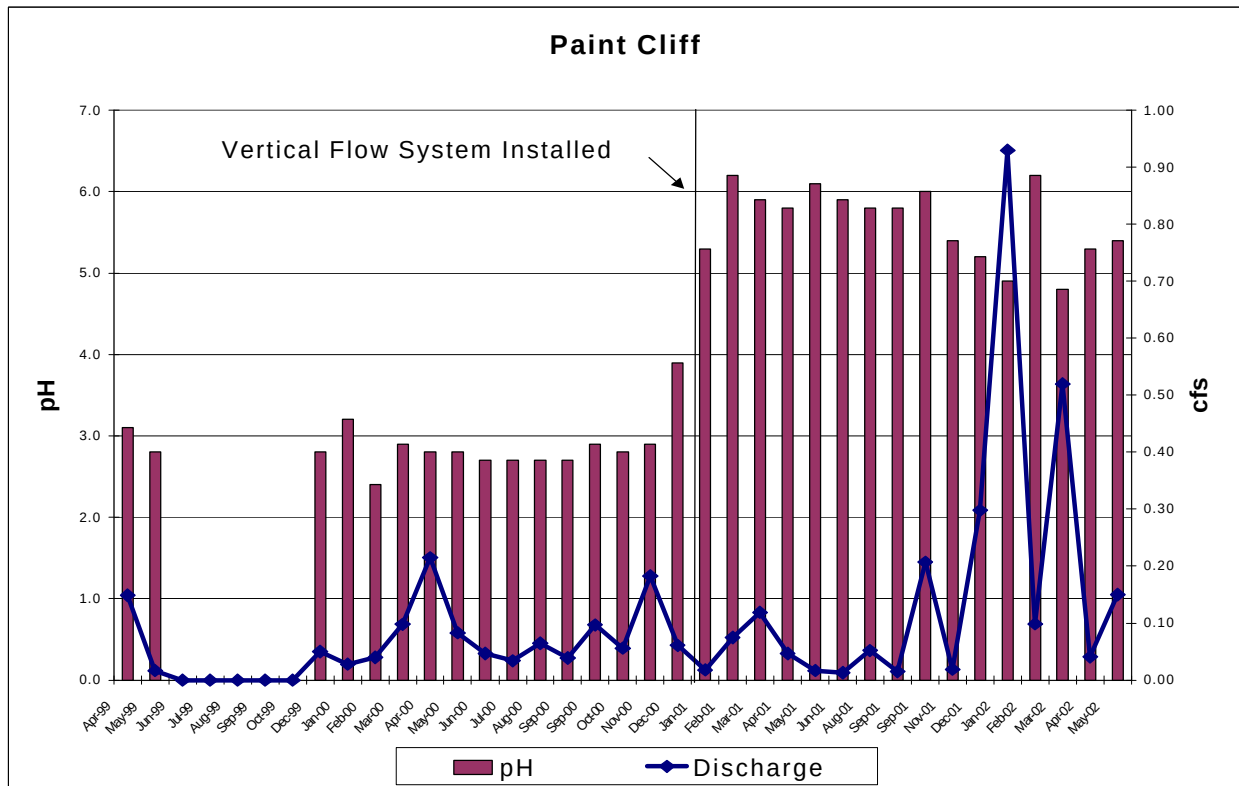


Figure 20. Paint Cliff pH and discharge.

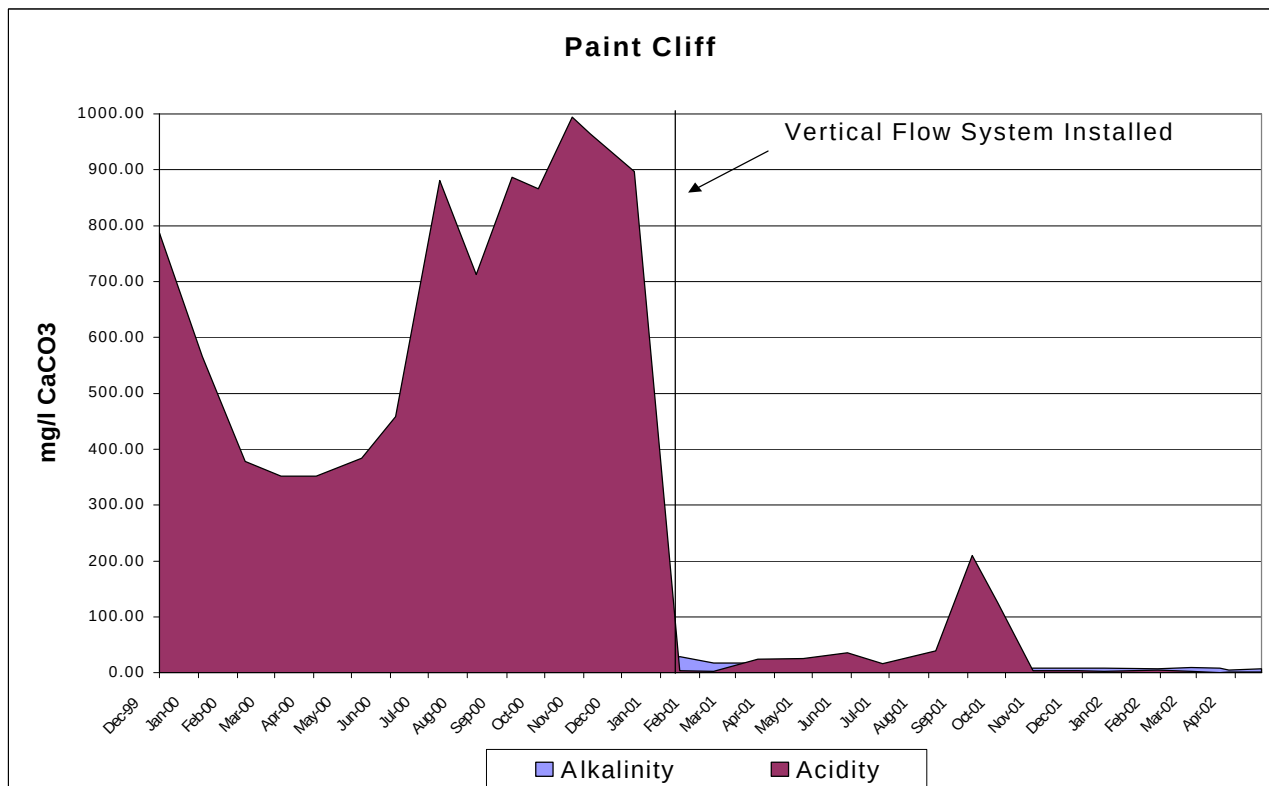


Figure 21. Paint Cliff acidity and alkalinity.

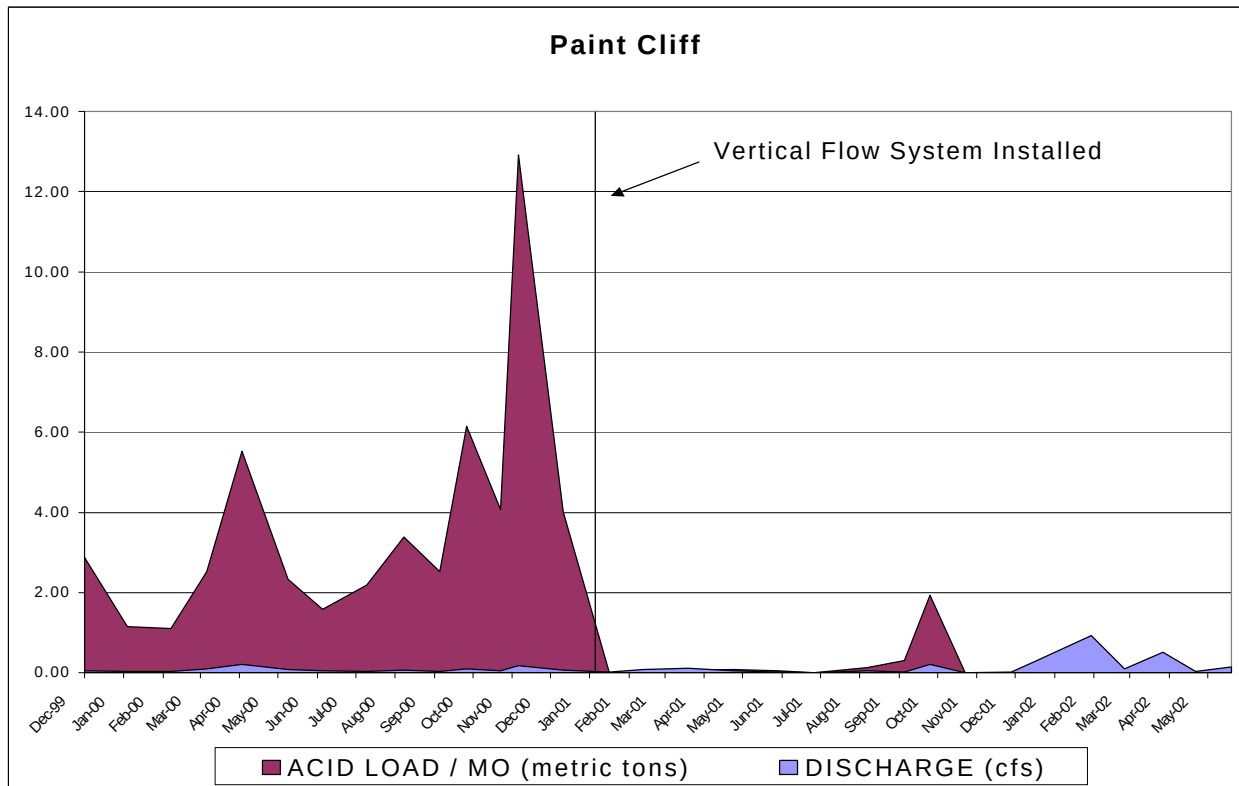


Figure 22. Paint Cliff acid load.

Biological Monitoring

Aquatic macroinvertebrates were collected spring/summer and fall/winter beginning in 1999. USFS personnel are analyzing aquatic macroinvertebrate results. Complete results of the macroinvertebrate study are not available at this time. Preliminary observations and results indicate that species diversity and numbers are improving. The proportion of intolerant orders appears to be increasing.

Fish were collected in early summer beginning in 1999. Monitoring station WO-01 is located upstream of the AMD impacted tributaries on White Oak Creek. Fish were sampled at this location on June 2, 1999. Only three species were collected. Blackside dace, a federally threatened species, was one of the three species collected. Blackside dace were previously unknown in this watershed. The total IBI on this sampling date was 32, a ranking of poor. Due to the presence of Blackside dace in this stream segment and this monitoring station's role as an upstream control the decision was made to suspend sampling at this site.

Monitoring station WO-02 is located immediately downstream from the mouth of Cabin Branch; the first AMD impacted tributary discharging into White Oak Creek. This site was sampled twice in 1999. On both of the sampling dates, June 2, 1999 and October 19, 1999, no fish were collected from this stream segment. In February 2000 dosing of the stream with sand-sized limestone particles began. On July 17, 2000, six months after limestone dosing began, one species of fish was collected from this previously dead section of stream. Ninety-one creek chubs, a tolerant species, were collected. The total IBI for this stream segment on this date was 26, a ranking of very poor to poor. On July 23, 2001 this stream segment was sampled again. Four species of fish were collected on this previously dead section of stream including barcheek

darters and the federally endangered blackside dace, both intolerant species. The total IBI was 34 a ranking of poor (Fig. 23).

Monitoring station RC-00 is located immediately upstream from the mouth of White Oak Creek on Rock Creek and is the upstream control site for Rock Creek. This site was sampled only once, August 5, 1999, due to its role as an upstream control site. There were 10 species of fish collected, six of which were intolerant species. The total IBI was 40, a ranking of fair.

Monitoring station RC-01 is located on Rock Creek immediately downstream from the confluence with White Oak Creek. The water quality in this section of stream is highly variable. During periods of low flow the entire flow of Rock Creek immediately upstream is diverted through a cave, discharging from a spring 3000 feet downstream from the monitoring site. This results in the water at this site during low flow being entirely from the White Oak Creek watershed. In addition, a spring discharges at this site whose source is the severely AMD impacted Jones Branch tributary. During high flow this section of stream receives water from the high water quality section of Rock Creek. The highly variable nature of the water quality and the mobility of fish result in dramatic changes in fish populations on different sampling dates. This site was sampled on three separate dates in 1999. On June 2, 1999 nine species of fish were collected, five of which were intolerant species. The IBI was 44, a ranking of fair. Two months later on August 5, 1999 only three species of fish were collected, one of which was an intolerant species. The IBI on this date was 24, a ranking of very poor. Two months after the August sampling date on October 19, 1999 the stream segment was sampled again. Sixteen species of fish were collected; seven of which were intolerant species. The IBI on this date was 40, a ranking of fair. On July 17, 2000 the stream segment was again sampled. Limestone dosing began six months prior to this sampling date. The total number of species collected was six, three of which were intolerant species. The IBI on this date was 32, a ranking of poor. On July 23, 2001 the stream segment was sampled again. Eight species of fish were collected; four of which were intolerant species. The IBI on this date was 32, a ranking of poor (Fig. 24).

Monitoring station RC-02 is located on Rock Creek immediately downstream from the mouth of Roberts Hollow. This stream segment was sampled three times in 1999. On June 2, 1999 no fish were found. On August 5, 1999 five species were collected, three of which were intolerant species. The IBI was 34, a ranking of poor. On October 19, 1999 this stream segment was sampled and again no fish were collected. On July 17, 2000, six months after limestone dosing began, 13 species, nine of which were intolerant species, were collected. The IBI on this date was 44, a ranking of fair. On July 23, 2001 sampling resulted in the collection of nine species, seven of which were intolerant species. On this date a brown trout was collected, the first trout to be collected on the AMD impacted section of Rock Creek. The IBI on this date was 42, a ranking of fair (Fig. 25).

Monitoring station RC-03 is located on Rock Creek at the mouth of Koger Fork. This site was sampled three times in 1999. On June 2, 1999 13 species of fish were collected, eight of which were intolerant species. The IBI for this date was 46, a ranking of fair to good. On August 26, 1999 only two species of fish were collected, one of which was an intolerant species. The IBI for this date was 29, a ranking of poor. On October 19, 1999 12 species of fish were collected, eight of which were intolerant species. The IBI for this date was 48, a ranking of good. On July 17, 2000, six months after limestone dosing began, the number of species collected was 13, eight of which were intolerant species. The IBI was 37, ranking poor to fair on this date. The presence of green sunfish and the increase in largescale stonerollers lowered the

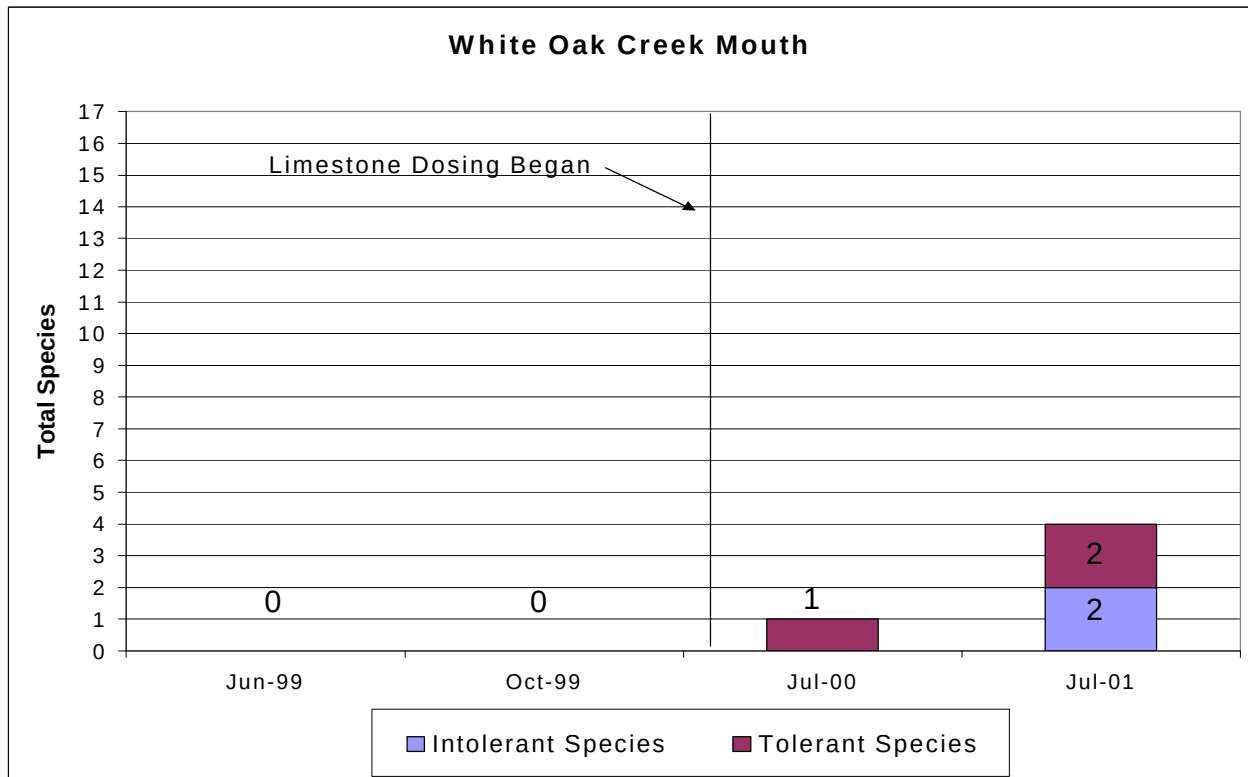


Figure 23. White Oak Creek station WO-02 fish species.

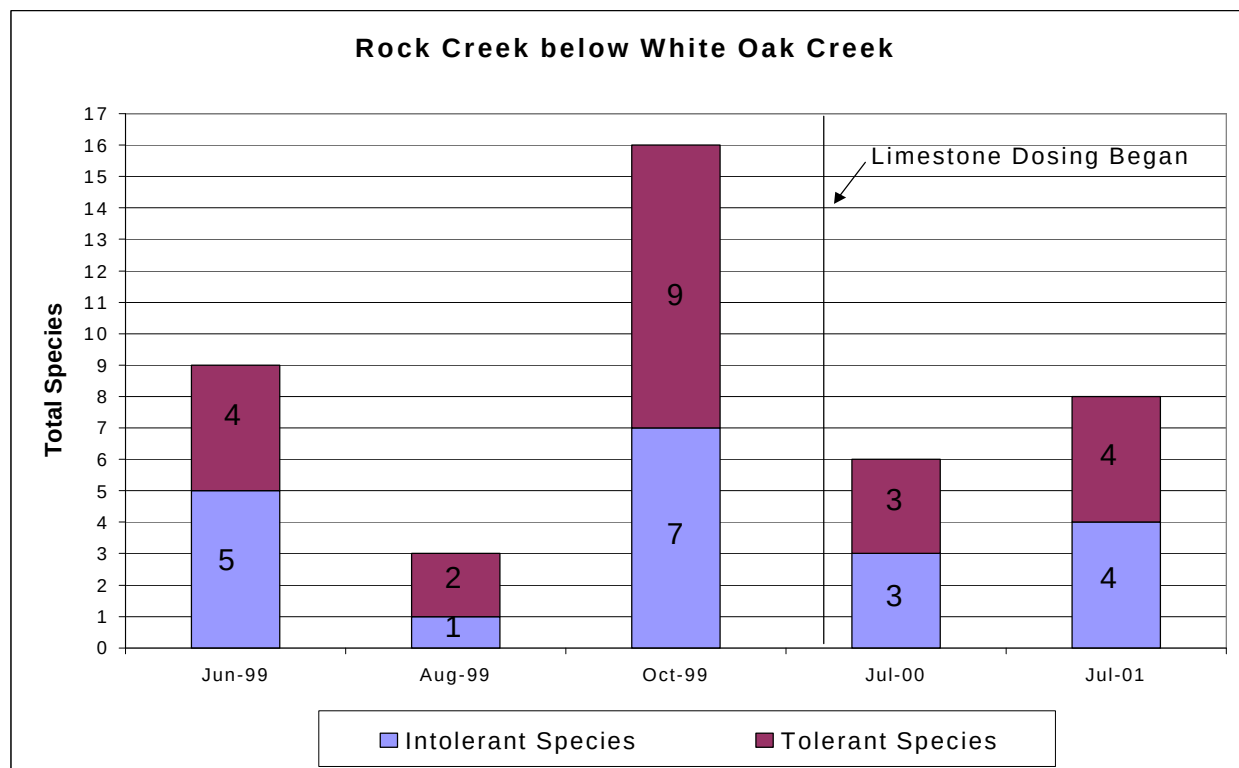


Figure 24. Rock Creek station RC-01 fish species.

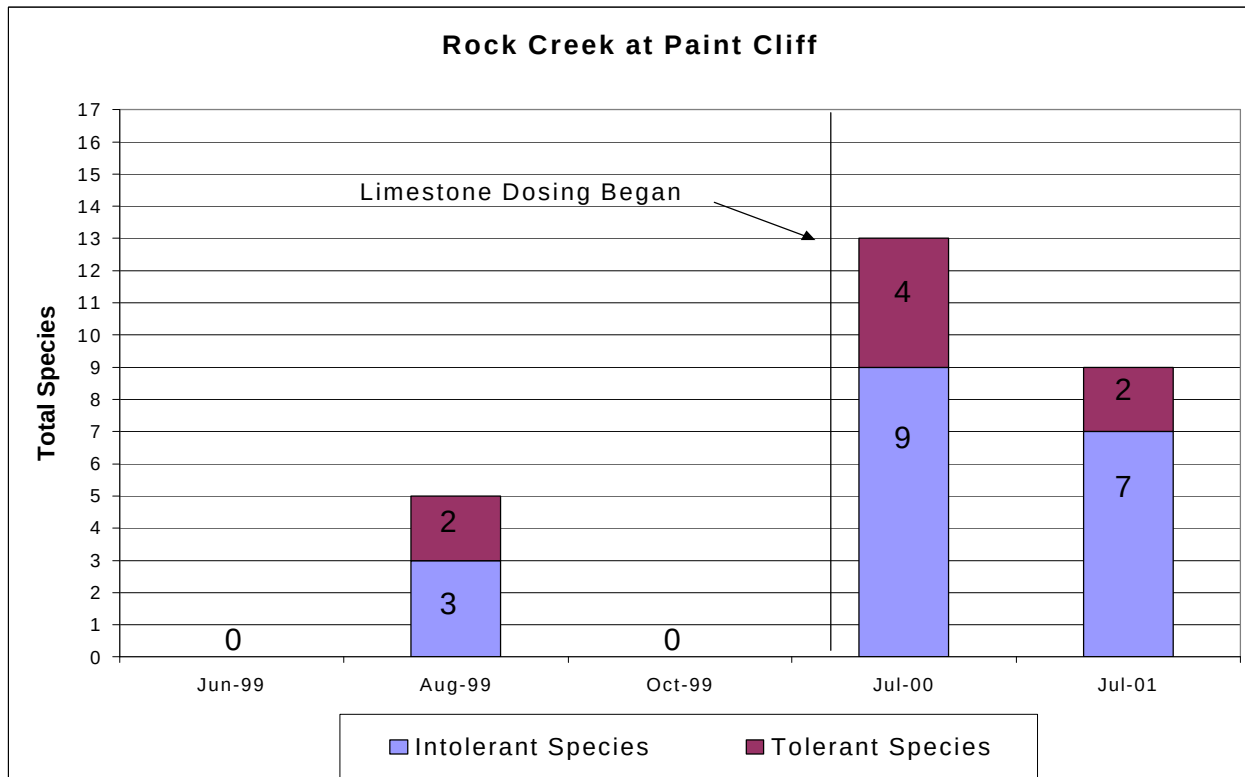


Figure 25. Rock Creek station RC-02 fish species.

IBI score. On July 23, 2001 the number of species collected increased to 15, with 11 species being classified as intolerant. The IBI on this date was 48, a ranking of good (Fig. 26).

Monitoring station RC-04 is located on Rock Creek at the mouth of Grassy Fork, immediately downstream from the Water Tank Hollow site. This stream segment was sampled three times in 1999. On June 2, 1999 10 species were collected, five of which were intolerant species. The IBI on this date was 38, a ranking of poor to fair. On August 26, 1999 six species of fish were collected, with three species being classified as intolerant species. The IBI on this date was 34, a ranking of poor. On October 19, 1999 only two species were collected, none of which are classified as intolerant. The IBI for this date was 22, a ranking of very poor. On July 17, 2000, six months after limestone dosing began, 14 species were collected; seven of which are classified as intolerant. The IBI for this date was 44, a ranking of fair. On July 23, 2001 10 species were collected, with eight species classified as intolerant. The IBI on this date was 46, a ranking of fair to good (Fig. 27).

Fish populations have increased in both diversity and numbers in the White Oak Creek and lower Rock Creek watersheds since limestone dosing and AMD abatement reclamation in the watersheds began. Stream segments in both White Oak Creek and Rock Creek that were dead or severely stressed have improved. IBI scores have consistently increased after limestone dosing and AMD abatement reclamation practices were initiated. Additional AMD abatement reclamation projects in the lower Rock Creek watershed will further improve water quality in the watershed, positively impacting fish populations.

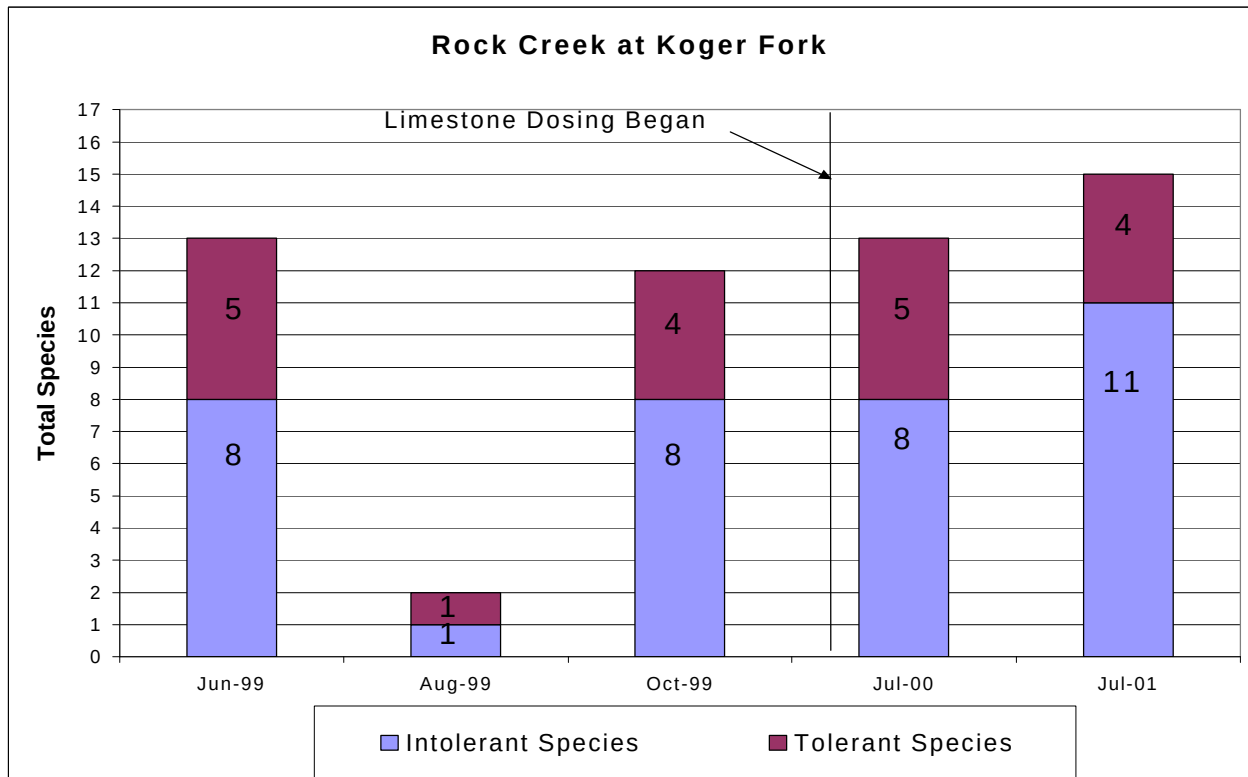


Figure 26. Rock Creek station RC-03 fish species.

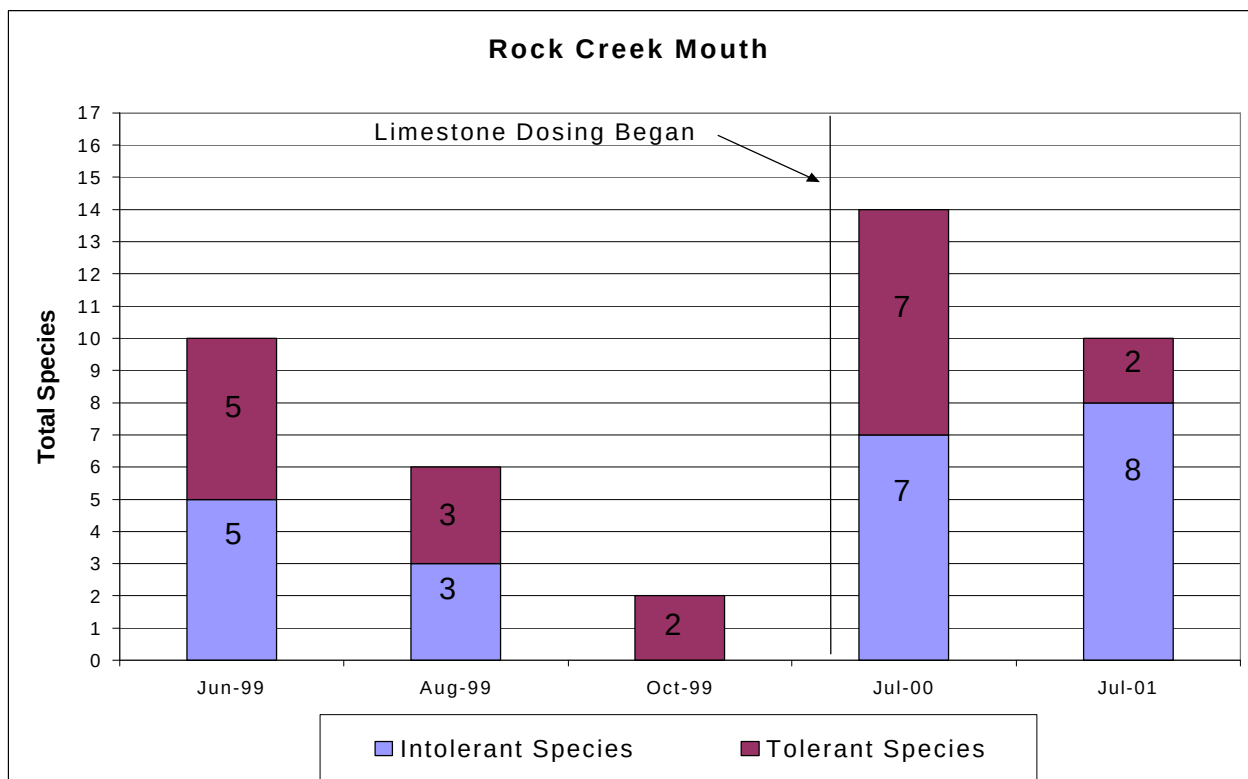


Figure 27. Rock Creek station RC-04 fish species.

CONCLUSIONS

Acid loading from Rock Creek into the Big South Fork of the Cumberland River has been reduced from a monthly average of 110 metric tons (121 US tons) to near zero after completion of the Rock Creek Acid Mine Drainage Abatement Project. Techniques used to accomplish this goal include monthly dosing with limestone sand, removal and treatment of acidic refuse from the banks of Rock Creek, installation of open limestone channels, and installation of a modified vertical flow system at Paint Cliff.

Monthly dosing of selected tributaries in the lower Rock Creek watershed has resulted in a change from net acidity to net alkalinity at Rock Creek's confluence with the Big South Fork of the Cumberland River. Monthly dosing has also resulted in a change from net acidity to net alkalinity in White Oak Creek at its confluence with Rock Creek. The use of the direct application of limestone sand to the tributaries has resulted in significant reductions in acidity at very low cost. This method can be used to improve water quality in impacted streams while sources of funding for more permanent abatement techniques is being sought. As funding levels increase and reclamation is performed, limestone dosing may be reduced or eliminated.

Removal of 25,000 cubic yards of pyritic coal mine refuse from the north bank of Rock Creek at the three acre Water Tank Hollow site and the Paint Cliff site has eliminated over 80 tons of acidity entering Rock Creek annually from direct washing of the refuse into the stream. Revegetation of the sparsely vegetated site has reduced the sediment load into Rock Creek by 500 tons annually. Treating the pyritic coal mine refuse from the Water Tank Hollow site and the Paint Cliff site by mixing it with agricultural limestone and placing it in compacted lifts at the pre-existing Roberts Hollow refuse fill reclaimed two acres of sparsely vegetated refuse. The combination of the treated refuse and the installation of OLCs reduced acid groundwater seepage entering the Roberts Hollow tributary. Revegetation of the site further reduced the sediment load entering the stream at Roberts Hollow.

Installation of the open limestone channels (OLCs) at the Co-op North portal drainage and at the unnamed tributary below Roberts Hollow has reduced net acidity by 100% and 99% respectively. Acid loading has been reduced to zero at the Co-op North site and to near zero at the unnamed tributary site. Installation of the OLCs has resulted in an increase in pH, calcium concentrations, and alkalinity, and a corresponding decrease in acidity and dissolved metals. The documented changes in water chemistry illustrate the value of OLCs in treating acid mine drainage.

Installation of the modified vertical flow system at Paint Cliff has greatly improved water quality at a high acidity, high metal load discharge site. The sites close proximity to Rock Creek limited the room for alternative abatement techniques. The high aluminum concentration in the water gave concern for the installation of a conventional vertical flow system with smaller diameter drainage pipes and a standpipe. The flow-through design installed at Paint Cliff may minimize plugging of the limestone bed with precipitates. To date there has been no problem with plugging, however the outlet spillway elevation had to be lowered to adjust the water elevation in the treatment cell after initial coating of the limestone layer above the organic layer with precipitates. The spillway has only needed to be adjusted once. The system as designed can not handle the entire flow during high flow events. Diversion of the excess flow into a second vertical flow system would solve this problem. An increase in freeboard on the treatment cell may also solve the problem by adding storage and increased head as the water level rises. The treatment system is currently reducing acidity levels by an average of 650 mg/l CaCO_3 .

Previous studies have found that 300 mg/l CaCO₃ reductions in acidity is the upper limit for this type of system. The acid reduction seen at this site may not be sustainable in the long term. If the modified design proves to be successful over a longer period of time a second treatment system may be installed in series with the first.

The combination of the reclamation techniques used on the above sites in conjunction with limestone sand dosing in the lower Rock Creek watershed has reduced the acid load entering the Big South Fork of the Cumberland River to near zero. Fish populations are rebounding with increases in numbers, diversity of species, and numbers of intolerant species. Sections of the streams that were once dead or severely impacted by AMD are being re-colonized by fish.

Additional reclamation work being planned for the severely impacted tributaries of Jones Branch, Roberts Hollow, and Poplar Spring Hollow will continue to reduce acid and metal loading, improving water quality further in the lower Rock Creek watershed. As additional funding allows reclamation projects in other impacted tributaries in the lower Rock Creek watershed the dependence on limestone dosing of the tributaries will be reduced.

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THE TANOMA PASSIVE MINE DRAINAGE TREATMENT PROJECT

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ABSTRACT

Mine Drainage from the defunct Clearfield Bituminous Coal Corporation's underground mines has impaired the upper Crooked Creek watershed in Indiana County, Pennsylvania. The mines form an interconnected and partially inundated complex, covering 4,500 acres. The primary mine drainage outlet, known locally as the 'Tanoma Borehole' has discharged continuously since mining completion in the 1950s, averaging 2,500 gpm (3.6 mgd), and degrading Crooked Creek for several miles.

In 1995, at the request of the Crooked Creek Watershed Association, the Pennsylvania Department of Environmental Protection, Bureau of Abandoned Mine Reclamation, PA-DEP-BAMR, decided to address the Tanoma borehole discharge. BAMR established a monitoring program and initialized water sampling, stream bioassessments, and a hydrogeologic study to evaluate the potential for relocating the discharge to a suitable site for passive treatment. Critical to this evaluation was the protection of an aquifer located above the mine and used for domestic consumption. The relationship of mine discharge volume to in-stream iron concentration was evaluated to determine an effective design sizing criteria.

A two-phase construction approach was undertaken, with new cased and grouted boreholes installed in the first phase. After evaluating the new boreholes, phase two treatment system construction and sealing of the original boreholes occurred. An overflow borehole was left open for monitoring and for mine pool discharge in the event that system capacity was exceeded.

Since full-scale treatment of the mine discharge began in June of 2001, the passive treatment system has removed an average of ~70% of the total iron and converted over 90% of the ferrous or dissolved iron to ferric iron while experiencing flows up to ~3,000 gpm. An important result of system operation to date is that the in-stream iron concentration has consistently been lower than 1.5 mg/L which is the State's regulatory limit and which was one of the design goals for the project. This period includes the historically worst months (the summer and fall months) for water quality impacts. Stream surveys are showing that water quality is rapidly improving and the density and diversity of aquatic life is recovering.

INTRODUCTION

The Tanoma Borehole reclamation project was truly an innovative project that embodies the 21st century approach to watershed restoration by engaging the public and forging partnerships to achieve the greatest environmental benefit. Through the cooperation of a number of federal, state, and local government agencies working hand-in-hand with environmental groups and the general public, 3.5 miles of the upper Crooked Creek have been restored. This restoration has allowed for the re-establishment of indigenous aquatic life. Fish and macroinvertebrates have already begun to return to reclaim this waterway, once polluted by mine

drainage. This project is significant because it demonstrated that a discharge, once thought to be untreatable due to its outfall location, could be relocated and successfully treated at a remote location. This was accomplished while carefully considering and mitigating for any potential negative impacts associated with the relocation, including impacts on local residents. The Tanoma passive mine drainage treatment system has functioned well since being put into service late in 2000.

MINING AND ABANDONED MINE PROBLEM HISTORY

The site is located within the headwaters of Crooked Creek in Rayne Township, approximately 9 miles northeast of Indiana PA. The village of Tanoma is immediately downstream of the mine discharges. Figure 1 depicts the location of the other known discharge points for the Tanoma Complex as well as the location of the treatment facility. Boreholes B3 and B6 were not included for treatment consideration because the mine water discharging at these points is non-pollutional.

Pennsylvanian Period, Allegheny Series lithologies exist within the project area. The Lower Freeport Coal Seam outcrops east of the project area along Two-Lick Creek and also to the north along Rayne Run. Lithologies dip toward west-southwest (2%) in accordance with the regional geologic structure. The most prominent structural feature is the Dixonville Syncline. The axis of the syncline bisects the project area trending in a northeast southwest direction. The trough of the syncline passes beneath the village of Tanoma and is also proximal to the location of the Tanoma Borehole (C7). In the vicinity of Boreholes C7, C6, and MP-1 the Lower Freeport coal is approximately 100 to 110 feet beneath the surface.

The Clearfield Bituminous Coal Corporation operated a number of Lower Freeport seam underground mines in the upper Crooked Creek Watershed. Three of these mines, the Barr Slope Mine, the Clymer No. 1 Mine, and the Clymer No. 3 Mine contributed to the development of the Tanoma mine drainage discharges. The Barr Slope Mine opened around 1900, the Clymer No. 1 Mine opened in the 1910s and the Clymer No. 3 opened in the 1930s. The three mines operated in the Lower Freeport or “D” coal seam and are extensively interconnected such that they can be considered as a single abandoned underground mine complex. The mines closed in 1962, 1952 and 1956 respectively. The three mines all had two slope-type entries, with the Barr Slope entries located near the Village of Dixonville, the Clymer No. 1 entries located at the Village of Sample Run and the Clymer No. 3 entries located at the Village of Weimer. The complex covers an area of over 4,500 acres, and the average coal seam thickness was 42 inches. A large underground mine pool developed in the Clymer No. 1 and Clymer No. 3 mines following abandonment. Due to the down dip advance of the mining, the complex is approximately 50% inundated. The mine pool has been calculated to contain roughly two billion gallons of water.

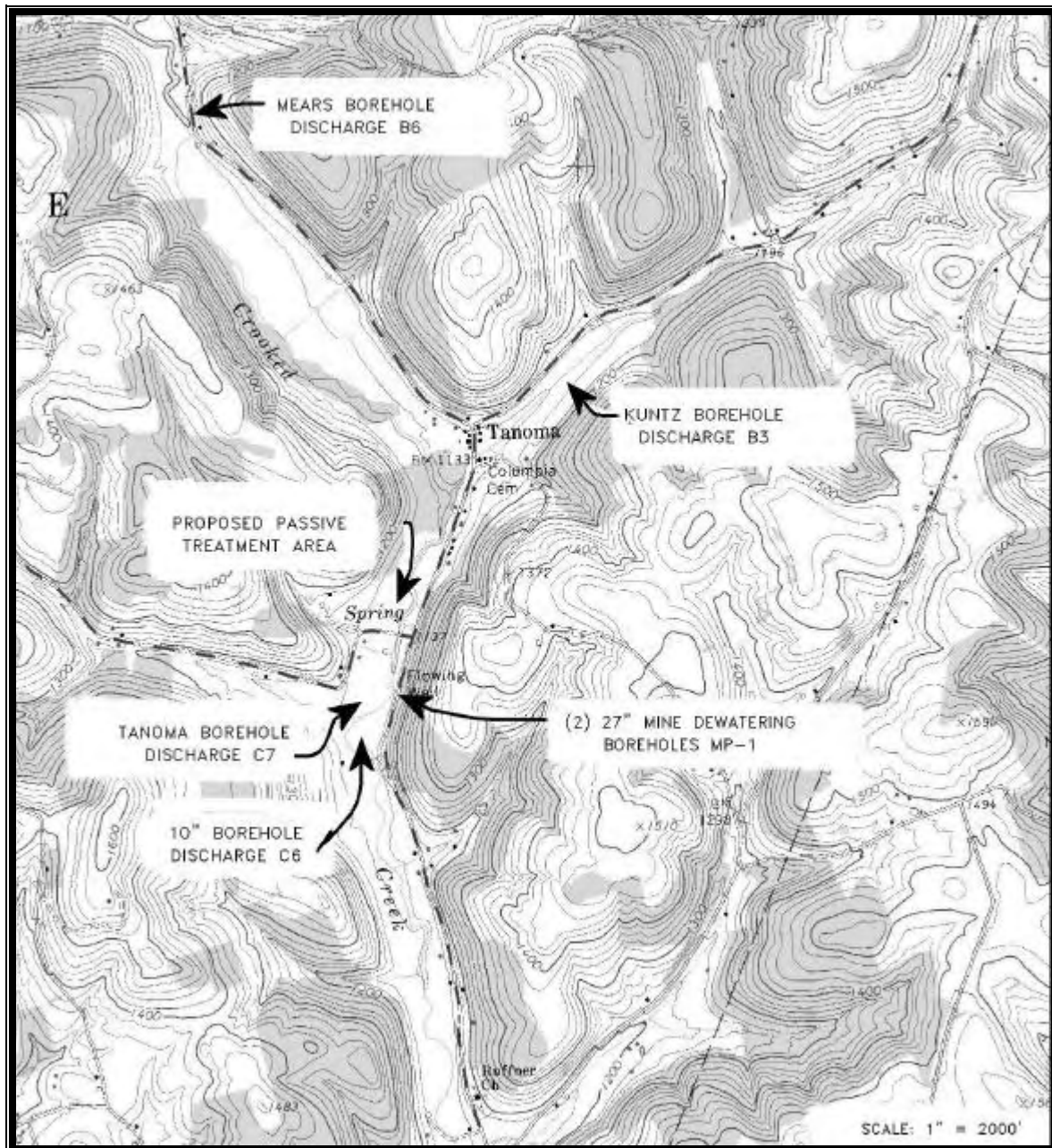


Figure 1 - Location of Boreholes and Treatment Area (From Clymer 7.5' U.S.G.S. Quadrangle)

The most prominent outlet of mine drainage from the complex was a twelve-inch discharge borehole known locally as the 'Tanoma Borehole' or the C-7 borehole. The borehole was located within the Crooked Creek stream channel just upstream of the Village of Tanoma. The borehole had discharged continuously since shortly after mining operations at the two mines ceased in the 1950s. The discharge averaged 2,500 gallons per minute (3.6 million gallons per day) and contained significant dissolved iron (~20 mg/L) and some free acidity (~10 mg/L) that

significantly degraded the water quality within Crooked Creek for several miles below the discharge point.

Located near the Tanoma Borehole were several other boreholes which discharge mine water periodically. One of these is known as the C-6 borehole and consists of a 10-inch vertical borehole. Between boreholes C-6 and C-7, and located on the opposite bank from the boreholes, are two 27-inch overflow boreholes known as the MP-1 boreholes. Figure 1 shows the location of the various discharge boreholes. The MP-1 boreholes are capped with steel grating and discharge seasonally when the mine pool rises due to spring rains and winter snow melts. The MP-1 boreholes served as dewatering boreholes when the mines were operating. Water in the mines was pumped to a sump area at this location and then pumped to the surface through the MP-1 boreholes and discharged directly into Crooked Creek. Several other boreholes, openings, and man-ways into these two Clymer mines are known to exist, but no significantly degraded mine drainage discharges have been documented.

Following closure of the mines, discharge water quality from the Tanoma Borehole has improved. Table 1 summarizes historical changes in mine pool water quality at this site. The discharge is now consistently alkaline (120 mg/L). The concentration of iron has also decreased slightly to approximately 15 mg/L. However, the volume of the discharge in relation to the normal base flow of Crooked Creek has resulted in significant iron precipitation that covers the stream bottom coloring it orange for several miles below the discharge during periods of low stream flow. Stream monitoring completed during 1996 and 1997 showed that the Tanoma Borehole discharge accounted for an average of 42% and a peak of 83% of the total stream flow within Crooked Creek. This sheer volume of contaminated mine water results in significant adverse impacts on the water quality and the associated density and diversity of aquatic life in Crooked Creek for several miles downstream of the discharge.

The Lower Kittanning Coal seam (B Seam) is located approximately 150 feet below the Lower Freeport Coal and has been, and continues to be, mined in the general area. Several abandoned underground operations exist within and adjacent to the project area. These operations were developed in a manner similar to the Lower Freeport operations. Entries were driven westward (down-dip) from the Two-Lick Creek watershed into the Crooked Creek watershed. The Tanoma Mining Company currently has an active Lower Kittanning operation underlying the majority of the project area. Surface facilities, including the portals, preparation plant, coal refuse disposal area and mine drainage treatment facilities are located approximately 2 miles north of Tanoma along Rayne Run. Significant portions of the Lower Freeport Tanoma Complex, including the majority of the mine pool, overlie this active operation. Coal removal was initiated in 1983 and continued up until the fall of 2001. Mine maps indicate that first mining (50% coal removal) has occurred in areas directly underneath the Lower Freeport mine pool during the mid to late 1990's. First-mined areas underlying the pool are completed and have been sealed. No retreat mining occurred.

PROJECT BACKGROUND

In 1995, the Crooked Creek Watershed Association approached the PA-DEP-BAMR with a request to consider abatement of the Tanoma discharges under the newly established AMD 10% Set-Aside Program. A detailed monitoring and evaluation program was established for the site since no detailed monitoring or analysis of the mine pool and discharges had been completed since the early 1970s.

Table 1 - Water Quality Summary - Borehole Discharges

	Tanoma Borehole C7			10-inch Borehole C6			Mears Borehole B6			Kuntz Borehole B3		
	1970-79	1980-89	1990-96	1970-79	1980-89	1990-96	1970-79	1980-89	1990-96	1970-79	1980-89	1990-96
Min. Flow	1044	no data	283	no data	no data	no data	80	no data	15	no data	no data	75
Median Flow	2154	no data	301	no data	no data	no data	240	no data	60	no data	no data	75
Max. Flow	4722	no data	3000	no data	no data	no data	300	no data	79	no data	no data	75
No. of samples (n)	19	0	10	0	0	1	11	0	9	0	0	1
Min. Ph	5.5	5.9	6.1	5.6	no data	6.6	5.8	6	6.04	5.7	no data	6.4
Median pH	6.4	6.4	6.47	6.3	no data	6.6	6.35	6.41	6.58	6.3	no data	6.4
Max. pH	6.65	7.17	7.15	6.5	no data	6.6	6.9	7.3	7.16	6.9	no data	6.4
No. of samples (n)	57	55	17	10	0	1	16	55	17	8	0	1
Min. Net Alkalinity	-120	60	34	-111	no data	162	29	30	144	11	no data	142
Med. Net Alkalinity	100	120	133	-28	no data	162	68	90	172	49	no data	142
Max. Net Alkalinity	155	175	180	99	no data	162	115	170	222	101	no data	142
No. of samples (n)	53	55	17	8	0	1	12	55	18	5	0	1
Min. Iron	0.24	2.8	0.44	0.36	no data	13.9	0.04	0.01	0.03	0.1	no data	0.77
Median Iron	10.7	7	11.4	27.4	no data	13.9	0.17	0.04	0.045	0.565	no data	0.77
Max. Iron	40	19.5	22.4	45.5	no data	13.9	2.4	3.6	0.32	1.58	no data	0.77
No. of samples (n)	57	55	17	10	0	1	16	55	18	8	0	1
Min. Manganese	no data	0	0.08	no data	no data	0.84	no data	0	0.03	no data	no data	0.41
Med. Manganese	no data	1.1	0.86	no data	no data	0.84	no data	0.1	0.06	no data	no data	0.41
Max. Manganese	no data	2.5	1.03	no data	no data	0.84	no data	0.3	0.42	no data	no data	0.41
No. of samples (n)	0	52	17	0	0	1	0	52	18	0	0	1
Min. Sulfate	300	270	113	520	no data	353	91	100	306	23	no data	210
Med. Sulfate	565	450	367	880	no data	353	326	250	520	267.5	no data	210
Max. Sulfate	1850	590	556	1200	no data	353	380	390	688	390	no data	210
No. of samples (n)	56	55	17	10	0	1	15	55	17	8	0	1

Note: Flow is expressed in gallons per minute (gpm) , all other parameters are concentrations in milligrams per Liter (mg/L)

From May 1996 through April 1997, all of the mine pool discharge points were extensively sampled and monitored. The total combined flow of the discharges (from the C-6, C-7 and MP-1 boreholes) ranged from a low of 1,174 gpm in August 1996 to a peak of 5,397 gpm in December 1996. The average flow was just over 2,500 gpm. The total iron concentration ranged from a low of 7.9 mg/L to a peak of 22.4 mg/L. The discharges were determined to be contributing an average of 233 lbs/day of iron to Crooked Creek. The in-stream iron concentration downstream of the boreholes ranged from 1.23 mg/L to 7.81 mg/L. In all but two sampling events, the acceptable in-stream standard for iron (1.5 mg/l) was exceeded.

Table 2 summarizes the pre-design monitoring of the discharges, stream flow, and the in-stream iron concentration.

Macroinvertebrate surveys of Crooked Creek were conducted by BAMR staff in the fall of 1994 and in the early summer of 1996. Both surveys indicated good diversity and density of macroinvertebrates upstream of the Tanoma Borehole. The 1994 survey found very good diversity and large numbers of insects upstream of the discharges. Immediately below, there was a drastic reduction in both the number of taxa and total insects, with partial recovery found at a station located approximately 2.5 miles below the discharges. The 1996 survey, which utilized the EPA's Rapid Bioassessment Procedures (RBP-III), discovered similar findings with 40 insects representing 11 taxa upstream, 17 insects representing seven taxa immediately below the discharges, and 35 insects representing 10 taxa approximately 1.5 miles downstream. While the upstream samples in both surveys had good representation by the more pollution intolerant ephemeroptera/plecoptera/trichoptera taxa (mayflies/stoneflies/caddisflies), these taxa were almost non-existent immediately below the discharge, and only trichoptera were represented further downstream. Fish habitat has also been negatively impacted by the mine drainage discharges. The Ken Sink Chapter of Trout Unlimited reported that the instream iron concentration exceeded the limits for trout stocking. Trout have been historically stocked in Crooked Creek upstream of the Tanoma Borehole, but not below.

Table 2 – Pre-Design Monitoring of Discharge Flow Rate and Total Stream Flow.

Date Sampled	Upstream Station Flow (gpm)	Downstream Station Flow (gpm)	Unnamed Tributary Flow (gpm)	Calculated Flow for Mine Drainage Discharges (gpm)	% of Total Stream Flow Due to Discharges	Downstream Fe Concentration (mg/l)
5/30/1996	3199	5768	105	2464	42.72	3.00
7/2/1996	1760	3473	0	1713	49.32	4.19
7/30/1996	1631	3187	105	1451	45.53	4.05
8/15/1996	217	1418	27	1174	82.79	7.81
9/25/1996	5513	7409	4	1892	25.54	2.92
11/20/1996	4946	8591	240	3405	39.63	2.76
12/5/1996	12370	18739	972	5397	28.80	1.65
1/30/1997	12586	16527	764	3177	19.22	1.50
2/21/1997	19837	23254	1380	2037	8.76	1.23
3/25/1997	3588	7050	306	3156	44.77	2.74
4/24/1997	2601	4786	185	2000	41.79	3.03

PROJECT IMPLEMENTATION CHALLENGES

Several challenges were quickly evident soon after the monitoring and evaluation program got underway. First, the sheer volume of the discharges (1,174 to 5,397 gpm) was going to make treatment with passive mine drainage technology very difficult. To construct treatment ponds with any significant detention time, many acres of land would be needed. Second, the location of the discharges was a problem. The Tanoma Borehole (C-7) discharged directly into Crooked

Creek at stream level. The 27-inch overflow boreholes (MP-1) as well as the C-6 borehole were also located close to the stream in an area with little land available for construction of a passive treatment system. Third, the active Lower Kittanning underground mining operation underlies a significant portion of the abandoned Lower Freeport workings, including essentially the entire flooded portion. Careful planning and coordination with the active Lower Kittanning underground mine operation was necessary. Finally, many homes in the area relied on private wells for their water supply, and manipulation of the mine pool would require careful analysis to ensure protection of these aquifers.

An extensive hydrogeologic study of the area was initiated in late 1996. All available mapping and historical mining information was compiled and evaluated. Site surveys were conducted. A comprehensive water quality and quantity monitoring program, including stream and discharge gaging, was conducted on a monthly basis. Several coordination and data exchange meetings occurred with the active underground mine operator, Tanoma Mining Company. The objective of the study was to evaluate the potential for relocating the primary discharge point of the mine pool to a point downstream where sufficient land was available for construction of a passive treatment system.

A critical element of this evaluation also included the protection of the aquifer located well above the mine that was being used for domestic water supplies. The Village of Tanoma and all nearby residences rely upon individual water supply systems. No public water supply system exists within the immediate vicinity. Springs and wells provide water for domestic use. Hydrologic information indicated that many of the wells produce inferior quality water with elevated metal concentrations. A number of wells have been developed in close proximity to the mine pool and are undoubtedly hydrologically connected to some degree. Clearly any significant change to the mine pool elevation has the potential to impact these wells. The study concluded that it would be technically feasible to relocate the discharges approximately 1,000 feet downstream to an abandoned 10-acre pasture for construction of the passive treatment system. The selected location would afford the construction of new boreholes into the mine complex and would provide the required artesian discharge into the treatment system without significantly changing the mine pool elevation. Figure 3 illustrates the acceptable range of mine pool elevations that the selected site needed to be capable of maintaining. An elevation of 1131 was chosen as the invert elevation for the new discharge boreholes.

A two-phase construction approach was selected. The first phase would be to drill new boreholes at the proposed treatment location with valves for control of the discharge. The new wells would be carefully constructed by casing and grouting the boreholes down to the elevation of the mine. This would ensure protection of the upper aquifer that was heavily relied upon by local residents as a source for their domestic water wells. Survey control and detailed mine mapping of the abandoned mine workings were provided by the active underground mine operator, Tanoma Mining Company. This aided the Department's efforts in precisely locating the new boreholes and resulted in encountering mine voids in all holes that were drilled. Once the wells were constructed and demonstrated to adequately redirect the discharges of the mine pool, the second phase of the project could be undertaken.

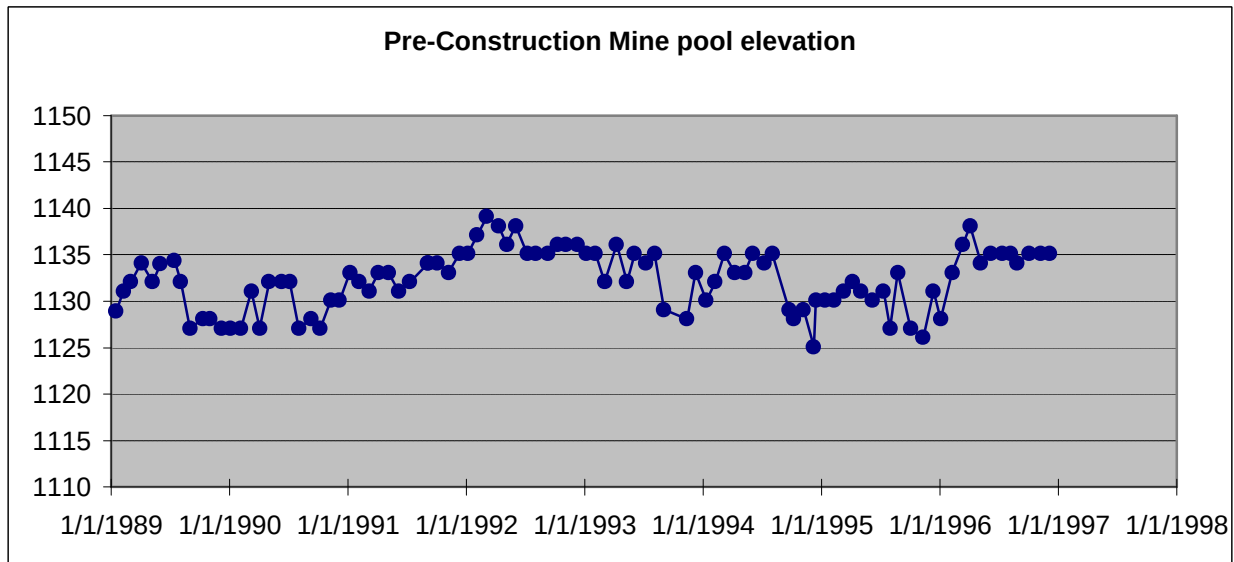


Figure 3 - Mine Pool Monitoring Data Collected Prior to Construction

The second phase included construction of passive mine drainage treatment facilities at the downstream site, opening of the valves on the new wells to redirect the mine pool discharge to the newly constructed treatment system, and finally, the sealing of the Tanoma Borehole (C-7) and the C-6 borehole. The 27-inch overflow boreholes (MP-1) would be left open to provide for monitoring of the mine pool and for mine pool discharge in the event that the pool would rise that high in the future.

A significant observation during the study involved the relationship of the volume of the mine drainage discharges to the in-stream iron concentration as measured downstream of the borehole locations. This relationship is illustrated in Figure 4. The periods when the discharge volume was the highest (winter and spring), the in-stream iron concentration was the lowest due to the normally high base flow in the stream. During the drier summer and fall months, the discharge volume dropped off, but the in-stream iron concentration rose to levels (> 1.5 mg/L total Fe) intolerable for most aquatic life. This was the result of low stream base flow relative to the mine drainage discharge volume. This relationship was key in determining the design criteria that would be used for the development of the final project plan.

Other design challenges developed at the newly selected treatment area. First, the property owner was unwilling to allow the construction of a treatment system on his property without compensation. The owner was willing, however, to sell the property to the Department or any other conservation group for the purpose of constructing the treatment system.

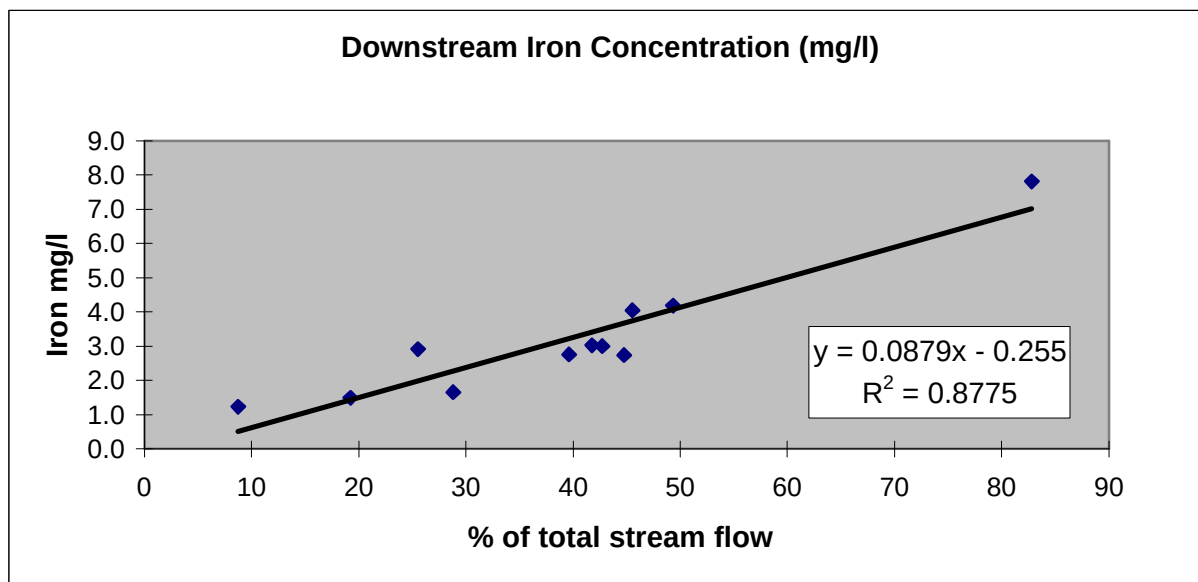


FIGURE 4 – Relationship of mine drainage discharge flow rate as a percentage of the total stream flow to the in-stream iron concentration.

The site also had a private water line and two gas well gathering lines that bisected the site. Coordination with the gas companies and water line owner needed to be completed such that these facilities would remain functional and accessible following construction of the treatment system.

PROJECT DESIGN APPROACH

Analysis of the mine drainage discharges consistently indicated that the mine water was net alkaline with a moderate to high concentration of dissolved iron. From a passive mine drainage treatment perspective, this is the easiest mine water to treat. The engineering difficulties at this site involved the complete relocation of the discharges and the need to treat from between 1.5 to 8.0 million gallons per day (MGD) of mine water. Even at the downstream location selected for treatment, less than 10 acres of land was available for construction of the system.

Using the inverse relationship of discharge flow rate to in-stream iron concentration discussed in the previous section, a decision was made to select a maximum design flow rate which would maintain a constant in-stream iron concentration of 1.5 mg/L or less. The hydrogeologic study determined that this equated to a maximum flow rate of 2,500 gpm or 3.6 MGD. A decision was also made to target the maximum iron concentration observed during the pre-design discharge monitoring of 22.4 mg/L.

The design of the passive treatment system was completed using the above design criteria. Due to the limitations of the proposed project site, including topography, utility lines, and proximity to the stream, a passive treatment system consisting of an approximate one acre settling pond followed by two multi-chambered aerobic wetlands was laid out. The system was designed to allow for the rapid aeration of the mine water and for the necessary detention to allow for the oxidation, hydrolysis and precipitation of the iron sludge. The two wetland

treatment cells total approximately 7.5 acres. Analysis of the on-site soils for engineering properties indicated that the material would be ideal for construction of the earthen pond embankments.

CONSTRUCTION SUMMARY

The relocation of the Tanoma discharges to the proposed downstream treatment area began with drilling of three new six-inch diameter wells in the summer of 1998. The wells were cased and pressure grouted down through the upper aquifer that was being used for several nearby residential water wells. A detailed groundwater monitoring program documented the pre and post construction conditions of the adjacent private water supplies. Pump tests of the new wells confirmed the hydrologic connection to the Tanoma mine pool. Monitoring of all nearby water supplies determined that they would not be impacted by the relocation of the deep mine discharge.

After the successful installation of the new discharge wells, the PA-DEP-BAMR began negotiations with the property owner for the subdivision and purchase of the property required for treatment. Approximately 10.1 acres was subdivided from a larger tract and sold to the Southern Alleghenies Conservancy (SAC), a local environmental stewardship group that agreed to take ownership of the property. The PA-DEP-BAMR funded this property acquisition with funds from the AMD 10% Set-Aside Program. The survey for the subdivision was completed in October 1999, and the sale of the property was finalized in the spring of 2000.

While the property was being secured, final design for the project including permitting, development of detailed plans and specifications, and the obtaining of construction easements from the gas companies, water line owner and SAC were being finalized. The project was let, and construction on the passive treatment system began on June 4, 2000. The contractor was Casselman Enterprises of Somerset, PA. Once the treatment facilities (settling pond and two aerobic wetlands) were constructed, a portion of the mine water was redirected from the new discharge boreholes via pipes with flow control valves into the newly completed treatment system. Finally, the Tanoma Borehole (C-7) and the C-6 borehole were permanently sealed thus beginning the restoration of a 3.5 mile reach of Crooked Creek. A final inspection for the project was held on December 8, 2000. The final project costs are as follows: installation of new discharge boreholes - \$19,783.50; property acquisition cost - \$38,000; sealing abandoned Tanoma boreholes - \$7,535; and construction of the passive treatment system - \$351,367.31. Figure 5 shows an aerial view of the completed project in October of 2000.

POST CONSTRUCTION MONITORING AND STREAM RESTORATION RESULTS

Flow into the completed treatment system was limited to approximately 200 gpm for the first six to eight months of operation to allow for the wetland plants to acclimate and to get established. On June 8, 2001, the valves controlling the influent were opened completely, allowing the full volume of the discharges to enter the treatment system. Figure 5 shows the inlet wells and the settling pond during January 2001. Since full-scale treatment began, the treatment system has experienced flows ranging from 77 gpm in December 2001 to 3,003 gpm in May 2002. Flows were lower than expected through the fall of 2001 and early winter of 2002 due to a general drought condition over much of Pennsylvania. The drought has since ended, and the influent flow rate has been at or above the expected flow rate since February of 2002.

The influent mine discharge has averaged 11.6 mg/L of iron, and the treatment system has removed an average of 68% of the total iron and converted 93% of the ferrous, or dissolved iron, to ferric iron. The treatment system has, on average, removed 2,689 lbs/month of iron, and has removed over 16 tons of iron since full-scale treatment began in June of 2001. Table 3 is a summary of the treatment performance of the Tanoma passive mine drainage treatment system.



FIGURE 5 – Aerial view of the completed Tanoma Mine Drainage Treatment System.

The most important result of the treatment system operation to date is that the in-stream iron concentration, as measured downstream of the effluent, has consistently been lower than 1.5 mg/L since full-scale operation of the system began in June 2001. This period includes the historically worst months (the summer and fall months) for water quality impacts from the Tanoma discharges. The highest measured in-stream iron concentration was 1.33 mg/L in May of 2002 and the lowest measured in-stream iron concentration was 0.158 mg/L in October of 2001. The target concentration selected during project planning and design was an in-stream iron concentration not to exceed 1.5 mg/L. Table 3 also shows a summary of the downstream monitoring of the total iron concentration.

Domestic water wells in the vicinity of the project have been monitored periodically since the completion of the project. The relocation and treatment of the Tanoma discharges has not had any negative impact on the quantity or quality of the water supplies.

TABLE 3 – Summary of flow and water quality monitoring at the treatment system to date.

MONTH	Influent Flow Rate (gpm)	Influent Total Fe (mg/L)	Effluent Total Fe (mg/L)	Downstream Total Fe (mg/L)	Total Fe Removal Rate (%)	Total Fe Removed (lbs/day)	Total Fe Removed (lbs/Month)	Total Influent Fe (lbs/Month)	Influent Ferrous Fe (mg/L)	Effluent Ferrous Fe (mg/L)
PRE-DESIGN	1174 - 5397	7.9 - 22.4	n/a	1.50 - 7.81	n/a	n/a	n/a	--	--	n/a
Jun-01	1792	12.5	1.47	0.750	88.2	237.6	7,127.5	8,077.4	12.50	0.28
Jul-01	1190	9.0	2.68	0.581	70.3	90.7	2,811.3	3,999.6	9.00	0.65
Aug-01	522	12.0	1.27	0.832	89.4	67.3	2,087.1	2,334.1	12.00	0.47
Sep-01	302	12.5	0.91	0.223	92.7	42.1	1,262.2	1,361.3	12.50	0.26
Oct-01	149	13.6	0.43	0.158	96.8	23.6	731.2	755.1	13.60	0.04
Nov-01	107	11.9	0.40	0.199	96.6	14.8	443.7	459.2	11.90	0.14
Dec-01	77	14.4	0.48	0.180	96.7	12.9	399.4	413.2	14.40	0.16
Jan-02	709	12.9	0.42	0.300	96.7	106.3	3,294.7	3,405.6	12.90	0.21
Feb-02	969	12.4	2.99	0.720	75.9	109.6	3,068.9	4,044.0	12.40	0.05
Mar-02	1702	9.7	4.95	1.170	49.0	97.2	2,720.9	5,556.4	9.70	2.91
Apr-02	3003	8.5	5.23	1.190	38.6	118.8	3,325.2	8,611.1	8.50	2.61
May-02	2724	9.43	3.98	1.330	57.8	178.4	4,996.5	8,645.3	9.43	1.33
Jun-02	2,029	6.89	3.79	1.080	45.0	75.6	2,116.9	4,705.0	6.20	0.56
Medians	969	12.00	1.47	0.720	88.2	90.7	2,720.9	3,999.6	12.00	0.28
Total pounds of iron (Fe) removed since full-scale treatment was initiated.							34,385.5			

The MP-1 boreholes have also been monitored since full-scale treatment began in early June 2001. Above normal precipitation during the spring of 2002 has resulted in discharges of untreated mine drainage from the MP-1 boreholes. In spite of this, instream iron concentration has remained below the target level of 1.5 mg/l. Surveys of the stream are showing that the water quality in the upper Crooked Creek is rapidly improving and the density and diversity of aquatic life is already recovering. Several species of fish have been observed in areas where the stream was nearly devoid of life only a short time ago. The stream bottom no longer has the brilliant orange coloration associated with the iron precipitates that smothered the life of many of the streams bottom dwellers. A macroinvertebrate survey of the stream was completed in late October 2001. The results are very positive and extremely encouraging. Upstream of the treatment system, 107 insects were collected representing 14 different taxa. Downstream of the treatment system 100 insects were collected representing 14 taxa. Thirty-three of the downstream insects collected belong to the pollution intolerant taxa of mayflies/cadisflies/stoneflies, which shows a dramatic improvement compared to the pre-construction sampling.

CONCLUSIONS

In conclusion, the Tanoma Borehole reclamation project and the documented restoration of 3.5 miles of the upper Crooked Creek watershed is a unique example of successful abandoned mine reclamation and creative problem solving that lead to the elimination of impacts from abandoned mines and resulted in a dramatic improvement to the environment. The project demonstrated that a discharge that was previously considered to be untreatable could be successfully relocated and treated while protecting and maintaining the quality of an uncontaminated groundwater aquifer. The project also demonstrated that an in-stream target concentration for contaminants could allow for less than 100% of the discharge to be treated. The project analysis and reclamation techniques used in the Tanoma South reclamation project can be duplicated at other mine drainage discharge sites once thought to be untreatable. Upper Crooked Creek, for the first time in nearly 100 years, has been restored to near pre-mining water quality and now supports fish and other aquatic life.

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RAPID-FLOW BIOLOGICAL WASTEWATER TREATMENT SYSTEM PILOT PROJECT (JEROME): RESEARCH PLAN

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ABSTRACT

Acid mine drainage (AMD) may provide a key component to increased efficiency in the treatment of municipal and feed-lot effluent streams. The addition of AMD to these waste-water streams would adjust the pH and Oxidation-Reduction Potential (ORP) of this effluent, resulting in a mixture optimized for an aggressive biological based treatment system.

This presentation describes a 30,000 gallon Pilot Project of an algae based, “rapid-flow wetlands” system designed to use AMD for this effluent adjustment. The presentation covers the theory, construction, operations, monitoring measurements, and the preliminary findings.

The Pilot Project was designed to investigate the efficiency increases predicted from; Using algae as an aggressive bio-mass, Adjusting effluent stream pH and ORP, Adjusting effluent stream Carbon:Nitrogen:Phosphate ratios, and Increasing influent / algae contact opportunity through rotational re-circulation

The Pilot Project was constructed from off-the-shelf components that may be found in any well stocked home supply store. The design provides a low cost, small footprint test environment that may be easily replicated. The Pilot Project occupies an area 60 by 40 feet and was built for less than \$20,000, including instrumentation and lab-trailer.

Monitoring measurements are accomplished via electronic metering (for pH, ORP, conductivity and temperature), photometry (for Nitrogen, Phosphate and Dissolved Oxygen) and Ultra-Violet (254nm) Absorption (for Carbon).

For reasons of monitoring and control, the Pilot Project was designed to operate in a batch, pumped mode. Design modifications will be presented that will allow this system to operate in a continuous, gravity driven mode.

Funding was provided, in part, through a grant from the U.S. Bureau of Reclamation, Science and Technologies Division. Location was provided the City of Jerome, Arizona. This area is known for abundant mine tailings and AMD discharge; the result of two centuries of extensive copper mining and 50 years of intensive copper smelting.

ACRONYM LIST

C	Carbon
C:N:P	Carbon: Nitrogen: Phosphorous Ratio
DOC	Dissolved Organic Carbon
Eh	ORP / REDOX measured on a different scale
FPS	Feet per Second
FT	Foot
GPM	Gallons Per Minute
IN	Inch
N	Nitrogen (NH ₃ , NO ₂ and NO ₃)
NH ₃	Ammonia
NO ₂	Nitrite
NO ₃	Nitrate
ORP	Oxidation / Reduction Potential
P	Phosphorous / Phosphate (PO ₄)
pH	Power of the concentration of Hydrogen Ions (Acid / Base)
PO ₄	Inorganic soluble phosphorus
REDOX	Oxidation / Reduction Reactions

OVERVIEW

Literature research on the prevailing biologically based wastewater treatment systems, such as constructed wetlands, indicates that there are substantial efficiency gains to be had by utilizing a more efficient nutrient removal process. A more efficient process would be characterized as one that;

1. Uses a biological process with a higher metabolism,
2. Increases water / biota contact probability, and
3. Adjusts influent constituents to the ratios most readily usable by the biology.

Increasing the efficiency of biologically based wastewater treatment systems would reduce the amount of land required while increasing the amount of water that the system could process. This would result in a lower cost-of-ownership for the owner / operator.

This Research Plan describes a Pilot Project that incorporates all of the characterizations described above. This system uses a combination of:

1. High metabolism periphyton (algae) based organic systems,
2. A method for increasing water / biota contact, and
3. A method for adjusting influent C:N:P and ORP / pH ratios.

The Pilot Project is to be located in Jerome, Arizona and will be built employing above ground construction utilizing readily available, low-cost materials

Should this Pilot Project be successful there are a number of transferable technology components that may be used on similar projects of the same or larger scale. A reasonable expectation is that these technologies could be used in:

1. Further Research
2. Waste Water Treatment
3. Feed Lot Effluent Treatment
4. Acid Mine Drainage Treatment

BACKGROUND

Periphyton (algae) based biological wastewater treatment systems are outside the norms when compared to traditional constructed wetland. Traditional constructed wetlands rely heavily on long term contact of the water with biological processes that occur in and around large life forms such as cattails and bulrushes. This greatly restricts the surface area contact of the water with the biota and hence constricts the efficiency of the wetlands. Periphyton is comprised of large colonies of small life forms, many of which are microscopic in nature. Thus the surface contact ratio in a periphyton based biological systems are substantially higher than in a traditional constructed wetlands. This can lower treatment costs and increase efficiency by lowering detention times and increasing flows. Periphyton contact efficiency can be further enhanced by the use of circular growth containers, known as Mesocosms. The Mesocosm design to be used in the Pilot Project can best be described as a re-circulating basin where water velocity is approximately 1 FPS. Thus these Mesocosms will more closely model a quick running stream as opposed to a slow moving marshland. The use of quick running water eliminates the mosquito issues associated with conventional constructed wetlands

The use and action of periphyton in influent nutrient and heavy-metal removal is well documented [6, 7, 8, 9, 10, 11, 12]. In short, periphyton exhibits a prodigious ability to remove these water constituents due to its high metabolism rate and short doubling times. There have been a number of periphyton-based “commercial” systems made available, but all of these systems have shortcomings that restrict their usage. Research shows that periphyton grow, and hence remove nutrients, best in a high ORP, low pH environment [1, 2]. In all cases studied, the ORP / pH of the native water (and hence the influent) is substantially skewed from the optimum growth area. Research also shows that the ability of periphyton to remove nutrients is limited, to a large extent, by the amount of available Carbon in the water. Further limitation is exerted by the ratio of Carbon, Nitrogen and Phosphorus (C:N:P), with the most ideal ratio being defined by the Redfield Ratio [13]. We believe that by modifying the influent pH, ORP and C:N:P content to match the optimum growth range will improve the nutrient uptake and therefore increase the efficiency of the process. The periphyton’s nutrient removal process will reduce the ORP and C:N:P content of the water while raising the pH. Figure 1 (appendix) shows the relationship between ORP / pH and biological reactions.

OBJECTIVES

1. To study the effects of pH / ORP and C:N:P modified influent on periphyton growth and nutrient uptake in respect to detention time.
2. To identify materials best suited for their ability to modify ORP / pH and C:N:P ratios.
3. To study the effects of varied re-circulation rates across the periphyton on growth and nutrient uptake.
4. To engineer systems and sub-component that facilitate the removal and handling of wetlands by-products, such as organic debris, in a manner that maintains biota growth at near optimal point.

DESIGN

COMPONENTS

The Pilot Project will contain the following sub-components:

- o A Holding Tank
- o A Mixing Tank
- o An initial Mesocosm (Mesocosm #1) for high ORP / low pH environment
- o A second Mesocosm (Mesocosm #2) for low ORP / high pH environment
- o Support Plumbing

Please refer to the Pilot Project Schematic in the appendix.

A Mesocosm is a term that describes one type of microcosm that is primarily used to test aquatic organisms inside of an enclosed system. Mesocosms are a model ecosystem, which is used to miniaturize and replicate the real thing. Mesocosms are used because they allow ecosystem replication and manipulation. The Mesocosm provides sufficient area for observations, sampling, and housing of a large variety and quantity of species. Mesocosms also provide sufficient size as to model the real ecosystem. Mesocosms can either use artificial or natural waters for studying.

DESIGN THEORY

The Holding Tank supplies system ballast. This tank needs to be as large as possible in relation to the volume of the Mesocosms. The Mixing Tank allows for C:N:P and ORP/pH modification. The identification of materials to provide this modification is one of the objectives of the Pilot Project. Initial findings indicate that Acid Mine Drainage may be a highly suitable material for ORP and pH adjustment. The design of the Mixing Tank must allow for sufficient flexibility in material addition and modification. It is possible that waters may be found that are problematic in only one constituent such as N. In this case the scope of the influent adjustment must also insure that water constituents such as C, N and P are in a balance that is usable by the biological environment (Redfield Ratio). It was decided that a partitioned tank would allow for the maximum flexibility. The partition will form a “clean” and a “mix” section separated by an underflow baffle. The “mix” side will be filled with material selected to accomplish the ORP, pH, C:N:P modification.

The Mesocosms provide the growing environment for the periphyton. Research indicates that nutrient uptake will be facilitated by separating the two basic biological processes: the high metabolism, high ORP / low pH environment most suited to NO₃, P and Heavy Metal removal; and the low metabolism, low ORP / high pH environment most suited to Nitrification / Denitrification. The high ORP / low pH environment is usually found in quick-running stream structures and the low ORP / high pH environment is usually found in pond like structures. Because of this a two Mesocosm system was selected. The Mesocosms will be formed as circular tanks. The first Mesocosm (Mesocosm #1) will be designed to resemble a small, fast flowing stream. This will be accomplished by building an island in the center of the Mesocosm. The second Mesocosm (Mesocosm #2) will be designed to resemble a small lake bottom. The metabolic process of periphyton lowers OPR and raises pH. Thus the biological process in Mesocosm #1 prepares the water for Mesocosm #2.

The Support Plumbing provides all the pumps and pipes necessary to circulate and re-circulate water as needed within the Pilot Project. The Support Plumbing must provide the following functionality:

1. It must provide the initial System Flow.
2. It must provide Mesocosm #1 re-circulation.

S Y S T E M F L O W

System Flow is defined as the basic flow through the system. System Flow represents the “new” water being added to the process. Thus System Flow to a great extent defines detention time. The targeted upper limit to System Flow is 55 gpm. It is desired that flow from tank to tank be gravity driven. Therefore the hydraulic connections between the Holding, Mixing, and Mesocosm Tanks will be formed using a series of “stair-step” weirs between these tanks to allow for flow based on an elevated water level in the upstream tank. System Flow is initiated by pumping water from the last Mesocosm (Mesocosm #2) to the Holding Tank. This will provide the initial elevation necessary to flow water through the Pilot Project. There is an additional requirement that there be a great deal of flexibility in the direction of the flow pumped from the final Mesocosm. For this reason a valve manifold will be required such that this flow can be directed, in proportion, to any of the tanks within the Pilot Project. The System Pump will be a constant speed pump. To allow for System Flow to be reduced below the 55 gpm provided by the System Pump, pipe and valves would be needed to feed a portion of the pump output back into the input of the pump. Additionally there is the requirement that the piping support a backwash operation.

MESOCOSM #1 RE-CIRCULATION FLOW

Mesocosm #1 re-circulation flow will be accomplished by pumping water from Mesocosm #1 back into the Mesocosm through a set of 4 hydro-jets spaced equidistant around the bottom of the flow channel. As with the System pump, the Mesocosm #1 re-circulation pump is a constant speed pump. Therefore it will require the same flow reduction valves described in the System Flow section. This pump will also support back flush.

VARIABLES

Management of system variables will be key to the success of the Pilot Project. The following are the identified variables and what may be done to influence them:

ORP/pH	-	proportional adjustment of System Flow
C:N:P	-	proportional adjustment of System Flow
M1 Recirculation	-	proportional adjustment of recirculation at pump
M1 Detention	-	proportional adjustment of System Flow
M2 Detention	-	proportional adjustment of recirculation to M2
Periphyton Density	-	harvesting

MESOCOSM DESIGN

The size of the Mesocosms was dictated by the area available to the Pilot Project. This area is approximately 60 X 40 feet. This allows the use of 30 ft pools as Mesocosms.

Mesocosm #1 will be a 30 ft pool with a 15 ft. island in the center. The island is to be built using used tires and aggregate filled. This results in a 7.5 ft. circular flume with a mean diameter of 11.25 ft and a circumference of (apx) 35 ft. This flume will be filled with .5 ft aggregate and 2.5 ft. water. Discounting the water in the aggregate, this channel holds (apx) 7,900 gal. The current targeted System Flow is 55 gpm. This gives a basic detention time of (apx) 142 minutes. The targeted recirculation is 1 FPS, which results in a rotational period of (apx) 35 seconds, or (apx) .6 minutes (for mean circumference). Correlating the rotational period with the detention time gives (apx) 237 rotations per detention period. The combination of detention period and recirculation results in the equivalent of a "river" 8,295 ft. or 1.6 miles in length. This circular flume will be populated with the epiphyton (plant) forms of periphyton. Epiphyton resemble seaweed and long grasses. The re-circulating water will flow through this periphyton mass. The ratio of periphyton mass to water volume is unknown at this time. As the periphyton mass will reduce the water volume, the final straight-flume equivalent will be somewhat less than the idealized numbers.

The first Mesocosm (Mesocosm #1) will contain a high ORP / low pH environment most conducive to epiphyton (plant) type growth. It is expected that much of the P removal will occur in Mesocosm #1, as well as substantial heavy-metal removal.

The diameter of the Mesocosm #2 will be the same as that of Mesocosm #1. However, the contour of Mesocosm #2 will be quite different than that of Mesocosm #1. Where Mesocosm #1 took the form of a stream like flume, Mesocosm #2 will be more pond like in nature. The pond like structure is required because the periphyton mass in Mesocosm #2 will be of the epilithon (rock) and epileton (mud) forms. These are low metabolism life forms. The bottom of Mesocosm #2 will be concave in shape and built of aggregate material. The aggregate material will provide ample surface area for the periphyton to colonize. This results in a detention volume of (apx) 8,908 gallons in Mesocosm #2. System Water flow within Mesocosm #2 will be drawn through the aggregate by the System Pump insuring maximum contact with the biota. Additionally there will be provisions within the System Pump and Piping to re-circulate water back to Mesocosm #2 to increase detention time.

The second Mesocosm (Mesocosm #2) will contain a low ORP / high pH environment most conducive to epileton (mud) type growth. It is expected that much of the Nitrification / Denitrification process will occur in Mesocosm #2. While the Nitrification / Denitrification process is normally described as an anaerobic (absence of Oxygen) process, this is not 100% descriptive of the required environment. A better term would be anoxic (low Oxygen). This anoxic environment is established at an ORP level of 200 or less [1].

Because of the re-circulating nature of the water in the Mesocosms, there should be an inherent efficiency over linear flows due to the constant rate of the re-circulating flow within the Mesocosm versus the varied rate of linear flow in non-pressurized channels. Additionally a re-circulating flow has the advantages of longer contact time and greater contact probability with the periphyton. In linear flow systems the constituents are substantially higher at the beginning of the flow, with periphyton population falling off as flow progresses through the linear system. To accomplish the re-circulation, the Pilot Project will include pumps in order add velocity to the re-circulating flows. This is necessary due to the small gravity gradient of the Pilot Project. In projects where a larger

gravity gradient exists, it may be possible to accomplish this re-circulation through flow channeling.

CONSTRUCTION

In general, the Pilot Project will closely resemble a collection of “Above Ground” swimming pools. The Pilot Project will be built above ground. The Pilot Project will be constructed in a manner that meets or exceeds those materials and methods used in commercial “Above Ground” swimming pools. The walls of the tanks will be fabricated by riveting 4 x 10 ft sheets of 26 gauge sheet metal to form the exterior wall. A 6 in. “cove wall” will be formed at the base of the wall. The tanks and Mesocosms will be double lined with 20 mil PVC liner due to nature of the water they contain. The top and bottom of the walls will be fitted with channel rails to increase rigidity. All tanks will allow for 1 ft of head space above nominal water levels. All tanks will be fitted with over-level floats for pump shutdown. The Holding, Mixing, Mesocosm #1, and Mesocosm #2 tanks will be connected by weirs formed from key-stone cuts made in the sheet-metal to form the stair-step weirs. These cuts will be riveted together and made watertight. The stair-step increment is to be 1 in. Thus the nominal water level of Mesocosm #2 is three (3) inches below the nominal water level of the Holding Tank.

TANKS AND MESOCOSMS

The Holding and Mixing Tanks will be lumber framed and will be covered. The lumber framing will support the walls of these tanks and the cover. The cover will reduce evaporation from these tanks.

The Mixing Tank will be constructed in two sections, separated by an underflow baffle. The baffle will separate the Mixing Tank into two segments; a “clean” segment and a “mixing” segment. Four lengths of 4 in perforated pipe will run from the underflow baffle across the bottom of the “mix” side of this tank. Water elevation differential between the “clean” and “mix” side of the underflow baffle will cause the water to flow up through and come in contact with the material in the Mixing Tank.

The Mesocosms walls will be supported by 16 pieces of $\frac{3}{4}$ in rebar equally spaced around the circumference of the Mesocosms and set 1 ft in the ground. This rebar will be attached to the sheet metal wall. The island in Mesocosm #1 will be formed from used tires and filled with aggregate. A 2 in perforated pipe will be embedded in the island to provide input to the re-circulation pump. Perforated pipe will be embedded in the aggregate bed of Mesocosm #2 to provide input to the System Pump.

The Mesocosms will be filled with aggregate to form the flow channels and provide a substrate upon which the periphyton will grow. Once the Mesocosms have been built and the aggregate installed, flow studies will be performed that will identify areas where the flow is problematic. Aggregate will be moved as necessary to insure that inter and intra-Mesocosm flows are behaving in a desired manner. Once the flow observations and corrections have been performed the Mesocosms will be populated with the initial periphyton colony.

The initial periphyton population will be undifferentiated as to species. It is expected that as the periphyton colony in Mesocosm #1 becomes established it will adjust

the ORP and pH of the water flowing into Mesocosm #2. This in turn will cause the periphyton colony in Mesocosm #2 to become predominated by species adapted to that environment. Thus as the Pilot Project runs the periphyton colonies in the two Mesocosms will become more and more differentiated until only those species most suited for these two environments will predominate.

PUMPS AND PIPES

System Plumbing is comprised of two (2) pumping and plumbing sub-systems. The sub-systems are:

- System Pump and Pipe

- Recirculation Pump and Pipe

The action of the System Pump and Pipe will be to draw water from Mesocosm #2, which will be the basis of system flow. Influent to the System Pump will be from a field of perforated pipe buried within the aggregate in Mesocosm #2. Effluent from the System Pump will be primarily directed to the Holding Tank, however there will be valving to allow the effluent of the System pump to be directed to the Mixing Tank, Mesocosm #1 and / or Mesocosm #2 in a flow proportional mode. This will allow for fine-tuning system flow rates, and thus detention times. Additionally, the valving will allow for back flushing the perforated pipe.

The action of the Recirculation Pump and Pipe will be to draw water from Mesocosm #1 and reintroduce that water via jets into the Flow Channel area of Mesocosm #1. Influent to the Recirculation pump will be from a perforated pipe buried within the island of Mesocosm #1. Effluent from the Recirculation Pump will be primarily to the Recirculation Jets within Mesocosm #1, however there will be valving to allow effluent of the Recirculation Pump to be returned to the influent side of the Recirculation Pump to allow for recirculation rate adjustment. Additionally, the valving will allow for back flushing the perforated pipe.

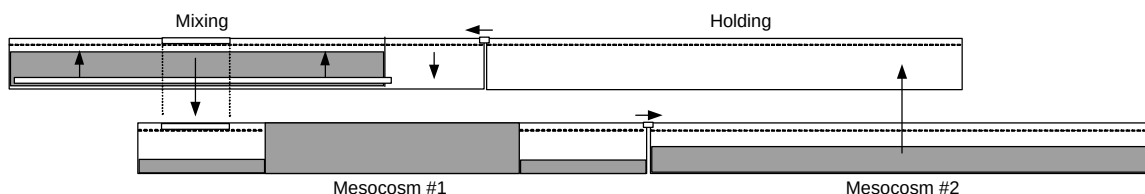
All pipes in the Pilot Project will be 2 in, schedule 40 PVC.

All pumps used in the Pilot Project will be off-the-shelf swimming pool pumps rated at 55 GPM.

METHODOLOGY

OPERATIONS

Drawing #1 illustrates the process flow of the Pilot Project.

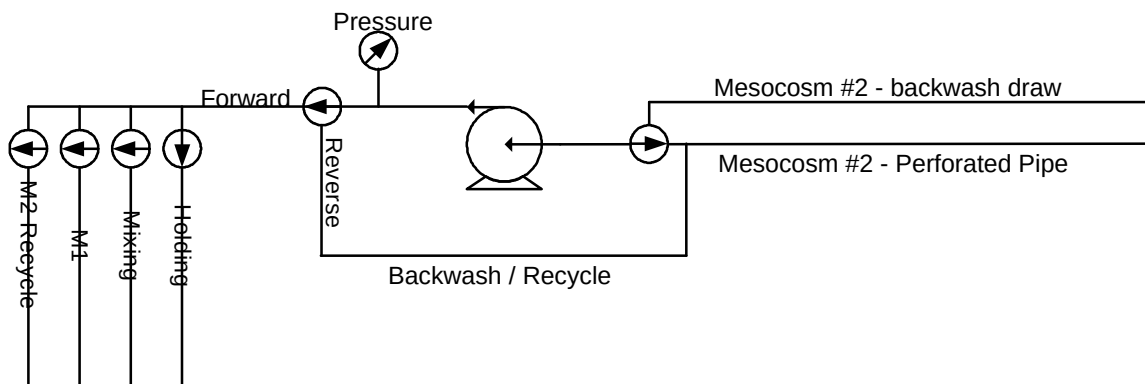


Drawing #1

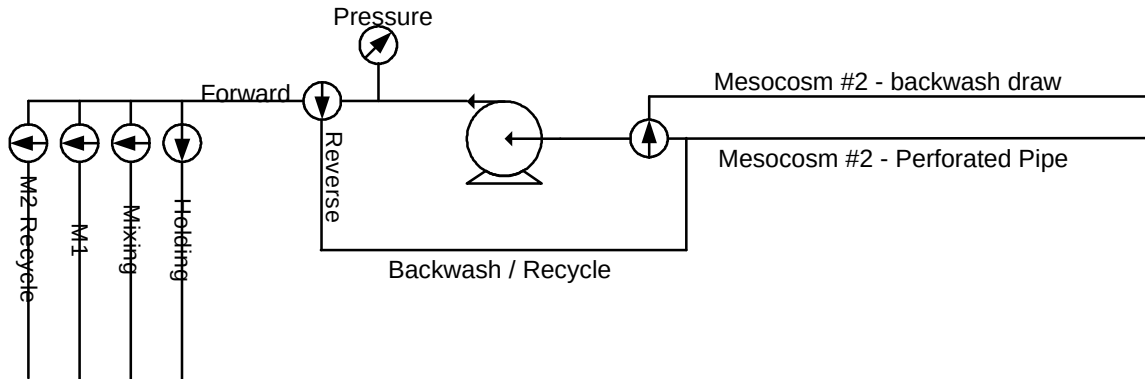
- o System Water is held in the Holding Tank. System Water will be pumped from Mesocosm #2 back to the Holding Tank, creating the basic system flow.
- o System Water gravity flows over a weir into the Mixing Tank based on an increased water level in the Holding Tank.
- o System Water flows up through the adjustment material in the Mixing Tank based on water level equalization between areas separated by the under-flow baffle.
- o System Water gravity flows into the first Mesocosm over a weir based on increased water level in the Mixing Tank. System Water re-circulates within the Mesocosm at a velocity of approximately 1 FPS, and is acted upon by the first colony of periphyton. The detention time in the first Mesocosm is dictated by the System Water flow rates and size of the Mesocosm. Detention time will be modified to insure that effluent from the Mesocosm shows an appropriate elevation in pH with a corresponding decrease in ORP.
- o System Water gravity flows into the second Mesocosm, over a weir based on increased water level in Mesocosm #1. System Water circulates and is drawn down through a rock bed by the action of the System Pump. Within the rock bed, the System Water is acted upon as in the first Mesocosm. The periphyton in the second Mesocosm will be of a different species set than that of the first Mesocosm. The species set of the second Mesocosm will be those more suited to the lower ORP and higher pH environment found there.

ACTIONS

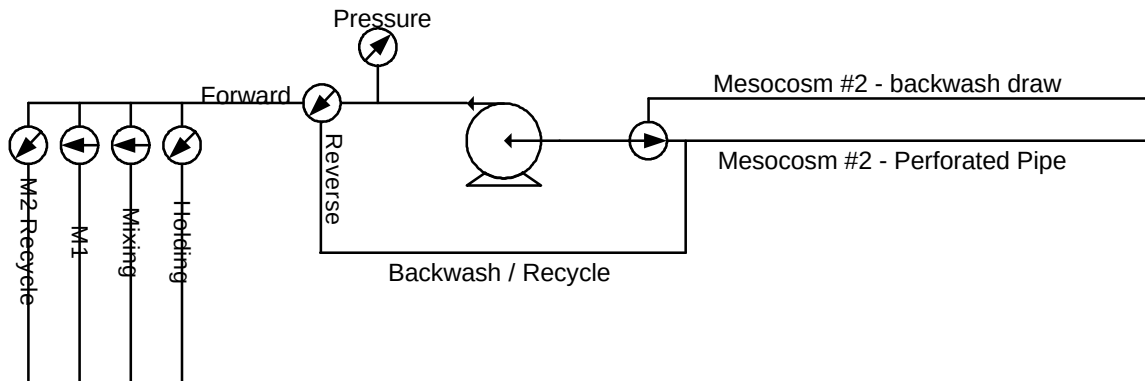
Much of the controlling actions that can be placed on the Pilot Project will be done by valve position modification on the System Pump Valve Manifold. The following diagrams show three of the many valve position setting.



The first configuration shows a “normal” operations mode. In this configuration the System Pump input valve selection is to the perforated pipe in the Mesocosm #2 aggregate bed. The Backwash / Recycle valve selection in the 100% Forward position. The Holding Tank valve is 100% open. In this configuration the System Flow is as specified in the Operations section, above.



In the second configuration, we see the valve position settings for a backwash operation. In this configuration the System Pump input valve selection is to the backwash draw located outside the aggregate bed. The Backwash / Recycle valve selection is in the 100% Reverse position.



In the third configuration, we see one of the many operating modes supported by this valve layout. In this configuration the System Pump input valve selection is to the perforated pipe in the Mesocosm #2 aggregate bed. The Backwash / Recycle valve selection is set to 50% Recycle. This reduces flow to about 27 GPM. The Holding Tank and the Mesocosm #2 Recycle valves are set to 50%. This directs about 14 GPM back to Mesocosm #2 (increasing detention time) and 14 GPM being sent to the Holding Tank. In configurations such as these special attention is made to the pump pressure to insure that it is under 10 psi. Pump and valve configuration changes will be noted on the Data Logging Form, figure 2, appendix.

MONITORING PROGRAM

The Pilot Project requires a significant monitoring process. During the operation of the Pilot Project, the following water constituents will be monitored;

What	via
1. Nitrogen (NH ₃ , NO ₂ , NO ₃)	Photometry
2. Phosphorous (PO ₄)	Photometry
3. Dissolved Oxygen (DO)	Photometry

4. Oxidation – Reduction Potential (ORP)	Meter
5. Acidity – Alkalinity (pH)	Meter
6. Temperature (Temp)	Meter
7. Conductivity (uS)	Meter
8. Carbon (C)	254nm UVAS

Where

1. Influent to Holding Tank
2. Influent to Mixing Tank
3. Influent to Mesocosm #1
4. Influent to Mesocosm #2

All constituents will be reported in standard units of measure [3]. All constituents will be sampled for all tank input points.

All measurements will be taken daily at the solar noon, rounded to the nearest 10 minutes. All measurements and valve modification will be recorded on the form shown as Figure 2 (appendix).

INSTRUMENTATION

ORP, pH, Temperature and Conductivity measurements will be taken using an Enviroequip WP80 or equivalent [4]. Organic Carbon will be measured using a Beckman UV 254nm Absorption Spectrometer, or equivalent [14]. All other measurements will be taken using an Orbeco Analytical Systems, Inc Model 975 MP or equivalent [5].

It is hoped that as the Pilot Project progresses, that over time the instrumentation can be augmented to include automatic sampling and data logging. It is anticipated that the cost would greatly increase, but also greatly enhance the ability for trend analysis.

DATA MANAGEMENT/PUBLISHING

Data gathered on the sample forms will be screened for outlier data and input to a Microsoft Access Database. Data will be correlated to detention time, summarized weekly and uploaded to an Internet site. A final status report will be published at the conclusion of the Pilot Project. One of the goals of the final status report will focus on what worked, what did not work and how best to implement the lessons learned. The status report will be published in conjunction with the Town of Jerome and U.S. Bureau of Reclamation.

PARTS LIST PRICES

Material	Size	Quantity	Units	Unit Cost	Extended Cost	Shipping	Tax	Sub-Total	Sub-Totals
Liners									
Liner (20 mil)	30' Round (20 mil)	4	ea	\$289.00	\$1,156.00	\$14.00	\$104.04	\$1,274.04	
Liner (20 mil)	12' x 28' Oval (20 mil)	4	ea	\$159.00	\$636.00	\$14.00	\$57.24	\$707.24	\$1,981.28
Fabrication Materials									
Sheetmetal	26 ga - pre-fab 3 x 10	36	ea	\$25.08	\$902.88		\$81.26	\$984.14	
Steel Rebar	1/2 inch #4 20'	40	ea	\$3.29	\$131.60		\$11.84	\$143.44	
Lumber - plywood	8 x 10 x 3/4 cdx	60	sheets	\$25.99	\$1,559.40		\$140.35	\$1,699.75	
Lumber - #2	2x4x10	80	ea	\$4.05	\$324.00		\$29.16	\$353.16	\$3,180.49
Aggregates									
1" - 3" Local Rock (50/50)		24	tons	\$12.50	\$300.00	\$150.00	\$27.00	\$477.00	
.5 - .75 Salr River Rock (50/50)		48	tons	\$28.35	\$1,360.80	\$300.00	\$122.47	\$1,783.27	
Bedding Sand		8	tons	\$7.00	\$56.00	\$50.00	\$5.04	\$111.04	\$2,371.31
Wire, Pumps, Pipe, Connectors and Valves									
pumps	10-10KNH1 (2 hp)	3	ea	\$499.99	\$1,499.97	\$64.00	\$135.00	\$1,698.97	
ozone generator	Model OZ500	1	ea	\$329.00	\$329.00		\$29.61	\$358.61	
Wire	12/3 DB	1000	ft	\$0.23	\$230.00		\$20.70	\$250.70	
Electric boxes	4 circuit	1	ea	\$30.88	\$30.88		\$2.78	\$33.66	
EMT		100	ft	\$0.17	\$17.00		\$1.53	\$18.53	
Pipe - sch 40	2 inch X 20'	250	ea	\$10.80	\$2,700.00		\$243.00	\$2,943.00	
Pipe fittings - barrel - 90 - T	2 inch	120	ea	\$1.50	\$180.00		\$16.20	\$196.20	
Pipe -perph	4 inch X 10'	6	ea	\$5.90	\$35.40		\$3.19	\$38.59	
Vavles 3-port	2 inch	10	ea	\$26.00	\$260.00		\$23.40	\$283.40	
Fence	75 x 50	250	ft	\$3.80	\$950.00		\$85.50	\$1,035.50	\$6,857.15
Lab									
Orbeco Analytical Systems	Model 975 MP	1	ea	\$1,000.00	\$1,000.00		\$90.00	\$1,090.00	
uv 254 Spectrophotometer	unk	1	ea	\$1,700.00	\$1,700.00		\$153.00	\$1,853.00	
ORP / pH meter	ORPH-7	1	ea	\$500.00	\$500.00		\$45.00	\$545.00	
Lab trailer	unk	1	ea	\$1,300.00	\$1,300.00		\$117.00	\$1,417.00	
Misc lab supplies					\$400.00		\$36.00	\$436.00	\$5,341.00
Misc									
Misc screws and fastners					\$600.00		\$54.00	\$654.00	
Tool Rental					\$350.00		\$31.50	\$381.50	\$1,035.50
Total									
						\$592.00	\$1,665.80	\$20,766.73	

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ANALYSIS - UV Absorbance (254 nm) to DOC Regression Equations
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Appendix A. Figures and Data Sheets

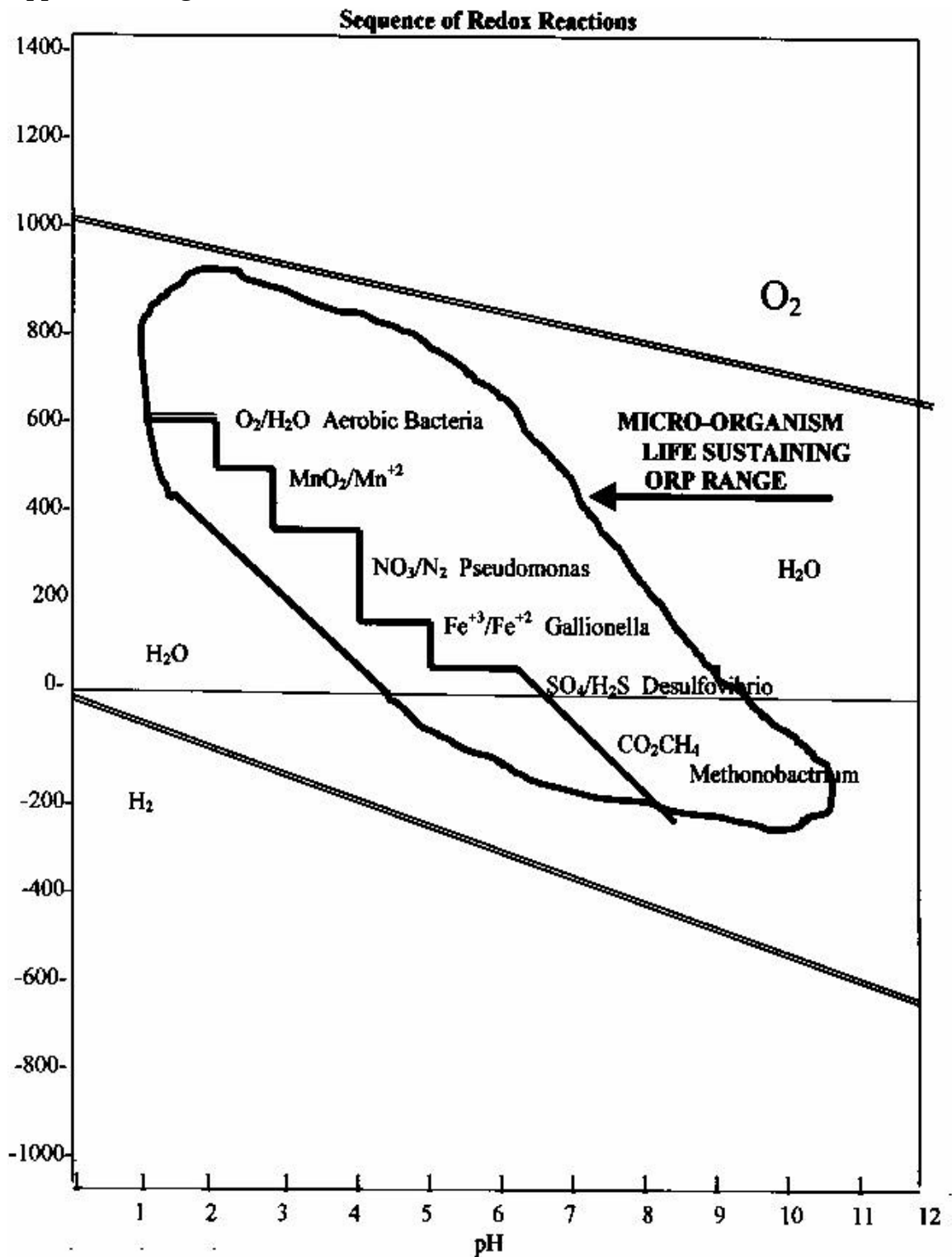


Figure 1 - ORP (eh) v. pH and biological reaction zones

Date:		
Solar Noon		
Weather		
Influent to Holding Tank		
NH3	NO2	NO3
PO4	DO	
ORP	pH	Temp
uS		C
Influent to Mixing Tank		
NH3	NO2	NO3
PO4	DO	
ORP	pH	Temp
uS		C
Influent to Mesocosm #1		
NH3	NO2	NO3
PO4	DO	
ORP	pH	Temp
uS		C
Influent to Mesocosm #2		
NH3	NO2	NO3
PO4	DO	
ORP	pH	Temp
uS		C
Notes:		

Figure 2 - Sample Data Logging Form

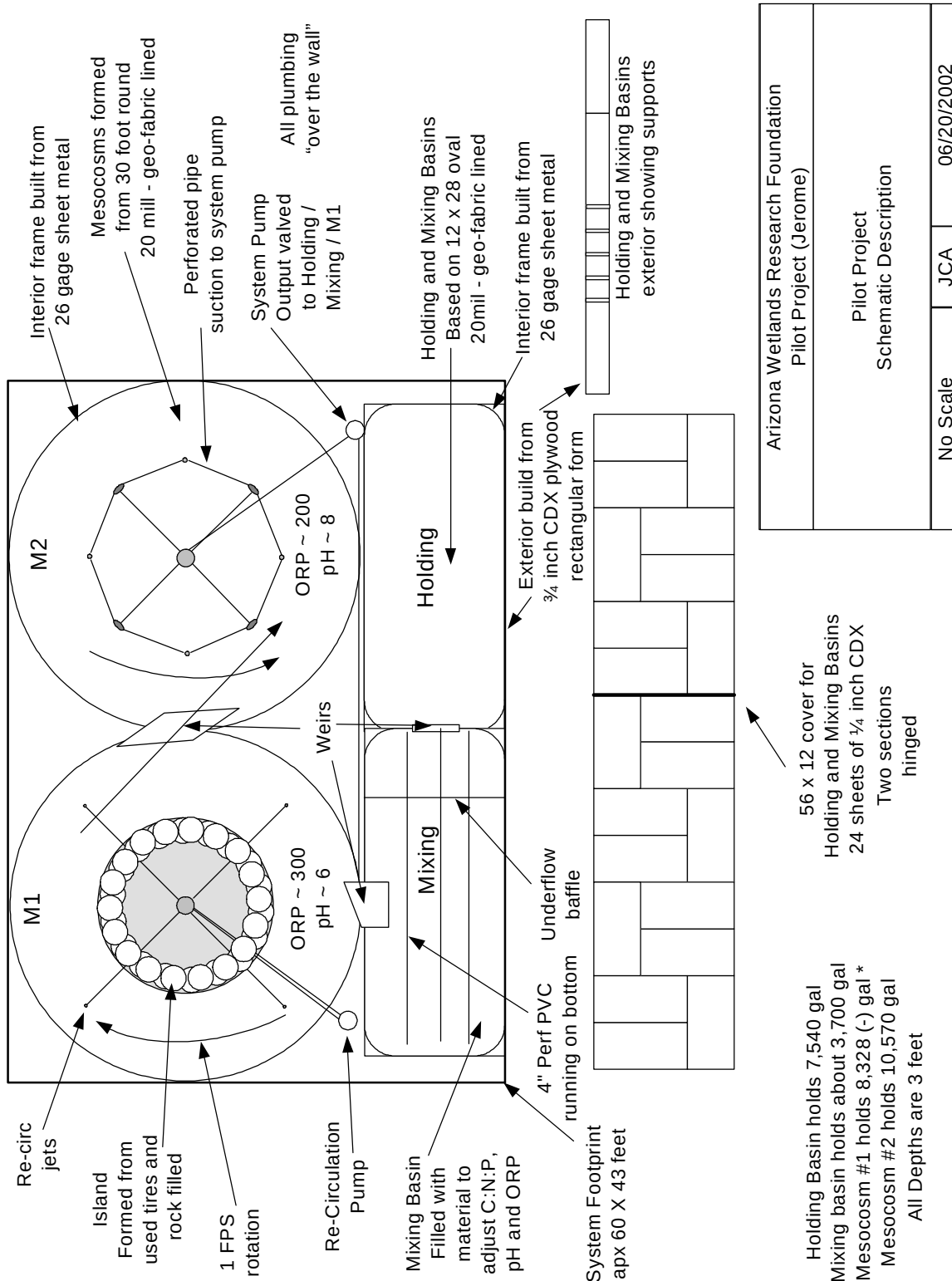


Figure 3 - Pilot Project Diagram

SPENCEVILLE MINE CLOSURE

Daniel Wanket, GEI Consultants, Inc.

Alberto Pujol, P.E., G.E., GEI Consultants, Inc.

William J. Walker, Ph.D., Walker & Associates, Inc.

Stephen Reynolds, R.G., California Department of Conservation
Division of Mines and Geology

ABSTRACT

Spenceville Mine is an abandoned copper mine located in the Sierra Nevada foothills of California. The mine was operated intermittently from the 1880's until 1918. The site was covered with mine tailings and overburden materials. In addition, the central portion of the site was occupied by a flooded open pit, which contained approximately 6 million gallons of acidic water with a pH averaging 2.5. The U.S Army owned the site from 1941 to 1962, at which time it was transferred to the California Department of Fish and Game (DFG) with the creation of the Spenceville Wildlife Refuge.

In 2000 the DFG developed a mine closure plan that addressed the following: (1) closure objectives; (2) geochemical and geotechnical characterization of the water and mine waste; (3) alternative remedial approaches for treating the mine water, disposing of the mine waste, and filling the pit; (4) evaluation of options in terms of technical and economic feasibility, regulatory compliance and environmental impacts; (5) preliminary designs and detailed costs estimates for two closure options; and (6) selection of a preferred closure plan based on how well each option met the closure objectives.

The closure plan was approved by the regulatory agencies in early 2001, and mine closure activities began in April 2001. In subsequent months a water treatment plant was constructed and used to treat the pit water. The treated water was then applied to land in the vicinity of the site. The mine waste was excavated, treated with lime, and placed in the dewatered pit. A layer of borrow soil was placed as cover over the entire site, and a mine impacted stream was restored to its original channel. In addition to these tasks, closure activities had to address the potential for unexploded ordnances, reclamation of shafts and tunnels in the dewatered pit, and documentation of cultural resources.

As of early 2002, site revegetation, erosion protection, water quality monitoring, and preparation of final reports are ongoing.

INTRODUCTION

Site Location

The Spenceville Mine site is located within the California Department of Fish and Game's (DFG) Spenceville Wildlife Refuge in the foothills of the Sierra Nevada Mountain range, about 20 miles southwest of Grass Valley, in Nevada County, California. The mine site is east of Beale Air Force Base.

Site History

Opened in 1863, the mine operated as the Well Lode Copper Mine from 1863 through 1865 and closed shortly after the Civil War ended. In 1872 Mr. Robert Skinner bought the claim for the San Francisco Mining Company and made \$15,000 worth of upgrades. In 1877 Mr. Skinner purchased the Grass Valley Copper Mines that butted up to the western margin of the San Francisco Mining Company's claim and shared the ore body. This purchase required \$100,000 in upgrades and the mines became the San Francisco Copper Mine and Reduction Works. In August of 1880 a head frame toppled into a vertical shaft. No fatalities occurred but the cost of clearing the shaft was extensive; in December of that year preparation began to operate as an open cut. Eight years later the mine closed. From 1888 through 1897 the Imperial Paint Company and Copper Works leached the tailings for copper cement and also used them as a pigment in the manufacture of Spenceville

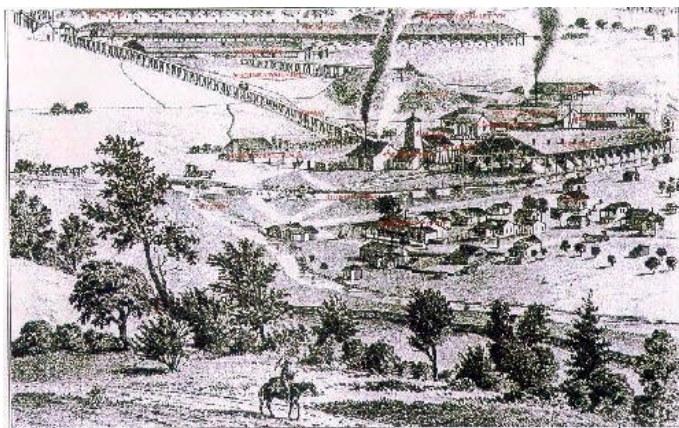


Figure 1 - Spenceville Mine circa 1880

Red/Venetian Red paint. The paint, enormously popular to begin with (Gold Medal in SF 1894 Winter Exposition) ended in infamy sometime around 1896/97 when it was discovered that the paint corroded structural nails and barns were beginning to collapse. In 1897 the Spence Mineral Company purchased the mine proper to manufacture sulfuric acid. Between 1915 and 1917 a fire razed the mine properties and all work there ceased for good. An artist's rendition of the Spenceville Mine circa the 1880's is shown in Figure 1.

The mine site has been abandoned since about 1918. The town of Spenceville, east of the mine site, continued to survive on agriculture up to 1941, when the military acquired the property and used the site as a training ground. The town was made into a mock German town where Army recruits trained in preparation for combat duty in Europe. In 1962 the Spenceville Wildlife Refuge was created via a land transfer to the DFG. The Spenceville Mine site and old town of Spenceville are within the Spenceville Wildlife Refuge boundaries. In April 1987, the California Regional Water Quality Control Board (RWQCB), Central Valley Region, asserted regulatory jurisdiction over the site by notifying DFG that the mine was regulated under the Toxic Pits Cleanup Act (TPCA) of 1984. TPCA required that all surface impoundments containing hazardous wastes be closed or modified so they were no longer hazards.

Site Description

The Spenceville Mine site area encompasses approximately 10 acres bounded on the east and south by Little Dry Creek and Dry Creek, respectively. The mine site is located at altitudes ranging from 300 to 500 feet. In the central portion of the mine site was a lake created in a flooded open pit (Photo 1). The lake contained approximately 6 million gallons of acidic water (pH ~ 2.5). The pool's



Photo 1 - Spenceville Mine pit

surface area was approximately one-half acre, and the maximum depth of the lake was about 60 to 70 feet. Surrounding the pit on the west and north were piles of waste rock and roasted ore waste that were deposited on the side of a hill (Photo 2). Little Dry Creek flows south and is approximately 80 feet southeast of the mine pit. It joins Dry Creek approximately 400 feet south of the mine pit.



Photo 2 - Mine waste

The pit water had elevated concentrations of sulfate, iron, copper and zinc. Periodic surface water runoff and ground water seepage, from the mine waste material and the open pit lake, discharged low pH waters that were high in copper, zinc, iron and aluminum to adjacent Little Dry Creek (Photo 3). The concentration of copper and zinc in the discharge was sufficient to be detrimental to aquatic habitat. In addition, the proximity of the acidic open pit lake to a public access road created a public safety hazard.

CLOSURE PLAN

A Mine Site Characterization/Closure Plan for the Spenceville Mine was completed by DFG in July 2000. The objectives of the closure plan were to clean up the mine site, treat and dispose of the open pit water, fill the pit, and implement grading, drainage, capping and revegetation measures to leave the site in a condition that minimizes the potential for further impacts to surface and groundwater quality. In preparing the closure plan, geochemical and geotechnical characterization studies of the water and



Photo 3 - Little Dry Creek adjacent to mine

waste materials were performed to fill data gaps that existed in previous work performed by others at this site.

After data acquisition and evaluation, alternative remedial approaches were developed for treating the mine water, disposing of the mine waste, and filling the pit. The various closure alternatives were evaluated in terms of technical and economic feasibility, regulatory compliance and environmental impacts. Based on coarse screening of the possible reclamation alternatives, two main alternatives for closure of the mine site were proposed for fine screening. Preliminary designs and detailed cost estimates were prepared for the two closure alternatives that passed the initial screening process. While both alternatives included dewatering the pit and treating the water in a lime neutralization plant, one alternative consisted of treating the mine waste with a liming agent and filling the pit with the treated mine waste. The other alternative did not treat the mine waste, but consisted of placing the untreated tailings into an engineered landfill, to be located near the mine site and above the 100-year flood plain. Because of the mineralized condition of the rock adjacent to the pit, this second alternative assumed that the pit would need to be filled with limestone rock. Based on the fine screening evaluation, the alternative that included treatment of the mine waste and placing the treated mine waste in the pit was selected for implementation.

A Mine Site Characterization/Closure Plan and an Initial Study/Mitigated Negative Declaration were prepared and submitted for approval by the State of California Regional Water Quality Control Board-Central Region, the lead regulatory agency for this project. The project was approved in April 2001.

MINE CLOSURE IMPLEMENTATION

Reclamation activities began in April 2001. Initial reclamation activities included securing the site perimeter with fencing, installing temporary erosion and sediment controls such as silt fences and limestone berms, construction of access roads, and site grading for laydown areas and treatment plant facilities. The major activities associated with the mine reclamation are presented below.

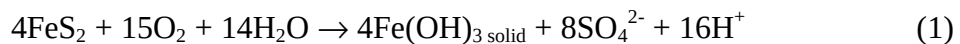
Water Treatment Plant

The purpose of the Water Treatment Plant at the Spenceville Mine was to treat the approximately 6 million gallons of acid mine drainage accumulated in the old mine pit so that the mine could be reclaimed. Treated water from the plant was discharged to a nearby land area in a safe, passive application process that resulted in minimal impact to the area soils and vegetation. The approach used for water treatment and disposal is described below.

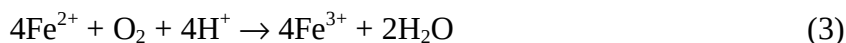
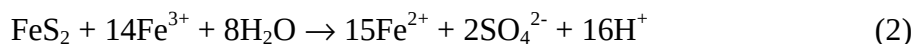
Pit Water Chemistry

One of the most common occurrences of acidic conditions in the environment is associated with the mining and exposure of coal seams and hard rock deposits containing base or precious metals. Pyrite occurs within the ore material due to the reducing conditions under which the metals were deposited. Mining operations expose the ore and associated sulfide minerals in the host rock to oxygen and moisture either in the underground workings or in the surface waste rock and tailings dumps.

The oxidation of pyrite under these oxidizing conditions is not a simple process, but may be generalized by the following reaction:



This reaction shows that in the presence of molecular oxygen, the iron (Fe) and sulfur (S) in the pyrite are oxidized by oxygen (O_2) to produce the stable iron solid, ferric hydroxide ($\text{Fe}(\text{OH})_3$), and dissolved sulfate (SO_4^{2-}) and acid (hydrogen ions). The release of hydrogen with a strong acid anion (sulfate) results in acidic solutions unless other reactions occur to neutralize the acidity released by the oxidizing pyrite. As reaction (1) proceeds, solution pH decreases and the reaction propagates by:



Presenting the reactions (2) and (3) in this form illustrates the importance of ferric iron (Fe^{3+}) as the primary oxidant of sulfide with oxygen serving as the primary oxidant of ferrous iron (Fe^{2+}). Also note that the oxidant ferric ion in solution is limited by the formation of ferric hydroxide ($\text{Fe}(\text{OH})_3$). The formation of this solid also creates acidity via:



At the Spenceville Mine, acidity has been created by the oxidation of pyrite in the underground workings along with the oxidation of copper and zinc sulfide minerals in ore and waste piles. As a result of reactions (1) through (4), pit water and tailings pore water have very low pH values (high acidity) approaching 2.4 in many cases and very high copper and zinc concentrations. At the cessation of mining (early 1900s) the pit filled with water and became acidic and metal rich due to the exposed oxidizing pyrite and copper/zinc sulfide minerals.

Acid Mine Drainage accumulated in the pit at Spenceville Mine was previously characterized by Walker & Associates, et al in the Spenceville Mine Closure Plan (July 2000) as shown on Table 1.

The data demonstrated these important features of the mine pit water:

- The pit is highly stratified. The top 0 to 15 ft is relatively dilute compared to the deeper portions of the pit.
- Meteoric water and runoff tend to both mix and dilute only the upper few feet of the pit. Mixing and turnover with the lower 15 to 60 feet of water appear not to occur.
- Acidity, metals and most of the major cations and anions all increased in concentration with depth. Sulfate increased from about 1000 mg/L in the top 3 ft to almost 15000 mg/L near the bottom of the pit. Dissolved iron (total) ranged from 100 mg/L in the surface water to about 4000 mg/L at the pit bottom. Dissolved Fe in the lower portion of the pit is

entirely Fe (II) suggesting that reducing conditions prevail in the lower part of the mine pit.

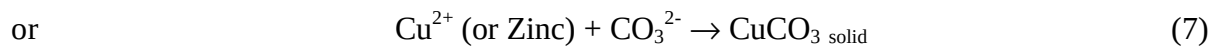
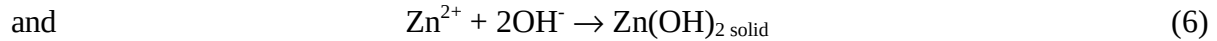
Table 1 Pit Water Chemistry (Mean of all Locations).

		3' depth (1988)	15' depth (1988)	45' depth (1988)	3' depth (2000)	15' depth (2000)	45' depth (2000)
Ph	[std units]	2.7	2.2	2.6	2.8	2.4	2.7
Alk.	[mg/L]	0	0	0	0	0	0
Acid.	[mg/L]	750	3700	11000	590	2640	9120
SO₄	[mg/L]	1300	4800	14000	742	3800	12100
Cl	[mg/L]	2	<4	<4	<40	<40	<40
Na	[mg/L]	19	30	55	10.1	23.5	41.2
K	[mg/L]	nd	8.6	29	1.2	0.8	0.25
Ca	[mg/L]	120	220	430	106	221	365
Mg	[mg/L]	75	200	530	20	175	494
Cd	[mg/L]	0.09	0.15	0.31	0.029	0.058	0.240
Cu	[mg/L]	30	160	230	18.9	86	202
Pb	[mg/L]	nd	nd	nd	0.009	0.023	<0.003
Zn	[mg/L]	20	45	220	9.80	22.7	145
As	[mg/L]	na	na	na	0.0054	0.024	0.0037
Ni	[mg/L]	na	na	na	<0.100	0.234	0.884
Fe (II)	[mg/L]	na	na	4900	na	na	3900
Fe (total)	[mg/L]	120	910	4900	na	na	3860

Conceptual Plant Design

The main constituents of concern in the pit water were copper, zinc, iron, and acidity. Because the solubility of these metals decreases with increasing pH, addition of alkalinity to the pit water (neutralization) simultaneously raises the pH and causes the removal of metals from solution via precipitation.

The removal of zinc and copper in the mine water is similar to the removal of iron by formation of ferric hydroxide discussed earlier (equation 4):



Thus raising the pH increases hydroxyl ions (OH⁻) and carbonate or bicarbonate (CO₃ and HCO₃) allowing metals to form solids and precipitate out of solution and thereby improving water

quality. The treatment plant at the Spenceville mine used this technique to remedy the cited constituents of concern in a single-phase neutralization process.

Plant Operation

Photos 4 and 5 show the pit in various stages of dewatering, and Photos 6 and 7 show the treatment plant during operation. Water from the pit was pumped at approximately 150 gallons per



Photo 4 - Mine pit dewatering, July 16, 2001



Photo 5 - Mine pit dewatering, July 26, 2001

minute into four 5,000-gallon reaction tanks from three pumps placed in the pit at 10, 25, and 45 feet below the water surface, respectively. The use of multiple pumps allowed blending of water to maintain consistent influent chemistry. Once in the plant, gravity flow was used to forward process water from one treatment unit to the next. In the first main reactor, an air line aerated the pit water to ensure that any ferrous iron existing under anaerobic conditions in the pit was converted to ferric iron, which is amenable to removal via neutralization. Neutralization in this reactor was achieved by the addition of hydrated lime slurry (30 % $\text{Ca}(\text{OH})_2$) to pit water in the well-mixed, aerated tank. A pH controlled lime pump was used to maintain tank pH at approximately 7.5, which is the titration endpoint that provides minimum solubility of the constituents of concern.



Photo 6 - Treatment plant

Effluent from the main reactor tanks drained into a 1,000-gallon flocculation/coagulation tank. In this tank, polymer that aids in the solidification and formation of easily filterable flocs was added to the reaction slurry containing neutralized water and metal hydroxide solids. After addition of polymer in the flash mixing chamber occurred, the mixture entered the gently mixed main tank for coagulation.



Photo 7 - Treatment plant and pit dewatering

Coagulation tank effluent drained into an upright 5,000 gallon clarifier with removable lamella plates. In the clarifier, metal hydroxide solids settled and drained out the bottom. Clean, treated water overflowed out the top and was collected in a pH adjustment tank and then to a 500,000 gallon holding pond before being pumped to the land application area for discharge.

Sludge from the clarifier was pumped into a solids holding tank. Sludge slurry was pumped to two parallel filter presses, where it was dewatered. Effluent

from the filter press was routed to the treated water holding tank and dewatered sludge was transported to a holding area on site before eventually being hauled to a licensed hazardous waste facility.

Treatment plant effluent water quality

Typical effluent water quality is presented in Table 2. Removal of the main constituents of concern (iron, copper, and zinc) as well as other trace constituents of concern (such as lead) was approximately 99%, as shown on Table 2.

Table 2. Bench Scale Treatment Tests Using Hydrated Lime.

		Initial composite pit water	Treated effluent	% Removal	Target Effluent Water Quality
pH	[std units]	2.54	7.0	-	6.5 to 9
Sulfate	[mg/L]	5547	3100	-	3100
Calcium	[mg/L]	231	1000	-	1000
Cadmium	[mg/L]	0.11	<0.05	-	0.005
Copper	[mg/L]	121	<0.1	>99.9	0.2
Iron	[mg/L]	853	9.3	98.9	<10
Magnesium	[mg/L]	229	170	0	<200
Manganese	[mg/L]	12	4.1	65.8	<5
Nickel	[mg/L]	1.0	<0.1	>90.0	0.1
Lead	[mg/L]	0.3	<0.005	>98.3	0.015
Zinc	[mg/L]	38	0.2	>99.5	2.0
Nitrate	[mg/L]	0.6	0.57	0	<10
Chloride	[mg/L]	4	3.8	0	<10

Mine Waste Excavation, Treatment, and Placement

Approximately 70,000 cubic yards (cy) of tailings were excavated and mixed with sugar beet lime to raise the pH. The treated tailings were placed in the pit and compacted to reduce their volume and compressibility.

Mine waste and mine-impacted materials at the site included the following:

- Hematite tailings: red-purple-black roasted ore material.
- Jarosite piles: piles of yellowish mine overburden material.
- Disturbed native materials: the areas mapped as containing “disturbed native materials” included three benches (flat areas) where various mine facilities were once located and the area to the east and south of the mine pit.
- Pit bottom sediments: mainly hematite mine waste that eroded from the hematite deposits and was transported into the pit by storm runoff.

Field batch testing was performed to determine the dosage of sugar beet waste lime required to neutralize each material. Based on these batch tests, the following minimum lime dosages were determined (weight of lime/weight of material):

- Hematite: 52 mg/g
- Jarosite: 274 mg/g
- Disturbed Native: 32 mg/g
- Pit bottom sediments: 78 mg/g

Initial access into the dewatered pit was via an excavated ramp on the east rim of the pit. The ramp was excavated about half way down to the pit bottom, at which point a temporary fill of lime treated mine waste and excavation rubble was placed from the bottom of the excavation to the floor of the pit (Photo 8). Prior to beginning excavation of the pit bottom sediments, a large crane with a clamshell bucket was mobilized to remove several vehicles and other debris that were found at the bottom of the pit. After removal of the debris, excavation and treatment of pit bottom sediments began the first week of August 2001. While excavating the pit bottom sediments, the depth to a hard rock bottom was found to be significantly deeper than originally anticipated. Several test pits were dug into the pit sediments to determine the characteristics and estimate the depth of material in the bottom of the pit. Each test pit exposed a layer of hematite mine waste and/or fill material used for construction of the pit ramp, overlying a deposit of non-reactive metavolcanic rubble of undetermined depth. To address the unanticipated thick deposit of rubble on the pit floor, the pit bottom sediments were removed and the upper two feet of coarse rubble material were replaced with a two-foot-thick layer of compacted crushed limestone (Photo 9). The crushed limestone layer provided a base for placing the treated mine waste, and provided buffering for potential migration of acidic water into the pit.



Photo 8 - Pit access ramp

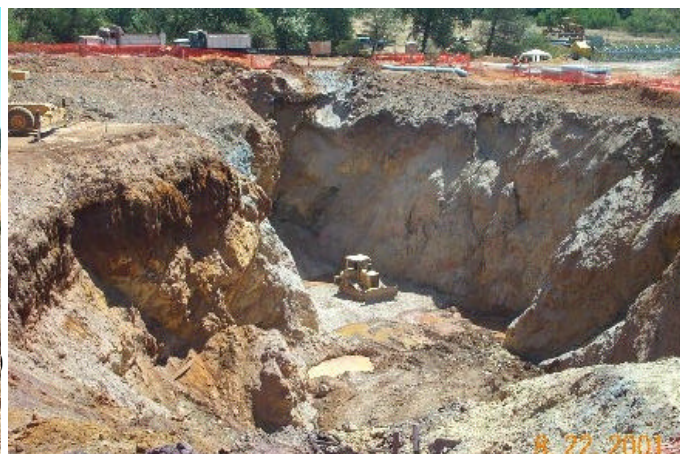


Photo 9 - Pit bottom stabilization with limestone

After treatment of the pit bottom sediments, placement of treated mine waste began. A conveyor system was set up for conveying the mine waste and lime into the pit (Photo 10). The conveyor system consisted of two sets of traps, motors and conveyors, one for the mine waste and the other for the lime. The two conveyors discharged onto a main conveyor, which transported the mixed mine waste and lime into the pit. A water spray nozzle was located at the end of the main conveyor to minimize dust generation as the material dropped into the pit. The speed of each conveyor was calibrated to obtain the proper lime dosage for each material. The lime and mine waste were further mixed at the bottom of the pit by dozers. The dozers spread the treated mine waste in 8-inch to one-foot lifts, and each lift was compacted with a sheepfoot roller. Treated mine waste was



Photo 10 - Mine waste placement with conveyor

compacted to 95% of the maximum dry density as determined by ASTM D698. Once the elevation of the treated mine waste in the pit approached the elevation of the pit rim, the conveyor system was removed and the mine waste and lime were placed, mixed and spread in the pit with dump trucks and dozers (Photo 11). Since the volume of material placed in the pit exceeded the capacity of the pit, a mound of treated mine waste was constructed over the pit. After all the treated mine waste was

placed, the side slopes of the mine waste pile were armored with riprap to protect the pile from erosion by Little Dry Creek and Dry Creek flood waters.

Quality control measures were implemented to provide a high level of confidence that the excavation, treatment and compaction of mine waste materials were satisfactorily completed. Quality control measure's included the following activities:

- In place density tests for compaction verification. Both sand cone and nuclear gage density tests were performed.
- In place dosage testing of the treated mine waste.
- Excavation of confirmatory test pits in excavated areas to confirm mine waste removal.



Photo 11 - Mine waste placement with trucks and dozers



Photo 12 - Post-excitation grading

After the mine waste was excavated, and prior to placement of soil cover, the slopes of the excavated surfaces were regraded locally. The slopes were graded to 3 horizontal to 1 vertical (3H:1V) or flatter to reduce erosion, facilitate revegetation, and smoothly merge the topography of the regraded site with the adjacent land. In steep areas, or areas which had an abrupt change in topography, clean fill from a borrow area was placed to flatten the slopes and provide a smooth topographic transition (Photo 12).

Reclamation of Shafts and Tunnels

Dewatering of the pit revealed several old adits and a shaft within the pit (Photo 13). It was determined that a mixture of 60 % limestone and 40% fresh bentonite (by volume) would be used to stabilize the adits and shaft. The purpose of the bentonite was to minimize seepage of potentially acid water into the pit, while the purpose of the limestone was to buffer any seepage that does move into the pit.

The limestone/bentonite material was placed into each adit as deep as possible with an excavator bucket. The shaft was filled with quarry rock to about 20 feet below the rim of the shaft. The remainder of the shaft was filled with the 60/40 mix of limestone and bentonite. After remediation, the adits and shaft were buried with placement of the treated mine waste in the pit.



Photo 13 - Shaft and adit in mine pit

Site Grading and Placement of Soil Cover

After initial site grading, and prior to placing clean soil cover, the excavated mine site subgrade was amended with 10 tons of sugar beet lime per acre, 67 cubic yards per acre of compost, and 100 pounds per acre of fertilizer.

A soil cover borrow area was developed off-site to provide soil for revegetating the mine. Prior to excavation of cover soil from the borrow area, the top 6 to 8 inches of topsoil were stripped and stockpiled for later use in reclaiming the borrow area. The cover soil was

loaded and transported to the mine site using wheel-scrapers with a capacity of about 20 cy. The cover soil was spread at the mine site by dozers to the specified thickness, which was two-feet thick over the treated mine waste pile and the footprint of the former tailings piles, and one-foot thick in the areas which had disturbed native material (Photo 14).



Photo 14 - Placement of soil cover

After placement, the cover soil was amended with 134 cubic yards per acre of compost and 100 pounds per acre of fertilizer. After amendment with fertilizer and compost, a wood chip mulch layer was placed over the cover soil to control erosion, help prevent the establishment of weed species and conserve soil moisture.

The borrow areas were reclaimed by grading the areas to blend in with the adjacent undisturbed contours and by amending and spreading the stockpiled topsoil over the graded substrate.

Stream Restoration

Little Dry Creek received run-off leachate from the waste piles and overflow of water from the mine pit, resulting in significant loading of metals and acidic water to the stream. Although the affected area appeared to be mainly restricted to the section of Little Dry Creek adjacent to the mine site, both these factors decreased the suitability of the creek as habitat for aquatic receptors. In addition, Little Dry Creek near the mine site had a hard-bottom substrate of cemented rocks, very little overlying sediment, virtually no submerged aquatic vegetation, and very shallow water in most places. This combination of features contributed to the creek offering poor quality habitat for aquatic species.

Based on a review of pre-mining site photos and a survey of the existing creek bed area, it was determined that the original pre-mining stream channel was east of the existing channel. Stream restoration thus included re-establishing the original stream channel. The construction work involved grading the stream and clearing the old channel before diversion barriers were removed to divert stream flows from the existing channel to the new channel. The altered streambed contains ponds, swales and large rocks to produce well-aerated water with numerous areas for establishment of pre-mining creek habitat (Photo 15). Re-colonization by benthic invertebrates from upstream locations following re-establishment of normal creek flow should result in re-population of the creek with a similar abundance and diversity of benthic organisms as present before mining occurred.



Photo 15 - Relocated Little Dry Creek

Prior to excavation of the new channel, the existing channel of Little Dry Creek adjacent to the mine site was temporarily diverted as part of the remedial work to permit removal of iron and aluminum hydroxide sediments and evaporative salts from the creek bed. Removal was performed by washing the creek bed with high-pressure water jets. After cleaning and excavation of the new channel, the old channel was filled with clean fill and lime rock to ensure neutralization of seeps in the channel and to provide a good growth medium for new vegetation.

As part of the investigation being conducted at this site in support of the remediation, benthic invertebrate samples were collected from multiple locations upstream and downstream of the mine site on Little Dry Creek and Dry Creek prior to the start of remedial activities. Invertebrate abundance and diversity were measured in these samples. Following completion of remediation activities, and after sufficient time has passed to allow for re-

colonization, these areas will be re-sampled for invertebrate abundance and diversity. Comparison of pre- and post-remedial survey results will permit evaluation of the effectiveness of remediation and its impact on the benthic fauna of the stream.

Site Revegetation

A revegetation plan was developed to provide a sustainable, erosion resistant vegetative cover using site-adapted species. Distinct planting zones were created for the relatively steep upper mine slopes, relatively flat lower benches (adjacent to Little Dry Creek) and the graded mine waste pile in order to foster a diversity of plant communities and wildlife habitats throughout the site, and to provide an erosion resistant vegetative cover in areas with varying slopes, landscape position, etc. The plants that will be utilized in the revegetation program are summarized in Table 3.

All species listed were chosen for their adaptability to the site, or for their erosion control or wildlife habitat potential. All native grass and forb seed used for this project will originate from northern California seed accessions. Seeds for the native tree and shrub species were obtained from areas adjacent to the mine site and are being grown as containerized seedlings.

Table 3. Summary of Plants for Site Revegetation

Planting Zone	Plant Type	Plant Common Name
Upper Mine Slopes	Trees and Shrubs	Foothill pine, Blue oak, Interior live oak, California buckeye, Redbud, Buckbrush, Coyote bush
	Native Grasses	Purple needlegrass, Blue wildrye, California oniongrass, Creeping wildrye
Lower Mine Benches	Trees and Shrubs	Blue oak, Interior live oak, California buckeye, Redbud, Coyote bush, Willow
	Native Grasses	Purple needlegrass, Nodding needlegrass, Creeping wildrye, Pine bluegrass, Blue wildrye, Squirreltail, California oniongrass, Deergrass
	Native forb seeds	Yarrow, Small-flowered lupine, California poppy, Spanish clover
Mine Waste Pile	Native Grasses	Purple needlegrass, Nodding needlegrass, Creeping wildrye, Pine bluegrass, Blue wildrye, Squirreltail, California oniongrass
	Native forb seeds	Yarrow, Small-flowered lupine, California poppy, Spanish clover

The riparian zone along Little Dry Creek was revegetated after stream relocation in December and January 2002. The remainder of the mine site will be revegetated in the Fall of 2002. It is anticipated that hand watering of the plants will be required when they are planted in the Fall of 2002, and during the dry season in 2003 (April – September) until the trees and shrubs have been established. Additionally, weeds will be controlled for several years following revegetation by hand pulling as well as the use of herbicides.

Archaeological Investigations

Archaeological investigations were conducted from June 2001 to November 2001 (Photo 16). These investigations revealed eighteen historical features or elements of features. Archaeological findings included a 126 foot by 30 foot concrete platform, which apparently was used to dry copper



Photo 16 - Archaeological investigations during excavation

cement with associated strap rail system to move the material, and a subterranean tar and felt covered wooden containment tank, 24 feet long by 12 feet wide, with canvas gaskets designed to be placed between wallboards and uprights. The most striking finds were made during mine waste excavation. A wooden conduit was discovered beneath tailings exceeding 25 feet in depth. The conduit was 134 feet long on a 10 percent grade with an internal channel that narrowed from 6 inches wide to 4 inches wide. Also, a tar covered brick

settling tank and a tar-coated canvas covered wooden tank were discovered beneath tailings of 14 to 16 feet in depth. The mine pit proper revealed an incline on the southwest wall with only strap rails missing, and a partially timbered vertical shaft was discovered in the west wall. Two ore buckets were recovered both with wooden trap doors in the base and one bucket has remnants of tar lining the inside. Overseas Chinese porcelain and stoneware shards were found near some refractory ovens.

Methodologies used in field exploration at the mine were varied and appropriate to the conditions. The concrete platform was one of only two features where simple archaeological tools were used. During removal of the extensive tailings heavy equipment was the initial choice. The equipment was used to locate historic surfaces at which point excavators used traditional archaeological tools. Artifacts that were revealed were bagged and tagged for future processing. All work was photographically recorded as were features and artifacts.

Unexploded Ordnances

As discussed above, from 1941 to 1962 the Spenceville Mine area was under the jurisdiction of the US Army. Information received from the US Army Corps of Engineers indicated that there was a potential for unexploded ordnances (UXO) and chemical warfare material (CWM) at the site and, specifically, that one of the areas proposed as a borrow source for clean soil cover was used as a bomb test range. Based on this information, a UXO and CWM specialty contractor was retained to provide UXO and CWM construction support.

Initial site activities included a records search at the adjacent Beale Air Force Base, UXO and CWM training to onsite personnel, a visual reconnaissance of the mine site area, and geophysical surveys of the borrow areas. Information obtained from Beale Air Force base described ordnance removal actions in 1947 and 1964 in the mine site vicinity, which, at the time, resulted in the discovery of many live UXO items; the live UXO items were removed upon discovery. Results of the geophysical survey and visual reconnaissance yielded about 14 ordnance related items, primarily scrap from 81mm and 60mm mortars. No live ordnances were discovered.



Photo 17 - Vehicles at bottom of pit

Subsequent activities addressed the potential for UXO and CWM in the mine pit, and the possibility of uncovering UXO during excavation of cover soil from the borrow areas. After the pit was dewatered, a visual and geophysical inspection of the pit bottom was conducted (Photo 17). UXO support continued during excavation and treatment of the pit bottom sediments, and during stripping of the borrow areas for cover soil. While several ordnance related items were retrieved, including an M-1 clip, M-4 105 shell casing, parachutes, and a site tube from gas tanks, no live ordnances or CWM were discovered.

SUMMARY

The Spenceville Mine Closure proceeded on schedule and, as of July 2002, is nearly finished (Photo 18). The only remaining portions of the closure are the drilling of two down-gradient groundwater monitoring wells, and revegetation of a portion of the site. In all, the project was completed in about 18 months and accomplished the following:



Photo 18 - Final site grading – note that filled mine pit is in center of photo

- The mine pit was drained in 8 weeks and treated water was used to irrigate nearby fields.
- The pit was backfilled with neutralized mine waste and then covered with clean fill. The shafts and adits were also treated and filled to minimize seepage.
- The site was contoured to fit pre-mining contours and much of the area has already been revegetated.
- The nearby stream, Little Dry Creek, was moved to its original location and stream habitat restored. Seeps and overflow from the flooded mine pit were eliminated.
- Intensive archaeological studies unearthed old mining structures and sites of cultural interest that were catalogued and preserved for future access.
- Surface water and groundwater have been restored to near pre-mining conditions. Both will be monitored for many years.

The Spenceville Mine site has been returned to usable open space consistent with the intent of the wildlife refuge.

REFERENCES

Walker & Associates and GEI Consultants, Inc., July 2000, *Mine Site Characterization/Closure Plan*, Spenceville Mine Site, Nevada County, California.

TECHNICAL PAPER SESSION 4 STREAM RESTORATION

Title: **Natural Channel Design, Construction and Planting on the Middle Fork South Platte River**

Authors: [John T. Windell](#)*, Professor Emeritus, Biology Department, University of Colorado, Boulder and **Eric August**, EIT, Aquatic and Wetland Company, Consulting Division

Title: [Natural Channel Design Process Using RIVERMorph Stream Restoration Software](#)

Authors: **Brian Belcher**, PE, Senior Project Engineer, Fuller, Mossbarger, Scott and May Engineers, Inc. and [George Athanasakes](#)*, Associate, RIVERMorph, LLC

Title: [A Categorization of Approaches to Natural Channel Design](#)

Author: [Peter Skidmore](#)*, P.G., Hydrologist, Fluvial Geomorphologist, Inter-fluve, Inc.

Title: [Abandoned Mine Land Restoration in a North Idaho Stream: A Geomorphological Perspective](#)

Authors: [Mike Stevenson](#)*, Hydrologist, USDI-BLM; **Steven W. Moore**, Bureau of Land Management, Idaho State Office; **G. Mathias Kondolf**, Department of Landscape Architecture and Environmental Planning University of California, Berkeley; and **Hervé Piégay**, CNRS- UMR 5600

NATURAL CHANNEL DESIGN PROCESS, USING RIVERMORPH STREAM RESTORATION SOFTWARE

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ABSTRACT

Over time engineers and scientists have come to the realization that river restoration is a complex process relying heavily on the use of field measurements and empirical relationships. The designer must measure and understand geomorphic parameters within the project reach, have a thorough understanding of the watershed, and must verify that the designed stream will transport sediment without significant aggradation or degradation of the channel bed.

A very popular method for designing natural stream channels consists of measuring geomorphic parameters from a reference reach and then “sizing” the reference reach parameters to match the design reach through the use of dimensionless ratios. To expertly use the reference reach approach for natural channel design, extensive geomorphologic data must be collected and analyzed during the design process. This data collection and analysis is time consuming and sometimes requires much iteration.

RIVERMorph LLC has developed a software package for the evolving stream restoration profession. This software processes geomorphologic data and is useful for assessment, monitoring and natural channel design. Relying on proven design techniques, this software streamlines the stream design, leaving the designer more time and budget for data collection and monitoring.

THE EVOLVING SCIENCE OF STREAM RESTORATION

Stream restoration as a science has evolved from ancient river training techniques used for irrigation, navigation and flood control projects into modern ecological restoration plans designed by teams of engineers, geomorphologists, biologists and skilled construction contractors. In the past decade the profession has witnessed a trend in stream restoration that started with bioengineered or “natural” bank stabilization practices that tended to address the effects of stream degradation, but is now focussing on cross sectional, planform and longitudinal geometry best suited to exist in the natural landscape. The later approach tends to address the causes of stream degradation, channelization for example, and mitigates those causes by mimicking natural systems that are stable in similar environments.

The art of restoration is in the way professionals condense reams of input data into construction drawings illustrating natural stream systems. Given a beginning point and ending point, a stream can form nearly infinitely many planform alignments; however, there are many times when only one or two alignments can work with all the site constraints.

RIVERMorph has been developed to allow designers to restore rivers on a meander wavelength scale, with the ability to iterate design constraints quickly in each wavelength. The outcome is a natural appearing stream system with variability in its planform, longitudinal profile and cross-section dimensions.

DEVELOPMENT OF THE RIVERMORPH SOFTWARE PACKAGE

Research and development for the software began in 1999. At this time research was focused on resistance equations and shear stress calculations needed for bank stabilization design. Later, basic geomorphologic data collection and stream classification were added to the first application (alpha version), which was developed in 2000. The software went through further development, including the addition of natural channel design equations, GIS, regional curves and graphing capabilities, until beta¹ testing in 2001 by private consultants, universities and government agencies. After incorporating revisions from the beta test and the latest available design algorithms, Version 1.0 was released in June, 2002.



DESCRIPTION OF RIVERMORPH CAPABILITIES

RIVERMorph is a product that combines useful techniques and algorithms from a variety of successful restoration professionals. The software is based on the philosophy that streams can be redesigned into stable reaches that exist harmoniously in the surrounding landscape and that this design process should be based on empirically derived relationships between stable streams and their inputs, i.e. water, sediment, flora and fauna.

RIVERMorph provides a data structure for the essential geomorphologic characterizations, and has data input forms for the following information:

- I. Survey Data
 - a. Total Station
 - b. Field Book
- II. Cross Sections
- III. Longitudinal Profiles
- IV. Particle Size Analyses
 - a. Pebble Counts
 - b. Sieve Analysis

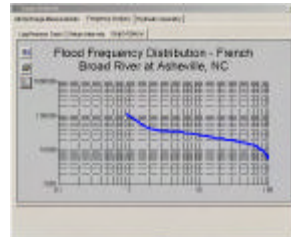
¹ Beta testing is the process of getting feedback from peers and potential users.

- V. Stream Classification
- VI. Pfankuch Channel Stability Analysis
- VII. Stream Visual Assessment Protocol
- VIII. Natural Channel Design
- IX. Cross Vane, W-Weir and J-Hook
- X. Design
- XI. Geographic Information System (GIS)
- XII. Regional Curves
- XIII. Resistance Equations
- XIV. Regime Equations (Williams)
- XV. Gage Analysis

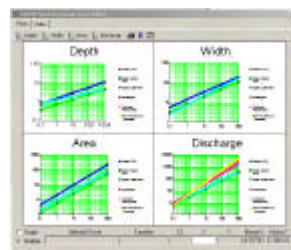
Input depends primarily on the intended use. Typically the input for a natural channel design involves unreduced survey data, pebble count data and bulk material sieve analysis data. Output includes calculated results stored in the database, reports and graphs that can be used to generate typical sections and details.

DESIGNING A STREAM RESTORATION PROJECT WITH RIVERMORPH

Restoration designs with RIVERMorph involve field data collection, design calculations, validation and conversion of results into construction drawings. The following description outlines the general process and tools available within the software to facilitate natural channel design.



RIVERMorph calculates flood frequency distributions and hydraulic geometry from downloaded USGS gage data.



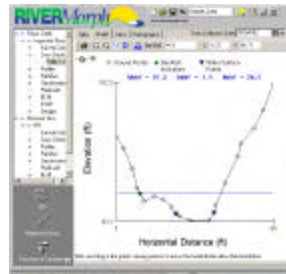
Regional Curves are displayed on interacted graphs that can be used to estimate cross sectional geometry as a function of drainage area.

1. Gage Analysis and Regional Curve Development

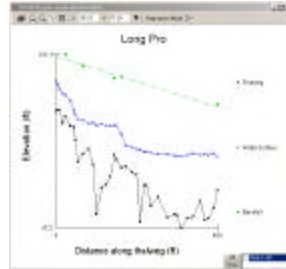
- a. Before field work, it is a good idea to download gage data from any nearby USGS gaging stations. RIVERMorph provides utilities for searching the USGS website and downloading peak discharge data into the RIVERMorph Project. The software can then be used to perform a flood frequency analysis and to generate hydraulic geometry for the gaging station. Begin field excercises at the gaging station and determine what elevation bankfull passes through the gage.
- b. Using a rating curve supplied by the local USGS office, you can then “calibrate” your ability to find bankfull elevation in other streams nearby. Also, the information from the gage can be used to plot a single point on a new regional curve for your area. RIVERMorph comes with some industry standard curves, like the Upper Salmon River by Emmett, 1975.

2. Impacted Reach Survey

- a. RIVERMorph defines a “reach” as a length of stream equal to approximately 20 to 30 bankfull widths. Determine the number of reaches along the impacted site and perform a geomorphic survey in each reach in accordance with Harrelson, 1994.
- b. The geomorphic survey is composed of a longitudinal profile, cross sections and sediment analyses. Begin by collecting the longitudinal profile data, marking locations where riffle and pool cross sections will be taken. Data should be gathered with frequency



Unreduced survey data is processed and graphed by the software. Cross sectional metrics width, mean depth and area are displayed on the graph.



This interactive longitudinal profile graph has a slope, depth and distance measuring tool to allow the user to quickly compile the dimensionless ratios needed for design.



Pebble count and sieve data is graphed and analyzed in the particle analysis module.



Once the survey data has been entered and reduced, RIVERMorph classifies the reach in accordance with the Rosgen Stream Classification System (Rosgen 1994).



The Pfankuch Channel Stability module is used to indicate the relative stability of the reach.



Bank erosion rates can be predicted using the Bank Erosion Hazard Index (BEHI) module.

sufficient to define pools, runs, riffles and glides, and should include the low flow water surface, bankfull elevation and other significant features, such as top of bank and terrace elevations.

3. Reference Reach Survey (Rosgen 1998)
 - a. The same geomorphic survey described above is performed in the reference reach.
 - b. A biological assessment (USDA 1998) and channel stability assessment (Pfankuch, 1975) are performed in the reference reach.
4. Natural Channel Design Calculations
 - a. Once the impacted reach and reference reach data has been input to RIVERMorph, the natural channel design module can be used to quickly iterate on a design until the proposed geometry matches the reference reach classification and has the ability to transport its sediment, as validated using critical dimensionless shear stress calculations (Parker, 1990 and Andrews, 1995).
 - b. Typical details for the plan view alignment of the channel thalweg and longitudinal profile are automatically produced by the software. Cross sectional details are customized by the user to generate the shape of the proposed channel that best suits the channel materials and reference reach patterns.
5. Grade Control and Bank Stabilization Structure Design

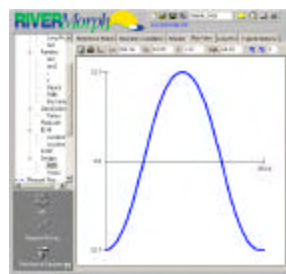
RIVERMorph includes design calculations for W-Weirs, J-Hooks and Cross Vanes. In smaller rivers, Cross Vanes are typically used for grade control structures. RIVERMorph is used to generate and validate Cross Vane geometry and spacing for the proposed reach.



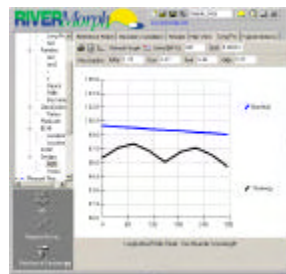
The Stream Visual Assessment Protocol (SVAP) module is used to rate the biological habitat of the reference reach.



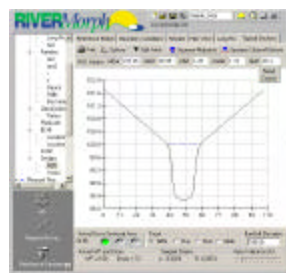
This Natural Channel Design module has slider controls, allowing the user to modify meander wavelength, deflection angle, meander width ratio, width to depth ratio and the riffle slope ratio while recalculating related parameters.



The plan view detail plots the thalweg coordinates for 1-10 meander wavelengths using a sine-generated curve (Soar and Thorne, 2001).



A longitudinal profile detail is created for the designed reach showing maximum depths in riffles, runs, pools and glides in each meander wavelength.



RIVERMorph uses Bezier curves to allow the user to customize the cross section details. The user can easily reshape the cross section and see the area, width, etc. updated.



The Vane module is used to design Cross Vanes for grade control structures. It also allows the user to design W-Weirs or J-Hook Vanes (Rosgen 2001).

6. Regime Equation Validation

The regime equations provided in RIVERMorph are very useful for providing a check for your design. Typically the equations are used to compare the design to the relationships of radius of curvature to width, meander wavelength to radius of curvature and others.

7. Regional Curve Validation

The design geometry should be consistent with Regional Curves developed for the project area. If there are no existing Regional Curves for the site, RIVERMorph can be used to construct them if some stable reaches and preferably gage sites can be located in the watershed or surrounding area.

8. Design Output

RIVERMorph generates tables of design geometry, as well as tables of coordinates for cross sections, plan view and longitudinal profile. These tables can be supplied to the CADD department for development into design drawings, or can be imported into GIS using “event themes”.

CONSTRUCTION AND MONITORING

RIVERMorph is a powerful tool to use during the construction process if unknown site conditions require a field change to a portion of the alignment, such as when shallow bedrock is encountered. Changes to the stream geometry, such as narrowing the meander belt width, can easily be evaluated using the software’s slider controls. RIVERMorph will adjust all the related channel dimensions and validate the sediment transport competency of the adjusted channel.

It is also crucial to collect as-built geomorphic survey data immediately after construction to begin the monitoring process. Ideally, reconstructed streams would be monitored for the long term; however, monitoring budgets are sometimes limited or entirely absent. The RIVERMorph project file used to design the reach is an excellent place to store any monitoring data collected in the new reach, making it easy to generate reports and to evaluate changes over time.

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A CATEGORIZATION OF APPROACHES TO NATURAL CHANNEL DESIGN¹

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ABSTRACT

Approaches to natural channel design have been categorized herein as analog, empirical, or analytical. Analog design replicates historic or adjacent channel characteristics and assumes equilibrium sediment and hydrologic conditions. Empirical design uses equations that relate various channel characteristics derived from regionalized or “universal” data sets, and also assumes equilibrium sediment and hydrologic conditions. Analytical design makes use of the continuity equation, roughness equations, hydraulic models, and a variety of sediment transport functions to derive equilibrium channel conditions, and thus is applicable to situations where historic or current channel conditions are not in equilibrium, or where applicable analogs or empirical equations are unavailable.

Analog, empirical and analytical approaches each have advantages and limitations. The advantage of the analog and empirical approaches is the intuitive simplicity of replicating desired channel and habitat characteristics from stable systems. Analog and empirical approaches require little or no evaluation of sediment transport, as their application assumes equilibrium conditions. Analytical approaches are required when no analog sites or empirical equations are applicable as a consequence of altered or changing hydrologic character and sediment inputs. Analytical approaches offer advantages when site constraints impose limitations on channel form, but may require considerably greater quantitative analysis to achieve final designs.

INTRODUCTION

Design of natural channels for the purpose of restoration, rehabilitation, relocation, stabilization, or habitat enhancement is a developing science. Designing natural channels to meet both ecological and engineering criteria necessitates incorporating approaches and considerations from numerous scientific and engineering disciplines. Because the developing industry of natural channel design lacks a standard approach to design a more comprehensive understanding of the spectrum of approaches to design is warranted. Contemporary research and development of channel design methodologies (Federal Interagency Stream Restoration Working Group (FISRWG), 1998; Watson et al., 1999; Soar et al., 2001) indicate that no single approach is appropriate for all project conditions or objectives.

Presented herein is a categorization of commonly applied approaches to channel design. Categorization is important to bring about an awareness of variable approaches and to facilitate discussion of the applicability of approaches to varying site conditions and data availability. This paper proposes the common terminology and categorization of approaches to natural channel design as analog, empirical, or analytical. Approaches to design have been similarly categorized in the literature (Shields, 1996; FISRWG, 1998; Watson et al., 1999; Inter-Fluve, Inc., 2000; Fripp et al., 2001).

All channel design is based on the premise that “natural” channels tend toward equilibrium between channel form and sediment and hydrologic inputs (Leopold and Maddock, 1953). Channel form is dictated by independent variables of hydrologic discharge, sediment supply, and character of boundary materials, including vegetation. Dependent variables are

¹ Adapted from Skidmore, Shields, Doyle and Miller, 2001. Proceedings of the 2001ASCE Wetlands Engineering and River Restoration, Reno Nevada.

those physical characteristics that define channel form (width, depth, slope, and planform), which can be selected using various approaches to channel design. Analog approaches can be conducted without any quantification of independent variables. Empirical approaches require only dominant discharge and therefore can be conducted without any quantification or consideration of sediment supply. Analytical design methods require some quantification of independent variables in some instances, and can be used to quantify independent variables in other instances.

ANALOG APPROACH

An analog in its simplest form is a template for design. The template may exist in another location, or it may have existed previously in the same location. The analog approach is otherwise referred to as the reference reach method (Rosgen, 1998), cognitive approach (FISRWG, 1998), carbon copy approach (FISRWG, 1998) or intuitive approach (Shields, 1996).

The analog approach involves an intuitive replication of desired natural condition. The probability of successful ecosystem recovery is directly related to how closely abiotic components of the system approximate the targeted state. The method of replicating existing or historic conditions to achieve a desired condition within the project reach can be used on the reach scale, or for individual components of design. In the former, all channel characteristics from an entire reach are replicated in design. In the latter, specific components of a reach may be replicated at the project site to address site-specific desired conditions. An example is the construction of specific habitat elements, such as pools or woody debris jams, based on replication of similar habitat elements in adjacent reaches or other nearby channels.

The analog method, in simplest form, requires careful measurement of channel parameters, and adoption of these same measurements in design. Consequently, analysis required for design is minimal. Design can be conducted without regard to or analysis of hydrologic statistics or sediment transport. However, evaluation of watershed stability prior to adopting an analog methodology is essential and may require considerable effort and analysis.

Four methods of application of the analog approach include:

1. *The reference reach approach* is well documented in Rosgen (1996) and includes measurement and subsequent replication of a number of channel parameters, including width, depth, slope, bed material gradation, flood prone width, and sinuosity, among others.
2. *The carbon copy approach* relies on replication of previous or historic channel characteristics (FISRWG, 1998). It is most commonly applied in the context of restoration of meander planform in channels that have been straightened. Historic channel alignment is often identified in the field, or in some cases from historic photos.
3. *Target or component analogs*, also termed reference reach methods by the Federal Interagency Stream Restoration Working Group (1998), are specific components of an existing channel that are used as templates for achieving desired conditions within a reach.
4. *Cross-section analogs* from stable reaches can be used to estimate dominant discharge and sediment transport character. Assuming that bankfull discharge is a fair indicator of dominant discharge (Andrews and Nankervis, 1995), bankfull discharge can be estimated using any of a number of hydraulic analysis tools

5. based on Manning's equation. Similarly, Fripp et al. (2001) describe application whereby a sediment rating curve is generated from an analog section and then applied to channel design at an adjacent location.

Analog approaches to design are limited by the same assumptions that make the approach valid – identical watershed and boundary conditions must be assumed between analog and design condition. Analog approaches for reach-scale design are not valid if controlling independent variables – sediment supply (load and gradation), hydrology (timing and volume), and boundary conditions (bank cohesion and vegetation) - are not similar for the analog and the project site under post-construction conditions.

Analogues are typically selected because of their apparent stability within a reach or watershed. However, unstable sections of the same reach, or unstable reaches within the same watershed, are often indicative of systemic disequilibrium, and therefore should be considered suspect in their eligibility for analog approaches. In such cases, where channel instability can be attributed to watershed factors, analog approaches may be inappropriate. Similarly, the carbon copy approach, which uses historic channel form as an analog, may unintentionally replicate unstable reach conditions. For example, reinstatement of a meander, which was previously cutoff through natural process in an otherwise stable stream reach, will not necessarily address the sediment transport character that led to the cutoff.

EMPIRICAL APPROACH

Empirical refers to relationships based on experience or observation alone. Empirical equations represent average conditions by reducing the range of variables from many observations to predictive formulas. Empirical approaches are based on observed conditions, as are analog approaches, but they include a larger data set than a single analog. In this respect the empirical approach is an intuitive extension of the analog approach, in that designs are based on examples of stable conditions in similar environments, but based on larger, and therefore theoretically better, data sets.

The empirical approach is otherwise referred to as the “Hydraulic Geometry Method” (Copeland and Hall, 1998; FISRWG, 1998; Fripp et al., 2001). Historic geomorphologic studies of stable, natural channels resulted in what have been termed ‘hydraulic geometry’ formulas (Leopold and Maddock, 1953), which quantified attributes of channels in regime. These formulas generally relate dependent variables such as width, depth, or slope to independent variables such as discharge or bed material size (e.g., Parker, 1979; Bray, 1982; Hey and Thorne, 1986; Williams, 1986; FISRWG, 1998), and are generated by regression of large, regional data sets.

Application of empirical approaches to channel design is well documented. Design values for physical channel attributes can be generated, using empirical formulas, from relatively few known or constant values. In this respect, they are particularly applicable to determining multiple channel geometry variables from a single or few variables. There are four requirements for application of empirical equations to channel design:

1. The watershed within which design is to be implemented must be stable and unchanging;
2. The watershed and the channels from which the data were derived must have been stable and in equilibrium;
3. There must be similar watershed character and channel attributes between empirical data set and design channel; and

4. Confidence limits, or scatter within the data, of the values generated from the equations must be acceptable.

The Federal Interagency Stream Corridor Restoration Working Group manual (1998) presents a comprehensive review of available empirical equations and references. While equations exist relating virtually every channel attribute to other channel attributes, equations relating channel dimensions to discharge are most reliable for width, less reliable for depth, and least reliable as predictors of slope (Wharton, 1995). Channel width, however, is strongly influenced by bank composition and vegetation (Hey and Thorne 1986; Millar and Quick, 1998), and these are rarely included as input variables in empirical equations. Alternatively, empirical equations can be developed for a river, watershed, or group of regionally similar streams if they do not otherwise exist. However, generating equations represents a tremendous field data collection effort, and careful consideration of the stability of the channels and contributing watershed.

In addition to being used to design channel dimensions from known, or assumed, constants or single variables, empirical relationships, in the form of regional regression formulas, can be used to estimate discharge. Regional regression formulas based on watershed characteristics or channel width and discharge have been developed for numerous regions, generally by the USGS. These formulas can be valuable to channel design efforts in that they often represent the only reasonable estimate of design discharge (Inter-Fluve, 2000). This application, however, is generally based upon the assumption that dominant discharge can be related to a specific return interval, such as the 2-year flow.

Empirical equations can be used to determine the primary variables (e.g., channel width), from which other components of design are derived, as well as values for virtually any other channel attribute. Equations are used to derive values for unknown variables from known, or assumed variables (Inter-Fluve, 2000). The applicability, details and intricacies of each set of equations can only be thoroughly evaluated from original sources that document the data sets used, and the statistical character of the equations and their resulting values. Comprehensive lists of valuable empirical relations and the regions from which their data sets were derived is provided in the Federal Interagency Stream Restoration Working Group manual (1998) and Wharton (1995).

Wharton (1995), in a comprehensive review of channel geometry empirical relations, states that the most significant problem in application of empirical relations is that they are only applicable over the range of conditions from which they were derived. In Williams' much-referenced publication on empirical relations for river meanders (1986), he summarizes the suite of empirical equations as "represent(ing) problems more than they do conclusions" with respect to universal application. Even when the conditions for sites used to generate an empirical formula match the design condition, the wide range of confidence limits is a problem for designers. Confidence intervals for estimates from hydraulic geometry formulas often span an order of magnitude.

Empirical equations and their application to natural channel design are inherently limited by their data sets. These limitations are expressed in a number of ways. A limited number of variables are included in development of empirical equations. Popular equations generally relate only channel geometry variables to one another, or relate discharge to geometry. Generally, empirical equations do not directly account for sediment supply, bed material gradation, bank cohesion, vegetative character, slope, or roughness, all of which influence natural channels. While many of these variables can be considered regionally consistent, they can vary

tremendously within a watershed, and thereby affect the legitimacy of the equations applied. In contrast to the basis of many empirical relationships, Hey and Thorne (1986) included vegetation density and bank shear strength in developing empirical equations for gravel-bed rivers in the UK. They thereby accounted for important independent variables otherwise rarely considered in empirical studies. While regionalization may account for some missing variables, regional data sets can also ignore the importance of local controls, such as bedrock geology, cohesive bank materials, large woody debris, the effect of elevation on character of vegetation (species and density), or rapid changes in sediment character in mountainous regions.

In addition, empirical equations fundamentally rely on the selection of a representative dominant discharge, most commonly the bankfull discharge, although other values may be used (Doyle et al., 1999). Determination of dominant discharge can be non-trivial (Johnson and Heil, 1996) and increasingly problematic in unstable channels, wherein its significance is questionable.

The use of empirical equations to design channel attributes is not appropriate under the following circumstances:

1. Aggrading, degrading, or otherwise unstable channels cannot be reasonably characterized using published empirical relationships (Shields, 1996);
2. Site constraints identified that restrict planform amplitude;
3. Where property or infrastructure protection requirements preclude the free migration of channel planform over time; and
4. Equations that do not specifically incorporate sediment transport are applicable only to channels with relatively low bed load (USACE, 1994).

ANALYTICAL APPROACH

Analytical approaches to channel design are gaining increasing popularity, particularly in constrained, urbanized and otherwise degraded environments, and are described in most recent comprehensive channel design guidelines (FISRWG, 1998; Watson et al., 1999). Analytical approaches rely on the solution of physically based governing equations (Millar and MacVicar, 1998) and generally require quantification of one or more independent variables to determine channel parameters. Analytical approaches are also referred to as “process-based” (Soar et al., 2001).

Analytical approaches are based on the premise that channels can be described by a finite number of independent and dependent variables (Griffiths, 1983; USACE, 1994; Hey, 1978; Hey, 1988). The number of variables identified ranges in the literature to as many as 15 (Hey 1978, Hey 1988) necessary to fully describe channel geometry in natural channels. The majority of these are dependent variables that adjust to the independent variables and to each other. It is impossible to account for all variables, thus the analytical approach, like the analog and empirical approaches, must rely on assumptions about variables, and must rely on values for variables derived by non-analytical means (analog or empirical). To compute the unknown variables, only three suites of equations are available: the continuity equation, flow resistance equations, and sediment transport equations (Shields, 1996).

Analytical methods are perhaps most valuable in their ability to estimate independent variables and to predict or determine resultant dependent variables when analogs and empirical relations are non-existent or inappropriate. Most equations and methods apply only to alluvial channels, not cohesive or bedrock channels, or those dominated by large woody debris (FISRWG, 1998). Analytical methods may be used to determine the following variables:

- Sediment load (if alluvial) and computation of sediment budget;
- Discharge durations or discharge return intervals, using continuous flow simulation models; and
- Channel geometry dimensions.

Numerous analytical methods are described in the literature (Shields, 1996; FISRWG, 1998; Copeland and Hall, 1998; Millar and Quick, 1998; Fripp et al., 2001; Soar et al., 2001) addressing varying components of channel design, from deriving hydrologic statistics and sediment load to testing sediment continuity in empirical or analog designs. Analytical methods can be categorized according to the specific component of design that they address: hydraulic, geometric, or sediment character. Analytical methods can be used to determine hydraulic and hydrologic design components, such as: water surface elevations for flood control related design; shear for bed and bank design; or extent and duration of inundation for revegetation design. Similarly, geometric components of design solved using analytical methods may include appropriate channel geometry dimensions of width and depth for given slope, or planform character. Sediment components of design include sizing of bed substrate, if imported or installed, and integrating sediment transport analysis with channel geometry iterations to ensure sediment continuity.

Various computational models (HEC-6, GSTARS 2.0, FLUVIAL-12, etc.) can be valuable for some elements of iterative design, or to check the validity of proposed designs in light of sediment continuity. FISRWG (1998) lists characteristics of 8 computational models that, with few exceptions, compute the aggradation or degradation potential of a design channel, and provides references for comprehensive reviews of the capabilities and performance of the models.

Analytical methods are inherently limited by data quality and quantity used in the equations or models. Furthermore, as analytical approaches often address multiple unknown variables, equations and models generally assume constant values for a number of variables, such as cross-section geometry (assumed trapezoidal), bed sediment size distribution (Shields, 1996), and ignore other variables such as channel planform. Most channel sediment transport models do not simulate bank erosion, although recently developed models provide this capability (e.g., CONCEPTS), but at a significant cost in terms of data needed and modeling expertise. Even correctly applied sediment transport relations may produce results that differ from actual conditions by $\pm 100\%$. Analytical approaches may require numerous assumptions that cannot be adequately verified or calibrated. Similarly, the output typically creates absolute values, rather than ranges of acceptable values for channel attributes, such as channel width and planform, which in natural streams vary considerably. Channel attribute values derived analytically may deviate considerably from any basis in natural or existing conditions. For example, planform generated using an analytical approach may be non-variable, if using a sine-generated curve as suggested by Langbein and Leopold (1966). Lack of variability in planform greatly reduces hydraulic variability, sediment sorting, and consequently, limits habitat variability.

The level of analysis (and related data requirements) of some analytical methods make them impractical for application except in well-funded applied and research arenas. The efficacy of many analytical approaches depends on ability to estimate sediment load, which can require an expensive and intensive effort. Furthermore, most analytical methods require considerable ability to understand and interpret complex mathematical and computation processes, as well as a background in engineering. Consequently, practitioners with limited backgrounds (or those with

solely natural science backgrounds) may be inadequately qualified to conduct analytical methods.

SELECTING AN APPROACH

Analog, empirical and analytical approaches all have strengths and weaknesses, as well as limited application. A given project may require elements of each approach. For example, Soar et al. (2001) present a methodology for restoration design of meandering rivers which begins with determination of effective discharge from an analog reach, continues with selection of channel width from empirical data sets which relate effective (bankfull) discharge to channel width, and then applies analytical or process-based equations in the SAM package (Thomas et al., 2000) to account for channel hydraulics and sediment transport. Soar et al. (2001) further suggests that meander wavelength be determined empirically after Leopold and Wolman (1957), and that meander shape be determined analytically using a sine-generated curve after Langbein and Leopold (1966). This approach is founded on the assumption that the analog reach is in equilibrium with its hydrologic condition and sediment supply, as effective discharge is originally estimated from an analog reach.

Factors that should be used to select an approach include:

1. Watershed stability and channel stability;
2. Availability of applicable analog and empirical equations; and
3. Degree to which independent variables of hydrology and sediment supply can be quantified.

Advantages and limitations of each approach should be carefully considered when applied to design of natural channels. The advantage of the analog approach is the intuitive simplicity of replicating desired channel and habitat characteristics. Similarly, the empirical approach offers the simplicity of deriving design-channel characteristics from measured relationships among physical channel attributes from other channels. Both analog and empirical approaches require little or no consideration of sediment transport, as their application assumes equilibrium conditions.

Analytical approaches are required when channel equilibrium is in question, and when no analog templates or empirical equations are appropriate as a consequence of changing or differing hydrologic character and sediment inputs. Further, analytical approaches are often necessary to perform details of analog and empirical design when specific design components are not addressed by analog data or empirical equations. The reliability of analytical methods is dependent upon the accuracy of input variables and the applicability of the models. The analytical approach often requires more data, more time, and more highly trained personnel to apply. However, there is additional benefit to the greater quantification of design components. Quantification of design relative to process ultimately enables managers to evaluate project success and failure relative to quantifiable processes. In a field that commonly fails to conduct post-project appraisals, analytical approaches to design will provide greater avenues for evaluation of designs relative to objectives.

Project cost is also a factor in selection of design methods. In an ideal world the best design methodology will be selected, regardless of cost. However, there are practical limits to the benefits gained from additional design analyses. Once the limitations of various design approaches have been identified, these approaches can be evaluated relative to their costs. By

evaluating cost *after* evaluating the benefits of various methods, budget can guide choice with the understanding of the consequences of that choice.

RESOURCES PROVIDING DESIGN METHODOLOGIES

A number of publications describing methods, and selection of methods, for natural channel design have become available in recent years. Those listed below describe analog, empirical and analytical techniques and their application, though with varying terminology.

1. Shields, F. D. Jr. (1996) Hydraulic and hydrologic stability. In: *River Channel Restoration: Guiding Principles for Sustainable Projects*. A. Brookes and F.D. Shields, Jr. (eds.) John Wiley & Sons Ltd.
2. Federal Interagency Stream Restoration Working Group (1998) *Stream Corridor Restoration: Principles, Processes, and Practices*. National Technical Information Service, U.S. Department of Commerce, Springfield, VA.
3. NHI (National Highway Institute) (2001) *Stream Stability at Highway Structures*, Third Edition. Publication no. NHI 01-002, Hydraulic Engineering Circular No. 20. March 2001.

CONCLUSIONS

While this paper assigns approaches to channel design to three distinct categories, the methods applied in progressive modern projects are perhaps best viewed as falling along a continuum, with geomorphic/analog approaches on one end of the spectrum, and analytical/engineered on the other. Practical, functional design occurs somewhere in the middle ground (Soar et. al., 2001). Millar and MacVicar (1998) apply the term “semi-theoretical relations” to certain analytical methods or assumptions developed from empirical data sets. And indeed, all but the simplest methodologies typically require elements of analog, empirical and analytical approaches. Contemporary methods for channel design, therefore, acknowledge the limitations, and embrace the value, of the three distinct approaches presented.

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ABANDONED MINE LAND RESTORATION IN A NORTH IDAHO STREAM: A GEOMORPHOLOGICAL PERSPECTIVE

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ABSTRACT

Pine Creek, a tributary to the South Fork Coeur D'Alene River, was heavily impacted by metals mining in the 20th century. By 1960, more than 156,000 ft of mine tunnels had been excavated. In excess of 260,000 yd³ of rock waste had been dumped, much of which made its way into the East Fork of Pine Creek. The increased sediment load destabilized the stream and resulted in more than a 50% widening of the channel of the East Fork since 1933. Consequent erosion of stream banks and metals-laden tailings in the floodplain contaminated Pine Creek.

Following large-scale flooding in 1996, the Coeur d'Alene Field Office of the Bureau of Land Management (BLM) and partners undertook efforts to accelerate mined-land reclamation and floodplain stabilization on affected public lands, including Pine Creek. Project work, originally enabled through emergency flood funds, has since been supplemented with funding from the Department of Interior's Central Hazardous Materials Fund and BLM's Abandoned Mine Land (AML) program.

Using sequential historical aerial photos that dated from 1933 to present, a reconnaissance-level geomorphic assessment of sediment sources, channel-morphology trends, and riparian vegetation provided a basis for selecting restoration strategies. Additional field investigations were used to develop site-specific recommendations for channel and floodplain restoration, including: stabilization of waste-rock piles, tailings removals, bank armoring, floodplain revegetation, and channel realignment. Possible applications at other AML sites are suggested.

Substantial coordination with the local county public works department was helpful on a variety of issues. Though the Pine Creek Restoration Project is ongoing, approximately 80 percent of the priority waste-rock piles have been stabilized through a combination of grading, armoring, or channel realignment. Preliminary results after three field seasons (including an estimated 15-year peak flow) indicate an improving trend in channel and floodplain stability.

INTRODUCTION AND BACKGROUND

The Coeur d' Basin Mining District is one of the world's largest producers of silver and a major historic producer of lead and zinc. The "Silver Valley" of northern Idaho and its fabulously rich hardrock deposits formed the economic foundation for the region in the 20th century. Pine Creek, a tributary to the South Fork Coeur d'Alene River, was heavily impacted by metals mining in the

20th century. In the Pine Creek watershed, extensive mining and milling activities, together with wildfires and timber harvesting, have dramatically impacted fluvial processes.

The Bureau of Land Management (BLM) is committed to restoration of public lands that have been impacted by environmental and physical hazards that affect water quality and public health and safety. As part of this effort, BLM and its partners are investigating and cleaning up priority abandoned and inactive mine sites. For more information on BLM Idaho's AML program, please refer to website, <http://www.id.blm.gov/aml/index.htm>

PURPOSE AND SCOPE

Mine waste removal and stabilization actions are key to removing heavy metal inputs from watersheds (see Fortier and Moore, 2002, in this volume). Once the mine waste has been managed, returning the stream to a stable pre-mining condition can be approached. This paper focuses on stream-stabilization efforts that have been pursued in the Pine Creek watershed. The methodology of this restoration effort has been based on concepts and recommendations developed in field observations and geomorphic research of (Kondolf and Matthews, 1996; Matthews, 1996; and Kondolf and others, 2000, 2002).

MINING HISTORY OF PINE CREEK

The Pine Creek area is located in the Yreka mining district in western Shoshone County, Idaho. An excellent and detailed mine history of the Pine Creek area is provided in Mitchell (1996). The following brief treatment is excerpted from that work. Major mines in the Pine Creek area include the Liberal King, Amy-Matchless, Constitution, Nabob, Sidney, Highland-Surprise, Little Pittsburg, and Hilarity Mines. BLM has been involved with investigations, mine-waste removal and stabilization, and stream restoration efforts on most of these mines during the past few years.

The Pine Creek area represents about 5% of the ore and 10% of zinc produced in the Coeur d' Alene mining district (Bennett, 1984). In the Pine Creek watershed, more than 156,000 ft of underground mine workings had been excavated by 1960, (Kondolf and others, 2002). Based on the extent of underground mine development, in excess of 260,000 yd³ of rock waste was generated and deposited in streamside waste dumps. Much of this waste made its way into the East Fork and main stem of Pine Creek.

The first rich lead-silver ore on Pine Creek was discovered in 1886 (Bennett, 1986). Although many of the deposits were discovered during the late 1800s, significant production of lead-zinc and associated milling did not increase until 1916-17 during World War I. Since the ore in the Pine Creek area was a complex mixture of lead and zinc, successful extraction of metals was not effective until flotation methods were developed during the 1920s (Mitchell, 1996). The bulk of the mine waste was generated during the period of 1941-1952, coinciding with wartime metals needs for lead and zinc. Most of the mine waste rock and flotation mill tailings were deposited along the floodplains of Pine Creek, the East Fork of Pine Creek, and their tributaries, where the sediment was susceptible to frequent erosion and transport. Large volumes of mine waste were input into the drainages, particularly during the numerous flood events between 1917 and 1996 (Matthews and Kondolf, 1996).

GEOLOGIC AND GEOMORPHIC SETTING

The geology of the Pine Creek watershed is dominated by metasedimentary rocks of the Precambrian Belt Supergroup. According to Lewis and others (2000), metasedimentary rocks exposed in the watershed are Middle Proterozoic, or approximately 1,600 to 900 million years old. Within the southern half of the Pine Creek watershed, headwater streams are underlain primarily by the Revett and Burke Formations (fig.1). A relatively small area of St. Regis Formation crops out in the upper reaches of the West Fork of Pine Creek. The lower, northern end of the watershed is underlain by the Prichard Formation. The relative stratigraphic positions and dominant lithologies are shown in Table 1. Structural controls include east-west- and northwest-trending faults. Mineralization in the Pine Creek area consists of lead-zinc-silver vein deposits occurring within the Prichard Formation in the East Fork of Pine Creek.

Table 1. General Stratigraphy in the Pine Creek watershed (from: Lewis and others, 2000).

Age	Stratigraphic Unit	Lithology
PreCambrian: Middle Proterozoic (1600 to 900 million years ago)	St. Regis Fm. (Ysr)	Purplish-red-green argillite
	Revett Fm. (Yr)	Argillaceous quartzite
	Burke Fm. (Yb)	Argillaceous quartzite
	Prichard Fm., undivided (Yp)	Dark-gray argillite

The Pine Creek watershed includes a mountainous area of approximately 80 mi² that drains northward through the town of Pinehurst into the south Fork of the Coeur d' Alene River. Elevations range from approximately 2,200 to 6,400 ft. Pine Creek has a West Fork and an East Fork, which merge 6 miles upstream from Pinehurst. There is very little flat land, with the exception of the alluvial valley bottomlands along the East and West Forks. Bedload in Pine Creek is dominated by coarse material consisting of resistant, quartzite cobbles and boulders of the Revett and Burke Formations. Less abundant, less durable clasts of argillite from the Prichard Formation compose the remainder of the stream deposits. Due to the nature of the source materials, floodplain deposits are low in organic matter content.

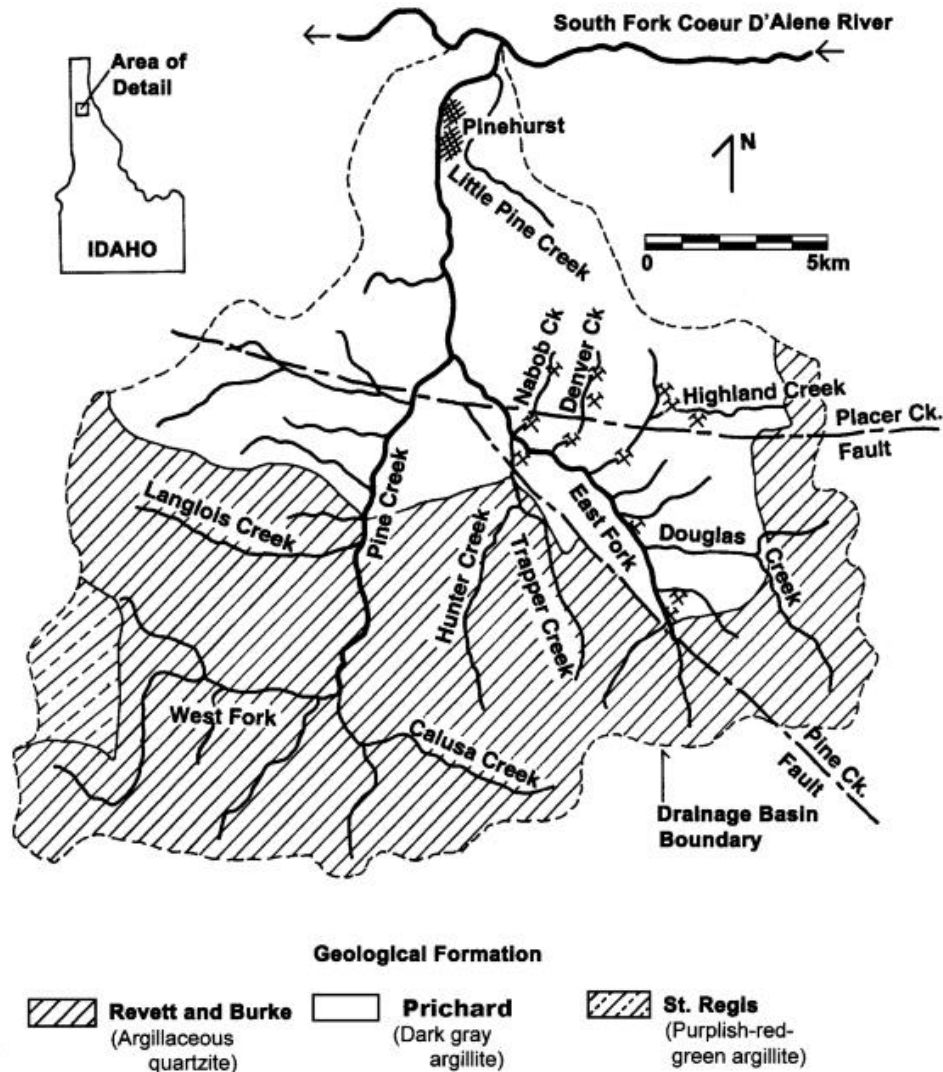


Figure 1. Generalized geologic map of the Pine Creek watershed (modified from Kondolf and others, 2002).

Several major events have influenced the fluvial geomorphic processes in the watershed (Kondolf and Matthews, 1996). Near the turn of the century, large cedars from the valley floors were extensively harvested. In 1910, the Coeur d'Alene Basin fire of 1910 burned the East Fork drainage down to the channel. From the 1920s to the 1950s, the ridgetops were extensively grazed. From the 1950s to the present, steep slopes of the West Fork have been logged. During the early part of the century, intensive mining has affected much of the watershed resulting in a large input of tailings and waste rock into the East Fork and its tributaries. Channelization has also occurred in the lower 2.3 miles of the West Fork.

Several major floods have occurred in Pine Creek during the 20th century, as well as a recent moderate flood in 2002. Prior to that, extensive flooding occurred in 1996, resulting in significant channel modification and erosion. Because of all these influential events, channel morphology and floodplain stability have been severely impacted in the 20th century.

ANALYSIS OF SEDIMENT SOURCES AND CHANNEL MORPHOLOGY

Kondolf and Matthews (1996) provided a reconnaissance-level investigation that provided insights to changes in channel morphology resulting from increased sediment inputs in the watershed. Matthews and Kondolf (1996) found that the removal of the mature bottomland cedar forest, in combination with increased sediment loads, caused the channel to cross a geomorphic threshold and adopt an unstable, braided pattern. This led to destabilization of alluvial valley floors. Particularly in the East Fork, the mining activities resulted in increased sediment loads that accelerated the evolution from a stable, narrow, sinuous channel to an unstable, wide, braided channel.

FIELD OBSERVATIONS OF SEDIMENT SOURCES, SEDIMENT DELIVERY, AND CHANNEL DESTABILIZATION

Many of the existing sediment sources in the East Fork watershed were obvious from field inspection, where large rock waste piles were visibly contributing coarse sediment to the channels. Effects of the 1996 flood were compared on two tributaries, Douglas Creek and Highland Creek. They are comparable in drainage area (6.3 vs. 5.0 square miles), relief, basin aspect, and fire history, but they differ in two respects: the presence of sediment storage sites in downstream reaches of Douglas Creek and in mining history. The Douglas Creek basin has not been subject to extensive mining or road construction, while the Highland Creek basin has been heavily mined, involving removal of vegetation, construction of roads and industrial development, and most importantly, discharge of waste rock into the channel. Thus, Douglas Creek illustrates the sediment transport regime likely prevailing in Highland Creek prior to mining and the resultant increased sediment yield, although with a lower reach in which deposition is more likely before reaching the East Fork channel.

Field observations indicate that during the 1996 floods, with an estimated return period of 50 years, the upper reaches of Douglas Creek were actively transporting bedload and reworking channel deposits. The channel remained narrow and stable, with fresh sediment deposits only in protected sites behind obstructions, low gradient reaches above controls, and spread out on wooded floodplains (Kondolf and Matthews, 1996).

In contrast to Douglas Creek, the active open channel of Highland Creek occupies most of the canyon bottom. The width of freshly deposited sediment varies, but is commonly 40- to 80- feet wide. Cedar stumps were buried under aggraded sediment (typically about 2-feet thick) along the length of the Highland Creek channel downstream of the mines. The fresh deposits included a large fraction of dark Prichard Formation lithologies, implying that much of this sediment was derived from mine rock waste dumps. In contrast, the channel upstream of the Highland Surprise Mine is narrow (typically 10-15-feet wide), with a continuous, dense riparian corridor along the bank, similar to the channel of Douglas Creek.

The channel morphology and evidence of aggradation downstream of the mines indicates a greatly increased sediment load in Highland Creek. This increased load has overwhelmed the sediment storage capacity of the valley bottom, and is being transported through the reach to the mainstem of the East Fork, forming an alluvial fan at the confluence. Significant aggradation, lateral migration, and fan building were again evident in April 2002, following a moderate flood with an estimated return period of 10-15 years.

Mine wastes have obviously played a key role in increasing bedload and destabilizing channels and bottomland deposits. However, the coarse sediments in the bed of Pine Creek consist primarily of white quartzite, most of which is derived from the Revett and Burke Formations, which outcrop over most of the basin. The mine rock wastes are composed principally of the Prichard Formation, which is predominately dark-gray- to black-laminated argillites. The overwhelming dominance of white quartzite in the bed material of the East Fork implies that despite large inputs of rock wastes near the point sources, these wastes do not constitute a large fraction of the sediment in the East Fork.

It is hypothesized that mine-derived sediment served to destabilize the channel, and that much of the sediment transported downstream was simply reworked from pre-existing bottomland deposits. This suggests that progressive destabilization of the channel does not reflect the downstream propagation of a wave of coarse sediment, but rather propagation of channel instability, such that most of the sediment visible at one point in the channel is probably derived from erosion of bottomland deposits a short distance upstream (Matthews and Kondolf, 1996). Another supporting observation is that relict cedar stumps, where present, are not buried by sediment as might be expected in the event of massive aggradation. In addition, photo analysis indicates that the increase in area of exposed, unvegetated, active channel did not progress downstream from the point sources of mine-derived sediment. Instead, the downstream reach of Highland Creek began to destabilize first, and the destabilization propagated upstream.

RESTORATION PROJECT DEVELOPMENT

As previously noted, the first step in the development of conceptual restoration designs for Pine Creek was a reconnaissance-level investigation of sediment sources and geomorphic history. This investigation was conducted soon after the flood of 1996 and the subsequent report (Kondolf and Matthews, 1996) was used by BLM as first step in defining several flood-related issues: problem assessment; restoration feasibility; and additional informational needs. The second step was to have aerial photography flown for the entire Pine Creek watershed. The stream corridor photos were enlarged to a scale of 1 inch= 100 feet. Mylar overlays were also generated at the enlarged scale and used to produce blue-line prints for field use and design.

With the aid of the post-1996 flood aerial photos, an additional field investigation was conducted. Building upon the reconnaissance investigation, a more detailed report outlining conceptual designs for stream restoration projects was produced for BLM (Matthews, 1996). This report includes conceptual design guidance for use in the planning and design of projects within the Pine Creek system. Additional site-specific investigations by BLM, including analysis of longitudinal profiles, cross-sections, channel hydraulics, and pebble counts, were used to develop specific design and construction drawings.

OVERVIEW OF CONCEPTUAL DESIGN FRAMEWORK

The design framework is based on two primary strategies: (1) the control of sediment sources; and (2) in-place stabilization of sediment deposits by channel restoration and re-establishment of the riparian forest. The recommendation to stabilize sediment in place was based upon the hypothesis that a geomorphic threshold was exceeded in the East Fork first, followed several decades later by the West Fork. This was a result of decreased bank and floodplain stability resulting from loss of the floodplain forest, together with increased sediment

loads. The potentially long wait necessary for flushing the sediment, as well as the potential impairment of flood-control infrastructure downstream in Pinehurst, are both arguments for stabilizing deposits in place upstream. The design framework from Matthews (1996) incorporates the following concepts:

1. Relocate the channel away from active hill-slope failures that are sediment sources.
2. Create a more meandering channel.
3. Implement actions to train the stream towards a single-thread channel.
4. Minimize channel grading by identifying areas with acceptable geometry.
5. Minimize efforts to adjust longitudinal profile.
6. Identify and incorporate existing stable floodplain surfaces.
7. Incorporate bedrock outcrops as locations for channel bends.
8. Stabilize bends with bio-technical log/root-wad/boulder structures.
9. Consider risks to existing development.
10. Revegetate channel toes and slopes.
11. Revegetate floodplain surfaces.

PROJECT CONTRACTING

Construction contracting was simplified by using a multi-year, indefinite quantities equipment rental contract. Basically, typical tasks were defined with general descriptions, including floodplain grading, willow trenching, and bank stabilization. A guaranteed overall minimum dollar commitment by BLM was offered. Bidders submitted hourly equipment rates and mobilization costs. Once the contract was awarded, BLM issued task orders specifying the equipment needed and an estimated number of hours to complete the task order. This proved to be very efficient and allowed for flexibility in implementing the tasks under a range of site conditions. Similarly, separate multi-year indefinite quantities, supply and deliver contracts were awarded for riprap and topsoil to allow for easy coordination between the soil and rock deliveries and the equipment placing the material.

PRELIMINARY RESULTS AND LESSONS LEARNED

Long-term monitoring is the only way to effectively determine changes in stream trends. BLM is monitoring the effects of restoration efforts using numerous reference cross sections, sampling sites, and photo points. After three field seasons, roughly 80% of the streamside rock dumps and tailings piles have been treated. This has involved a range of treatments including: regrading and toe armoring of steep waste rock piles in narrow tributaries; relocating the channel away from two rock dumps, one tailings pile, and three active hill-slope failures; and physical removal of tailings at five sites.

Treatment of Sediment Sources

Based on visual inspection and cross-section analysis, reduction of sediment loading from rock-pile stabilization appears to be successful, though additional toe stabilization is still needed at the steepest rock piles. This work is scheduled for the 2002 field season.

In three stream reaches the channel was moved away from steep, erosive waste rock piles. At two of the sites, the stream channels appear to be stable and properly functioning. The other site, on lower Highland Creek, did not function as well during an above-average flow. Bank erosion and lateral migration caused by the high sediment load upstream was evident. Bank stabilization was insufficient and the original channel design width appears to be too narrow to accommodate the elevated sediment load in this stream reach. Modified stabilization measures at this site are scheduled for fall 2002.

Following physical removal of floodplain tailings deposits, several of the sites have been regraded, covered with topsoil, and revegetated with grasses and willows. Vegetative success has been promising, particularly following the second year after planting.

Channel and Floodplain Restoration

During moderate to large floods, Pine Creek, particularly the East Fork, has repeatedly washed away hundreds of feet of paved county road, plugged or washed away undersized culverts, and scoured around bridges. BLM has replaced one undersized culvert and stabilized the channel and eroding streambanks above it. Following a recent flood with an estimated 15-year return period, the culvert performed well, while three other tributary culverts, on both forks of Pine Creek, required maintenance by the county. BLM has applied jointly with the local county public works department for cost-share funds to upgrade several culverts.

On a larger scale, the overall restoration efforts towards channel stabilization and floodplain revegetation on the mainstem and the lower East and West Forks of Pine Creek appear to be working. Approximately six miles have been graded, following the concepts developed in the previously described reports. Where stable geometry exists, the channel was not graded at all and bedrock outcrops have been incorporated for channel bends where feasible. Stable floodplain surfaces have been planted and revegetation efforts, which are relatively inexpensive, will continue as funding permits.

Lateral erosion of floodplain surfaces has been reduced by the comprehensive grading, revegetation, and bank-stabilization projects. Qualitative short-term results have been positive in many reaches where planted vegetation was recently covered by thin deposits of fine sediments, and bedload deposition at bridges and culverts following a ten year-event was about equal to or less than previous two-year events. Revegetation has varied by stream reach, but in general, trenched willows have been very successful. Containerized plantings have been successful also, particularly the one-gallon size alders and dogwoods. Planting with a Bobcat equipped with a six-inch auger has been the most efficient method for planting container stock. Because of cost and the extensive area of floodplain to be revegetated, use of topsoil has been limited primarily to priority areas on top of mine tailings removal sites. Topsoil has worked well for establishing grasses when applied four- to six-inches deep.

The major lesson learned from stream-restoration activities along Pine Creek is that a thorough understanding of the geomorphic processes is necessary for the restoration project design. Without proper consideration of the overall stream system, interim channel modification measures may be only temporary. In addition, a careful consideration of realistic timelines for recovery is essential. While land management agencies are often compelled to demonstrate

short-term results, we recognize that recovery in Pine Creek will take decades. An improving trend will depend far more on successful floodplain revegetation - working with natural processes - than extensive structural measures.

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**TECHNICAL PAPER SESSION 5
BIOLOGY / VEGETATION**

Title: [Effects of Cadmium on White-tailed Ptarmigan in Colorado](#)

Author: [Dr. James R. Larison](#)*, Professor and Avian Ecologist, Dept. of Fisheries and Wildlife, Oregon State University

Title: [Monitoring and Evaluating the Results of Bat Protection Efforts](#)

Authors: [K.W. Grandison](#)*, Associate Professor Biology, Southern Utah University; **J.M. Diamond**, Southern Utah University; **G.F. Diamond**, Southern Utah University; **V.J. Tyler**, Southern Utah University; and **M.R. Mesch**, Utah Division of Oil, Gas, and Mining

Title: [Revegetation of Nine Square Miles of Copper Tailings](#)

Authors: [Henry Sauer](#)*, Environmental/Soil Scientist, Greystone Environmental Consultants, Inc. and **Tom Williams**, Golder Associates Inc.

Title: [Vegetative Community Analysis of Biosolids Test Plots After Five Years of Growth](#)

Authors: [Rick Black](#)*, Senior Ecologist and Biological Programs Manager, HDR Engineering, Inc. and **Richard K. Borden**, Kennecott Utah Copper

Title: [Rooting Characteristics of Vegetation Established on a Refuse Pile](#)

Authors: [Priscilla W. Burton](#)*, Soils Reclamation Specialist III; **Paul Baker**, **Susan White**, Utah Division of Oil, Gas & Mining; **Bob Postle**, OSMBWRCC; and **Patrick Collins**, honorary member, Mt. Nebo Scientific

EFFECTS OF CADMIUM ON WHITE-TAILED PTARMIGAN IN COLORADO

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ABSTRACT

Cadmium is known to be toxic to vertebrates when test organisms are exposed to sufficiently high dietary concentrations. But because cadmium occurs as a trace constituent of most ecosystems, it has rarely been observed to have toxic effects on natural populations of wildlife. This paper summarizes the results of a multi-disciplinary study of the effects of metals on wildlife living in the ore-belt region of Colorado. It reports that white-tailed ptarmigan (*Lagopus leucurus*) in this region are: 1) exposed to uncharacteristically high levels of cadmium through their diets; 2) accumulate potentially toxic cadmium concentrations in their kidneys after just 700 days of exposure, and that approximately half of adult ptarmigan in the region; 3) experience cadmium-induced nephrosis of kidney tissue and, probably as a result; 4) develop calcium-poor leg bones. Additionally, this paper suggests that ptarmigan may not be the only herbivores in the region to be affected by cadmium but rather, may be indicators of a broader problem affecting ecosystems generally in central and southwestern Colorado.

INTRODUCTION

C.E. Braun of the Colorado Division of Wildlife (CDoW) reported high mortality rates and low reproductive success among certain populations of White-tailed Ptarmigan in Colorado (Braun 1969:62). At the time, Braun attributed these differences in fitness to some unknown environmental factor, possibly “quality of habitat.” Later, while working in the Animas River watershed in the San Juan Mountains of southwestern Colorado, Braun captured ptarmigan with unusually brittle bones (pers. comm.).

Over the past six years, I have studied the effects of trace metals on White-tailed Ptarmigan in the Animas River watershed in southwestern Colorado (Larison et al. 2000; Larison et al. 2001; Crock et al. 2000; Larison 1999, 2001;) attempting to determine if the Braun observations were somehow linked to one or more of the metals common to central and southwestern Colorado. Little is known about the effects of metals on natural populations. Most trace metal research to date has focused on “acute” rather than “chronic” exposure and has used captive animals, high dose rates, and short exposure times. Because the effects of a single, large dose are often quite different from those produced by repeated, small doses (Eaton and Klaasen 1996), studies of acute toxicity are only marginally useful in assessing risk to natural populations. In addition, most studies of metals toxicity among natural populations have been done in aquatic ecosystems. Few investigators have explored the effects of chronic metals exposure on terrestrial organisms or populations.

That we know so little about the effects of metals on natural populations is particularly troubling because human activities tend to mobilize metals (Lantzy and MacKenzie 1979, Nriagu 1979, Nriagu 1980, Nriagu and Pacyna 1988). In particular, mining activities such as those common to Colorado have contributed to a worldwide build-up of metals in biologically sensitive places (Roberts and Johnson 1978). Rising levels of contamination have been detected

in even some very remote ecosystems having been transported there by wind (Nriagu 1979). Nriagu and Pacyna (1988:139) have said, “mankind has become the most important element in the global biogeochemical cycling of the trace metals.” Concern exists that anthropogenic mobilization of trace metals is expanding the geographic boundaries of the metals problem and increasing the numbers of organisms and species affected.

A number of investigators have shown that these metals can have a cumulative effect on captive test subjects (Friberg et al. 1986); once herbivores ingest them, these metals begin to build up in kidney and liver tissues. When dietary exposure levels are high enough or when exposure times are long enough, some trace metals will eventually reach toxic levels in the kidney (Friberg 1952, Nordberg 1978). When test subjects are exposed to sufficient concentrations of metals, renal tubules eventually fail, producing a condition of metals stress (Richardson et al. 1973, Webb 1979, Elinder et al. 1981, Nicholson and Osborn 1983). Because damaged kidney tubules are less efficient than undamaged tubules, it has been suggested that a damaged kidney would be unable to maintain appropriate serum electrolyte balances and would permit calcium to be excreted (Ceresa 1945, Hiroto 1971, Hook and Hewitt 1986, Kido et al. 1988). In a cascading effect, calcium would be lost from bone tissue as the body borrows from the skeleton to make up for serum losses (Chang et al. 1980, Bhattacharyya 1991, Sacco-Gibson 1992). A number of researchers have documented a causal relationship between one such metal—cadmium—and skeletal weakening in test animals (Ceresa 1945, Larsson and Piscator 1971, Bhattacharyya 1991). This relationship has been reviewed thoroughly by Cooke and Johnson (1996) and Furness (1996).

METHODS

Over a period of six years, I used a multidisciplinary approach to overcome some inherent difficulties associated with the study of environmental toxins, *in situ*. I combined geological, botanical, physiological, and demographic studies to answer questions about possible metals poisoning in the White-tailed Ptarmigan, an herbivore (Larison et al. 2000, Larison et al. 2001, Larison 2001). I began with the broad hypothesis that metals were responsible for the brittle-bone condition observed by Braun among certain populations of White-tailed Ptarmigan in southwest Colorado. I postulated further that metals stress might have reduced fitness in at least some of these populations. To better understand how metals stress might be linked to the brittle-bone condition and to fitness, I generated a model and then collected new data to test assumptions about possible mechanisms involved. I asked: i) what potentially toxic trace metals are present in the study area; ii) how specifically are ptarmigan exposed to these metals, if they are exposed; iii) what tissues are affected by these metals; and iv) what life history changes occur in association with these metals. In the process, I traced metals through the ptarmigan diet, monitored accumulation rates and effects in target organs, examined tissue responses and damage, and evaluated possible effects on reproductive success and survival.

Ptarmigan Foods

Using ICP-AES total analysis, after Crock et al. (1999), I evaluated all plant species known to be consumed by ptarmigan for metals (i.e. Cd, Cu, Zn, Pb, Fe) and salts (Larison 2001). Samples of six different plant genera were collected from four study sites. These sites were scattered along the mineral zone of Colorado from Guanella Pass near Mt. Evans (39° 33'

N; 105° 42' W) to the San Juan Mountains (37° 54' N; 107° 44' W) north of Durango. Several of these sites are near abandoned mine sites; others were relatively metals free.

I sampled leaf buds and apex stems of several species of willow (*Salix spp.*) in winter. In summer, both erect and prostrate varieties of willow were sampled, as were *Trifolium spp.*, *Geum rossii*, *Bistorta bistorta*, *Carex ebenea*, and *Dryas octopetala*. Samples were taken only where birds were observed to feed. Each feeding area was sampled comprehensively. Each sample consisted of at least 200 g of plant tissue from as few as 10 or from as many as 300 independent plants, depending on species. Samples were collected either with powderless gloves or with stainless-steel scissors. Only those parts of each plant that were known to be preferred ptarmigan foods (Quick 1947, Braun 1969, Braun et al. 1993) were collected.

The physical preparation of materials were done by chemists at the USGS laboratory in Denver and consisted of drying, milling, and ashing after Peacock (1992). Samples were not washed because ptarmigan eat unwashed plant matter. Ashing was done in a muffle furnace, programmed to slowly ramp up to 500° C over a 5-hour period. Complete ashing was assured by maintaining this temperature for at least 12 hours. The furnace subsequently was allowed to cool for 8 hours before samples were removed. Samples were digested in a cocktail of acids (including hydrofluoric, hydrochloric, nitric, and perchloric) at low temperature and pressure, after Crock et al. (1983). Crock et al. (1999) report that cadmium and zinc both are digested completely by this procedure.

Animal Tissue

Using multi-metal tissue analysis, I measured cadmium concentrations in two geographically distinct populations to determine whether elevated metals concentrations existed in liver and/or kidney tissue of White-tailed Ptarmigan inhabiting the minerals-rich zone of Colorado (Larison et al. 2000, Larison 2001). The study population inhabited the mineral zone west and southwest of Denver, Colorado. The reference population inhabited Indian Creek and Ahtell Creek north and northeast of Anchorage, Alaska.

Multi-metal total analyses of tissues were performed by means of inductively coupled plasma-atomic emission spectroscopy (ICP-AES) by chemists in two independent laboratories, after Crock et al. (1999). At each laboratory, 1.0 g samples of tissue were digested in ultra-pure concentrated nitric and hydrochloric acids. The resultant ash was brought to a total volume of 10 ml in a matrix-matched nitric acid dilution. Multi-metal scans were made of each sample. At the UC-Davis Veterinary Diagnostic Laboratory, NIST bovine liver (1577b) and NRCC TORT-2 standards were run, as was a method blank and Cd-spiked samples. The TORT-2 was assayed at 26.7 ppm Cd, 106 ppm Cu, and 180 ppm Zn. At the Cornell University ICP Laboratory, a bovine NBS standard (1577b), assayed at 0.5 ppm Cd, 160 ppm Cu, and 127 ppm Zn was used.

Histopathologies were done on 39 kidneys and 12 pancreases at the UC-Davis Veterinary Diagnostics Laboratory. These tissues were embedded in wax, stained, thin-sectioned, and examined at varying magnifications using a light microscope. Tissues were examined for evidence of tubular damage and/or failure.

Bone Tissue

Bone tissue was analyzed for the presence of metals and for the salts concentrations (Larison 2001). Lyophilized samples were crushed, placed in acid-washed crucibles, and

covered with 20 % trace-metals-grade nitric acid for 2 hours. Samples were placed in a muffle furnace, “ramped up” to 450° C and held at this temperature overnight. Ashed samples (0.2 g) were digested in a cocktail of 2 ml concentrated nitric, 1 ml concentrated hydrochloric, and 2 ml concentrated hydrofluoric acids, after Briggs and Meier (1999). A 1:10 dilution of the sample was made using 1 % nitric acid. J. Crock, a USGS geochemist, analyzed these samples using an Inductively Coupled Mass Spectrometer (ICP-MS–Perkins Elmer Elan 6000). A dual detector calibration and auto-lens adjustment was performed prior to machine use, following manufacturer’s specifications. Two calibration standards and a 1 % nitric acid blank were run with each batch of samples.

RESULTS

Plant Tissue

Noteworthy levels of cadmium, zinc, and copper were detected in all ptarmigan food resources tested (Table 1). Cadmium concentrations ranged from 0.1 to 11 $\mu\text{g g}^{-1}$. Zinc levels ranged from 29 to 619 $\mu\text{g g}^{-1}$. Copper concentrations ranged from 1 to 21 $\mu\text{g g}^{-1}$. Metals concentrations were highest in plants belonging to the genus *Salix*. In the willows, cadmium levels were found at concentrations significantly above those reported elsewhere in North America (Peterson and Alloway 1979, Page et al. 1980).

Table 1: Mean metals concentrations in six plant genera collected in the mineral zone of Colorado (mg k^{-1} – dw).

Plant Genus	Cd	Co	Cr	Cu	Fe	Mn	Ni	Pb	Zn
<i>Geum</i>	0.23	0.29	1.62	6.81	2000	90	2.36	0.25	30.2
<i>Bistorta</i>	0.14	0.38	1.27	7.22	2000	238	3.61	0.68	53.2
<i>Carex</i>	0.15	0.60	2.20	7.60	3000	483	6.00	0.30	48.0
<i>Dryas</i>	0.20	0.30	3.40	5.00	7000	135	2.21	3.10	29.0
<i>Trifolium</i>	0.23	0.58	1.21	6.11	2000	139	2.10	0.44	51.5
<i>Salix</i>	2.84	0.84	1.45	6.46	2000	312	2.95	1.02	187

Animal Tissue

Elevated renal cadmium, zinc, and copper concentrations and elevated hepatic-cadmium concentrations were detected in White-tailed Ptarmigan throughout the mineral zone of Colorado (Figure 1). Among nine adult ptarmigan collected on and near Mt. Evans and Guanella Pass, four (44%) had kidney-Cd levels greater than 100 $\mu\text{g g}^{-1}$; all had levels greater than 50 $\mu\text{g g}^{-1}$. Among 25 adult ptarmigan collected in the Animas River watershed, 12 (48%) had kidney-Cd levels greater than 100 $\mu\text{g g}^{-1}$; all had levels greater than 40 $\mu\text{g g}^{-1}$. In contrast, birds in the reference population had only moderately elevated kidney-Cd levels as compared to the norm for birds. Only a single bird collected outside the mineral zone had a kidney-Cd level greater than 40 $\mu\text{g g}^{-1}$. In the mineral zone, 27 % of ptarmigan had kidney-Cd levels greater than 100 $\mu\text{g g}^{-1}$, 94 % had elevated levels greater than 20 $\mu\text{g g}^{-1}$, and only 6 % (all chicks) had kidney-Cd

levels below $20 \mu\text{g g}^{-1}$. Outside the mineral zone, 96 % of birds had kidney-Cd levels below $20 \mu\text{g g}^{-1}$. Only a single Alaskan White-tailed Ptarmigan had an elevated kidney-Cd concentration. The differences in means between populations (Colorado mineral zone versus non-mineral zone) were highly significant for kidney-cadmium, zinc, and copper as well as for hepatic-cadmium ($P < 0.001$ in all four cases) and not significant for liver-copper or for liver-zinc ($P > 0.5$).

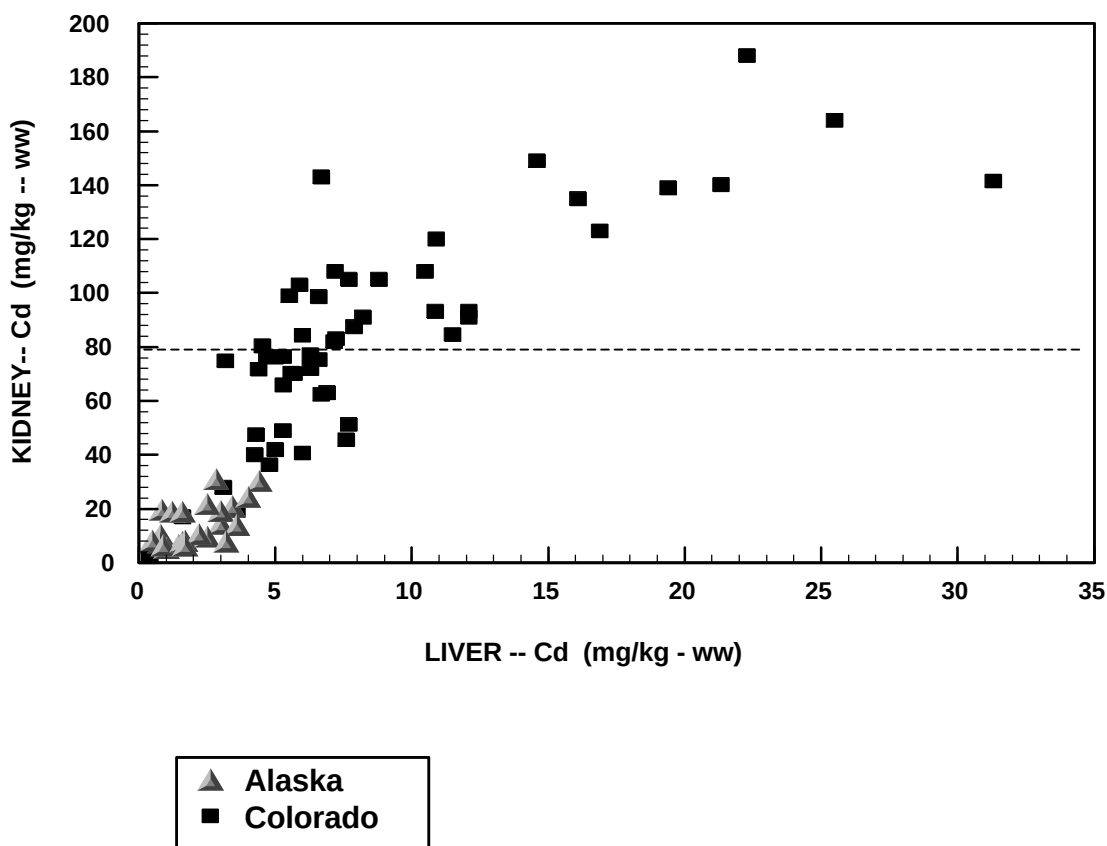


Figure 1. Kidney- and liver-cadmium levels in two populations of White-tailed Ptarmigan. Difference in means between populations is highly significant ($P < 0.0001$). Toxic threshold (dashed line) from Furness 1996.

Kidney-Cd and liver-Cd concentrations were correlated. A nearly linear relationship appeared at cadmium concentrations below the toxic threshold, but a reduction in the rate of cadmium accumulation occurred at higher kidney-Cd values.

Kidney-Cd levels were markedly age-dependent among ptarmigan in Colorado (Table 2). Chicks were relatively cadmium free (mean $1.1 \mu\text{g g}^{-1}$ Cd, SD = 0.8); 6-month old sub-adults had moderately elevated accumulations (mean $21.4 \mu\text{g g}^{-1}$ Cd, SD = 5.8); young-adults (9 – 23 months of age) had elevated levels (mean $59.5 \mu\text{g g}^{-1}$ Cd, SD = 29.7), adults (24 months old or older) had substantially elevated levels (mean $99.4 \mu\text{g g}^{-1}$ Cd, SD = 36.6); and older adults (36 months old or older) had cadmium levels above the toxic threshold (mean $100.5 \mu\text{g g}^{-1}$ Cd; SD = 21.4). An age-dependent pattern of accumulation was not discernible among birds in the reference population.

Table 2: Age-dependent kidney-cadmium accumulations in ptarmigan in Colorado ($\mu\text{g g}^{-1} \text{ ww}$)

Age	Mean	SD	n	CV
Chicks (0 to 1 month old)	1.1	0.8	3	73%
Sub-adults (6 months old)	21.4	5.8	3	27%
Yearlings (9 to 23 months old)	59.5	29.7	7	50%
Adults (24+ months old)	99.4	36.6	35	37%
Adults (36+ months old)	100.5	21.4	7	21%

When kidney-Cd levels were examined among known-age birds (banded either as chicks or as sub-adults with pigmented ninth primaries), a constant rate of accumulation was observed (Figure 2). This rate was calculated to be approximately $0.5 \mu\text{g Cd/day}$ of exposure. By projecting this rate over the lifetime of the ptarmigan, I estimated that the average ptarmigan in the minerals zone of Colorado accumulates potentially toxic levels of cadmium ($= 100 \mu\text{g g}^{-1}$) after 600 to 800 days of dietary exposure. Given the high dietary exposure rate measured in ptarmigan in the minerals-rich zone of Colorado, such an accumulation rate is reasonable and would necessitate a gut absorption rate of less than 1 %. Older birds (those with significant renal tissue damage) appear to excrete cadmium and other metals.

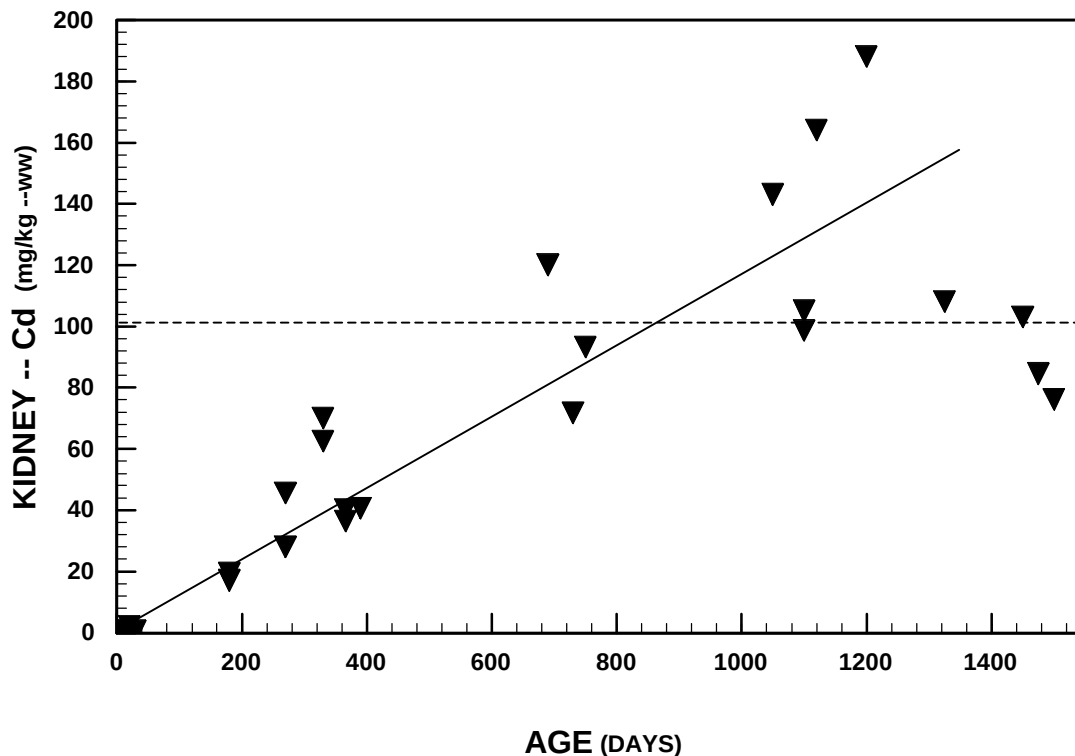


Figure 2. Kidney-cadmium accumulations in known-aged White-tailed Ptarmigan in Colorado. Toxic threshold (dashed line) from Furness 1966.

Histopathological examinations were performed on 39 ptarmigan kidneys, 12 from Alaska and 27 from Colorado. Among the Colorado birds: 9 were males, 17 were females, 1 was a chick of unknown sex, 3 were yearlings, and the remaining adults were of varying ages. Renal tubular damage (nephrosis) was observed in five females and eight males. Light-to-moderate numbers of dilated tubules lined by attenuated epithelium were observed in 4 adult females. Mononuclear interstitial inflammatory cell infiltrates were observed in five additional males. Amorphous concretions or fine granular metals deposits were observed in one female and three males. All male ptarmigan from the Colorado mineral zone had some sign of cellular damage in association with metals deposits. The single chick kidney from Colorado, all kidneys from Alaska, and all three kidneys from yearling ptarmigan from Colorado were unremarkable, showing no significant cellular damage. Most (57%) adult White-tailed Ptarmigan from the minerals zone of Colorado had some renal damage. This damage was most severe among overwintering females, and was most common among older adults. Forty-three percent of adults and all sub-adults had unremarkable kidneys. Pancreatic tissue was unremarkable in all cases.

Chemical Content of Bone

Femur ash, calcium, phosphorus, and calcium/phosphorus ratios were lower in White-tailed Ptarmigan with kidney-Cd levels greater than $100 \mu\text{g g}^{-1}$ than in ptarmigan from Colorado or Alaska with kidney-Cd levels below this threshold (Table 3). Femurs of birds with kidney-Cd levels greater than $100 \mu\text{g g}^{-1}$ contained 8–10 % less bone ash and bone calcium than birds

with lower levels. The difference in means between these two groups was not statistically significant for femur ash ($P < 0.09$) but was highly significant for femur calcium ($P < 0.01$). The calcium content in both the femur and tibiotarsus was inversely correlated with kidney-cadmium levels. The correlation was strongest in the femur.

Table 3: Femur ash salt (%) and metals (ppm) concentrations in White-tailed Ptarmigan from Alaska and two groups of ptarmigan from Colorado—one with kidney-Cd levels greater than $100 \mu\text{g g}^{-1}$, the other with lower kidney-Cd levels.

Category	Ash	Ca	P	Ca/P Ratio	Cd	Cu	Zn
Colorado							
< 100	34.1	40.1	20.8	1.96	0.50	2.6	332
> 100	31.1	37.8	20.5	1.85	0.91	2.6	313
Alaska	34.3	41.1	21.1	1.94	0.23	2.7	331
Poultry*	40 – 57	40 – 57	35 – 52	3.5 – 4.0	--	--	400+

* (Puls 1988)

The calcium/phosphorus ratio was low for all ptarmigan examined. It was especially low (1.85) for ptarmigan with high kidney-Cd levels. Although, generally speaking, bone does not accumulate high levels of cadmium, femur levels were 68 % higher in the mineral zone and 82 % higher for ptarmigan with kidney-Cd levels greater than $100 \mu\text{g g}^{-1}$ than for ptarmigan with non toxic kidney-Cd levels. Mean femur-zinc and copper levels were not significantly different ($P > 0.05$).

DISCUSSION

The minerals zone of Colorado contains unusually high concentrations of a number of potentially toxic trace metals; this much has been known for some time. The value of this study is that it provides evidence to support the hypothesis that at least some of these metals travel from the abiotic environment to terrestrial ecosystems by way of certain plants. The genus *Salix* appears to be the primary vector. Any herbivore consuming plants of this genus is potentially at risk of metals poisoning. We do not as yet know the extent to which past (or present, for that matter) mining operations contribute to the movement of metals from soils to ecosystems but it is likely that human activities in the ore belt region of Colorado have accelerated this process.

This study focuses on cadmium and uses the White-tailed Ptarmigan as an indicator of ecosystem health. It answers many questions about how cadmium moves through the food web and concentrates in ptarmigan renal and hepatic tissue. It documents toxicity, nephrosis, and declines in bone-calcium levels. But we do not yet know the effects of these metals on ptarmigan fitness.

It is now clear that cadmium affects ptarmigan in the Colorado ore belt, but we do not yet know the affect of cadmium on other herbivores in the region? Are elk, moose, beaver, snowshoe hare, or rodents in the area at risk? And what of the carnivores that regularly consume

cadmium-contaminated herbivores. Are they at risk? And, finally, this research begs the question, what affect is cadmium having on humans in this region?

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MONITORING AND EVALUATING RESULTS OF BAT PROTECTION EFFORTS

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ABSTRACT

Many States are authorized to close abandoned mines to protect the public from potential hazards. In Utah, abandoned mines are surveyed prior to closure to evaluate their potential as bat habitat. Those mines providing suitable habitat may be sealed with bat-compatible gates that allow bats continued ingress and egress. However, a few studies suggest that for some population sizes and certain species of bats, bat gates may actually decrease bat use of mine openings; few post-gate monitoring studies exist to document long-term effects of this technique for conserving bat populations. In two areas we are monitoring and evaluating the effectiveness of gated mines on existing, known bat populations. Objectives include: evaluating and ranking the effectiveness of techniques [e.g., night vision devices, infrared event counters (Trailmaster 500M), infrared video, ultrasonic detection equipment (Anabat) and mist nets or harp traps] to monitor bat use; using this information to develop a protocol for using the most reliable of these techniques; and establishing long-term monitoring sites. Evaluation criteria include purchase and operating costs, security concerns, equipment reliability and ease of operation, number of personnel necessary to gather and evaluate the data, the ease of analyzing the data, and type of information needed. We suggest a combination of techniques to meet long-term monitoring objectives. Infrared event counters are well suited to record relative bat activity inside mines over long periods of time with minimum observer disturbance and cost, but cannot be used to reliably gather information on bat behavior through gated entrances, or absolute numbers and species identification of bats. Ultrasonic detection equipment and mist net/harp traps are necessary techniques to reliably determine bat species composition. Infrared video cameras provide an accurate, permanent monitoring record of bat numbers and behavior. Protocols specific to each mine may be necessary to minimize observer and equipment effect on bat behavior. Efficient low cost monitoring can be accomplished using minimal equipment and personnel. Preliminary analysis suggests that bat behaviors do differ in gated and un-gated mine openings.

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INTRODUCTION

Concern over bat populations has been increasing in recent years and many bat species appear to be declining (Stebbins 1980, McCracken 1988, Tudge 1994). Of the 43 United States bat species, five are listed by the USFWS as endangered and 19 are former candidates for listing (Code of Federal Regulations 1991). Because bat populations appear to be declining, many agencies now recognize bats as a valuable species, worthy of inclusion in management decisions. Unfortunately, detailed data are lacking, and the present status of many bat species remains unknown (McCracken 1989). In addition, adequate funding is often unavailable to determine long-term trends in bat populations.

One of the primary causes of declining bat populations may be the loss of suitable habitat. However, in recent years, many cave dwelling bats have increasingly been found in abandoned mines (Pierson 1989, Brown and Berry 1991, Pierson and Brown 1992, Brown et al. 1993). This increase has largely been attributed to the dislocation of bats from caves due to an increase in recreational caving, and the commercialization of many caves formerly identified as bat roosts (Tuttle, 1979, Brown and Berry 1991). Twenty-six of the 43 U.S. bat species are now known to roost regularly in abandoned mines (Pierson et al. 1991, Tuttle and Taylor 1994). Of the 18 Utah bat species (Hall 1981, Zeveloff 1988), 14 species regularly occur in mines. Ten Utah bat species are former Category 2 (C2) candidates for federal listing (Federal Register 1994), of which eight species inhabit mines during some time of the year. As with caves, abandoned mines offer bats a stable microclimate and possibly reduced risk of predation (Belwood and Welch 1991, Tuttle 1993). Recent studies have shown abandoned mines throughout North America are being used for a variety of roosting needs including, maternity, hibernation and day and night roosts (Tuttle & Taylor 1994).

In Utah and elsewhere in the West, abandoned mines are being sealed to protect an increasingly curious public. In the Silver Reef mining district, located in southwestern Utah, over 140 abandoned mine openings have been closed with bat compatible gates or grates on public lands administered by the Bureau of Land Management Dixie Resource Area, the Dixie National Forest and lands in private ownership within the Silver Reef Historic Mining District. Prior to the gating effort, a graduate student from Utah State University conducted a warm and cold season survey in an effort to identify bat species and general use patterns within these mines. The study found extensive bat use throughout the area, including a large maternity colony of Townsend's big-eared bat (*Corynorhinus townsendii*), a Utah state-sensitive species (Lengas 1996). Eighty miles north of Silver Reef, is the Tushar Mountain Mining area, where abandoned mine openings are scheduled to be closed in the fall of 2002. Surveys in this area have also found evidence of extensive bat use including Townsend's big-eared bat (*Corynorhinus townsendii*), and a maternity colony of the long-legged Myotis (*Myotis volans*).

Although gating mines may offer a probable solution to protecting known bat habitat and decreasing human disturbance at roosts, few surveys have been conducted regarding long-term effectiveness and impacts of gate designs on bat populations. The high concentration of abandoned mine closures and the existence of pre-closure survey data make both Silver Reef and the Tushar Mountain mine areas ideal sites for evaluating the long-term effectiveness of bat compatible gates to further aid land managers in bat-gate decisions.

Study objectives include:

- Documentation of seasonal, monthly, and daily bat activity patterns for a selected group of gated and un-gated mines
- Identification of bat species using this group of gated and un-gated mines and monitoring bat population trends in these mines

This discussion will focus on the findings for the following objectives:

- Evaluation of external monitoring techniques for assessing bat activity at the mine entrances
- Collection of baseline data to compare bat use of both gated and un-gated mines.

METHODS

Study Area : Two mine areas in southwestern Utah were used for this study, one with

gated mines and one with un-gated mines. The Silver Reef and East Reef area underwent mine gating and closure starting in 1995, while mines in the Tushar Mountain mine area are scheduled for gating in Fall of 2002. The Silver Reef and East Reef mine areas are located in the Mojave Desert eco-region, at its transition to the Great Basin eco-region, at 3500 feet elevation. These reefs are located in sedimentary rock layers west and east of Leeds Utah. The Tushar Mountain mine area is situated in a coniferous and mountain brush canyon between 7000-8000 feet elevation. This mining district is located in conglomerate rock layers northeast of Beaver Utah.

Criteria for the gated mines chosen for monitoring in Silver Reef/East Reef (WH-48, WH-180, and G4-HO7) were known bat activity and accessibility (M. Mesch pers. com. and Lengas 1996, Silver Reef report 1999). G4-HO7 was not gated until November 2000. External surveys were also conducted at three un-gated mines in the Tushar Mountains (Rob Roy, 270753HO1; Mystery Snifter #2, 270628HO1; and Prince Mine, 270634HO1) east of Beaver Utah. The same combination of visual, video, acoustic and trapping techniques were used at gated mines and un-gated mines beginning in May and ending in October.

Sampling days were chosen as close to the new moon phase as possible to minimize possible effects of moonlight on bat behavior. In order to minimize the effects of weather on bat activity, simultaneous observations were made on gated and un-gated mines for three hours on three consecutive nights.

Bat activity and species composition were additionally assessed at each gated and un-gated mine location by mist netting a week after survey dates. Trapping was delayed to minimize disturbance effects on bat activity. Although most mines were netted monthly, the two mines with maternity colonies were netted only in the month of August after the critical reproductive times.

Several types of survey instruments were used to maximize observations of bat activity at both gated and un-gated mines (Table 1 and 2). During each survey, each mine had one to four observers present using a night vision scope, a lap top computer with Anabat™, a pre-installed Trail Master® infrared event counter (at the Silver Reef and East Reef mines only), two max/min thermometers, and a Sony™ Hi-8 digital infrared camcorder. All equipment was set up before 8:00 p.m. and camcorders were started at 8:30 p.m. and ended at 11:30 p.m. in order to document initial evening bat activity. Survey times began a half hour earlier in September, because of earlier sunset times. The following descriptions document use of techniques:

Infrared Event Recorders (Trailmaster 500M™ 1500's):

Infrared event recorders™ (TM) consisting of an infrared light transmitter and receiver/data logger were placed inside each gated mine for permanent monitoring of relative levels of bat activity year-round independent of observers. Because of theft concerns, these event recorders were not used in the un-gated mines. A single event was recorded as a hit on the receiver when an object (such as a flying bat) passed through and disrupted the vertical IR beam between the two components. Transmitters were placed on the roof of the mine approximately 4 to 6 feet directly above the receiver on the floor of the mine. The receivers were mounted on top of 8 inch spools on the mine floor. The elevation minimized rodent disturbance to the TM. The TM's were left in place 8-10 meters inside the mine entrance and monitored from 2000 to 2002. The event recorders were downloaded and batteries were replaced monthly to prevent data loss to power

failure. Data was grouped in 5minute periods using SASS Macros for graphical analysis.

Red light:

Flashlights fitted with a red cellophane covering were used for observation when no other visual aids were available. The lights were placed to shine across the mine entrance, but not directly into the mine. The numbers of bats seen entering and exiting each mine were recorded by observers sitting 5 to10 meters from the mine entrance. Observer distance was estimated, based on previous observations, as being close enough to observe bat activity at the mine entrance with the least amount of bat disturbance.

Night Vision Scopes:

In 2000, observers used night vision (7-Bravo generation-3™ or ITT 260 Night Quest™ binocular) scopes to record bat activity at mine entrances. Observers sat 5 to 10 meters from the mine entrance, and recorded bat entrances, exits and other behaviors such as circling inside the mine and flying past the entrance. In 2001, observers moved 25-30 meters away from the mine openings to minimize observer effect on bat activity. Night vision scopes were used only to record bat behavior in the general area but not bat activity in the mine adit.

Remote (I Spy™) Monitors:

Remote monitor cameras (I-Spy™) surveillance system were also used to indirectly observe bat activity at mine entrances. The camera lens was placed on the tripod along side the video camera. The receiver TV monitor could be placed as far as 30 meters away so the observers could watch bat activity with very little observer impact.

Digital infrared camcorders : _

Digital infrared camcorders (Sony nightvision ™ Hi-8) were used to record bat activity at the mine entrances. This allowed for a permanent record of survey data and more complete analysis of bat behavior at entrances. To minimize mine entrance obstruction, each camera was placed on a tripod, nestled near a rock or mine sidewall. Each camcorder had one attached infrared (IR) light with an extra IR light spotlight (Sony HVL-IRH2™)) source nearby. This setup minimized the effect of camera presence but still included the whole mine entrance in the camera viewfinder. The Hi-8, 120-minute digital tape yielded approximately 1 hour of recorded data, and three tapes were used per mine each night. The tapes were transferred to VHS tape after the sampling sessions and analyzed for: recording time, bat entrances, exits, circling and flyby behavior event numbers. Taping began approximately 30 minutes before sunset and continued for three hours (2030-2330, May-August, 2000-2300 September)

Anabat™ ultrasonic bat call detectors:

To aid in species identification, Anabat™ detectors were positioned on tables or on the ground approximately 10 meters in front of or to the side of a mine entrance, depending on the topography of the surrounding area. All bat calls >10 seconds long were recorded to document bat activity. Bat calls matching bat movements in or out of mine were documented for use in species identification. In addition, calls were recorded when captured bats were released and added to the species identification library for these mine areas.

Trapping:

Trapping was used at both mine areas to identify bat species using the mines. Mist nets were set as close as possible outside mine entrances to capture bats entering and exiting mine entrances. Captured bat measurements included weight, sex, reproductive status, body dimensions, and age to develop site-specific life history information.

Weather measurements:

Because seasonal differences in bat activity may be a result of unusual weather events during sampling, ambient temperature was measured during sampling periods and throughout the year. Max-min thermometers were placed at mine entrances and survey stations during each survey night, while temperature data loggers (Hobo® H8) were permanently installed 10-12 meters inside the gated mines and temporarily placed outside the un-gated mines. The un-gated mine loggers were downloaded at the end of the season. The gated mine loggers were downloaded monthly throughout the entire year.

Internal mine surveys:

In 2001, four bullet (size) camera lenses with infrared spotlights were installed inside the gated WH-180, to monitor the maternity colony area. Power and video cables were run from each camera through an adjacent shaft and left in place for hookup to a Sony Nightshot™ camcorder and external power source. Once per week May through June one hour of tape was recorded, alternating 5-minute recording cycles at each of the four cameras. These tapes were transferred to VHS tape and analyzed for bat numbers and species composition. In addition, plastic sheets were laid in the possible high-use areas to sample guano deposits.

In August of 2001 and 2002, internal mine surveys were conducted at the gated mines to estimate bat population numbers and locate specific roost use areas. Two observers surveyed all mine workings and determined numbers and distribution of bats through direct observation and documentation with a digital camera and Sony Nightshot™ camcorder.

Results

Comparison of Equipment recording bat numbers

The total number of events, i.e., bat entrances, exits plus circling, recorded using different monitoring techniques, varied substantially. In general, the camcorder video and TM event recorder detected the largest numbers of events. Sometimes totals were similar but other times the totals were very different (Figure 1). For most months in most mines, the number of events

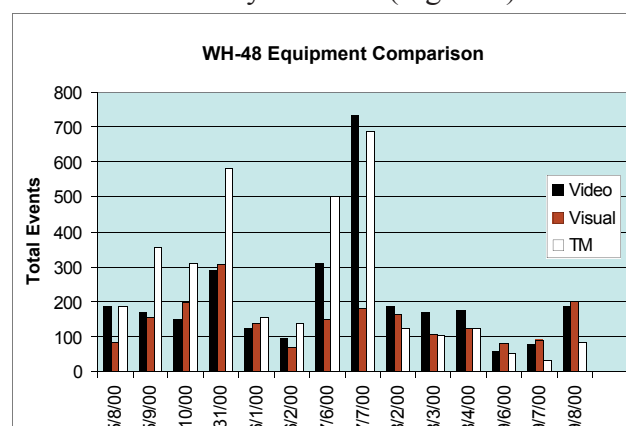


Figure 1. Comparison of total bat activity events recorded by three types of equipment: Infrared video camcorder (Video), Infrared goggles (Visual), and Infrared event counters (TM).

recorded on the infrared video doubled (and even tripled in one instance) the number recorded using other detection equipment. More importantly, using red light only for observations appeared to substantially increase variability in counts. For example in 1997, visual counts of bat events at the gated mines averaged 32 ± 45 per hour (Andrus 1997).

Different survey times show different in bat numbers using mines throughout the year. For example, both videotape analysis and night vision scope observations recorded consistently high average bat numbers (greater than 20 bats) at gated mines during April through September, and low levels of use before April and after September (Figure 1). Two gated mines and one un-gated mine showed consistently high average bat numbers

(>15 bats per survey hour). One gated and one un-gated mine consistently showed the lowest average bat use (>6 bats per survey hour).

Data from the TM recorders indicate that total bat numbers at gated mines varies throughout the season (Figure 2), and can be used to compare relative numbers using mines

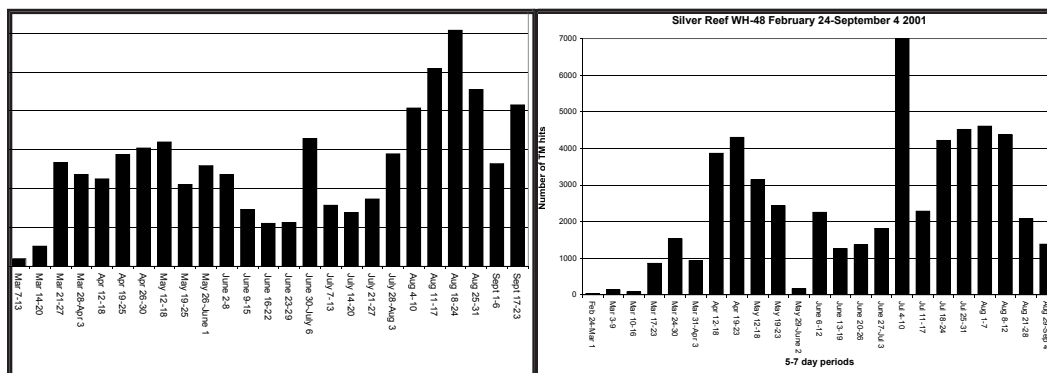


Figure 2. Seasonal variation in bat activity at two mines as recorded by infrared event counters (Trailmaster TM).

between years. The total number of events from the year at one gated mine peak just after sunset and just before sunrise throughout the spring and summer months (Figure 3).

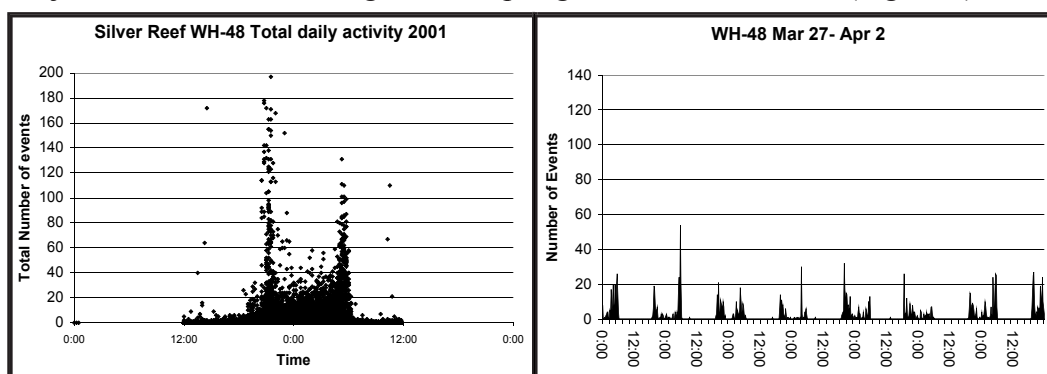


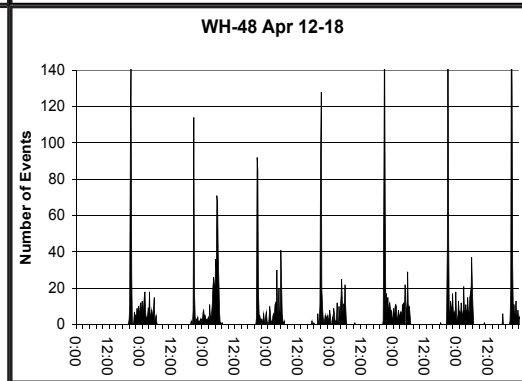
Figure 3. A summary of total daily events in a mine for one year as recorded by an infrared event counter.

However, the number of events varied between days of the week (Figure 4).

Bat information from internal survey and internal camera

Less than five bat flybys were recorded through the four cameras set up inside the maternity colony mine, and no bats were observed using the maternity roost site used in 2000.

In the internal survey, a large amount of guano was found in a smaller adjacent stope, but there was relatively little guano on the plastic sheets in the area of the maternity roost. Only six Townsend's big-eared bats (no juveniles) were observed roosting throughout the mine. In the other gated mine approximately 150-200 Townsend's big-eared bats (with at least 6 juveniles) were observed roosting in a very large stope near two shaft openings to the west of the adit.

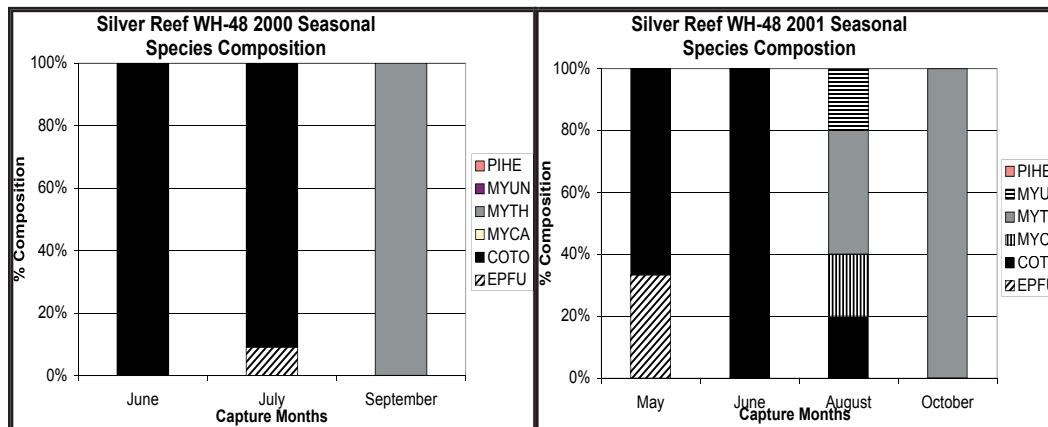


Figures 4a and 4b. A comparison of daily activity patterns in a mine during different weeks as recorded by an infrared event counter.

In both mines, bats were seen roosting in the upper drift levels only. Ringtail (cat, *Bassaricus astutus*) scat was found throughout the old maternity colony location, and a large amount was found at the new maternity roost location (away from internal cameras) within the mine complex. Ringtail scat was also found in concentrations in the lower drift level of the other gated mine. Ringtails were also observed at and on the gates during external surveys at both mine entrances.

No bats or ringtail scat were found in the newly gated mine, but bat guano and moth parts were scattered throughout the mine.

Both trapping and acoustic records for bat species identification show that bat species number and composition varies between months in each mine (Figure 5).



Figures 5a and 5b. Comparison of seasonal species composition of bats trapped in mist nets placed across mine portal at Silver Reef gated mine WH-48. Percentages do not represent equal trap effort.

In both areas there is a pattern of different bat species consistently captured during specific times of the season. For example, at gated mines, Townsend's big-eared bats were captured in all months except October, big brown bats were not captured in June and October, and *Myotis* species and western pipistrelles were captured only in August or later. Trapping success was varied considerably in different mines and different years. For example, in 2001, 5 species (8 individuals) (Townsend's big-eared bats (*C.townsendii*), big brown bats (*E. fuscus*), California myotis (*M. californicus*), western small-footed myotis (*M. ciliolabrum*), and fringed myotis (*M. thysanodes*)) were captured at one gated mine, one to two species were captured at another gated mine, but no bats were captured at the third mine. However, we were able to identify species using internal surveys, acoustic records and videotapes: *Myotis* species were seen in two internal surveys (2000 field notes), and Townsend's big-eared bats were seen in videotape surveys and recorded on Anabat® (2001 field notes).

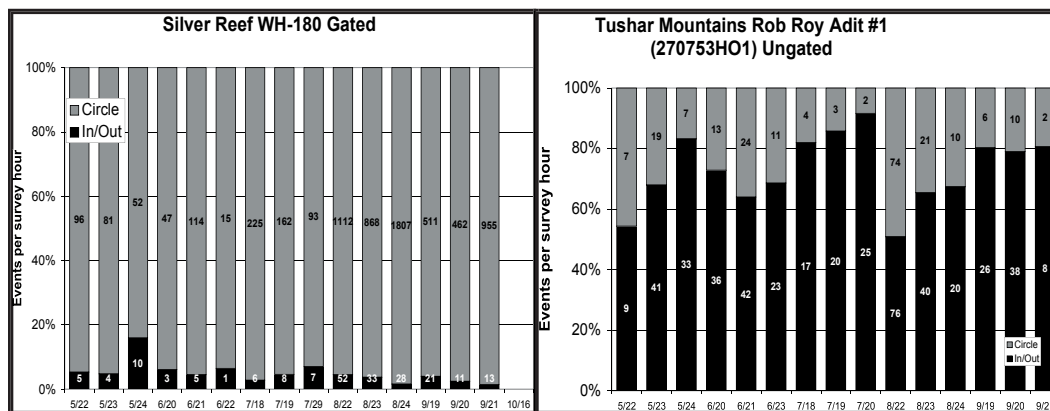
Accurate evaluation of bat status can only be determined from trapping. For example, the species and status of bats captured at un-gated mines included long-legged myotis (*M. volans*) gravid females, lactating females and sub-adult males.

Effect of bat gates on bat activity

In 1999-2001 field seasons, proportionately more circling bats were seen for longer periods of time in gated mines than in un-gated mines (Figure 6). The ratio of bats circling to in-and-out behavior averages 1:1 in un-gated mines and is usually greater than 5:1 in gated mines (Figure 6). In one gated mine, bat circling to in-and-out behavior ratios were consistent throughout the season (10:1), but in another this ratio varied from a low of 1:2 increasing to 10:1

in June through July and decreasing to 3:1 August through October (Figure 5).

In contrast, bat circling to in-and-out ratios were low (0:1-4:1; Figure 13) in the Tushar Mountain un-gated mines with only slight variability. Peak bat circling ratios were in August and September (Figure 6).



Figures 6a & 6b. Comparison of bat circling to exit and entrance events in gated and un-gated mines as recorded by infrared video camera in 2001.

Similarly, before gate installation in the East Reef mine, bats exhibited a low circling to in-and-out ratio (1:3). However, after gate installation, the circling to in-and-out ratio increased to a high of 10:1; and bats were observed using the crack above the gate for the first time.

In all years, at least 85% of bats entered and exited the gates through the top 1/3 of the gate bars or the top part of the portal in the un-gated mines (1999, 2000 and 2001 field notes).

Discussion

Equipment comparison: Although red-light assisted observations can detect relative use/non-use of mines by bats, the increased clarity of night vision infrared scopes and infrared video cameras allow observers to distinguish between actual bat entrances and exits (Figure 1). This data provides a more accurate picture of relative numbers of bats using the mines and differences in their exit and entrance behaviors in gated and un-gated mines. Use of the night vision scope, however, required an additional timer/recorder person. In addition, after a 30 minute continuous viewing period, using the night scope observer was subject to vision fatigue, making an accurate record for the four-hour sampling period problematic. Monitoring and analyzing bat activity at mine entrances was most detailed and accurate with the infrared video camera, because of the combined night vision view with a permanent record tape, which could be paused and re-played to clarify actual behavior. Bats can also be identified as large bats or small bats. The necessity of changing tapes every hour does introduce possible disturbance effects. Infrared event counters (TM1500™) can be left in place to collect data continuously for at least one month (longer when activity rates are less) before being downloaded. Thus TM's provide the most information on long-term activity patterns with the least amount of disturbance potential affecting bat behavior. Unfortunately, the nature of the events recorded cannot be determined from the event recorder, so the events may be triggered by bats flying in or out of the mine, and birds or small rodents passing through the beam. Thus, numbers generated by TM data reflect relative activity per time, and may include the same bats flying back and forth (circling) inside the mine. In addition, bats will fly around the TMs when they are initially installed in the mines (video observation), thus

short-term data gathered by TMs may not be comparable to long-term TM data.

Species Composition: Numbers of bats trapped in Silver Reef and East Reef continue to decrease as compared with 1999 and 1998. For example, July 1998, 24 Townsend's big-eared bats were netted; however in 2000 and 1999 only ten and eleven, respectively, were netted during a similar time period. Because most of the Townsend's big-eared bats captured in July were sub-adults, and overall few adults have been trapped since the first year of trapping, the decrease in numbers may not reflect an actual population decrease, but because bats are long-lived and extremely aware of their environment, there may be a learned avoidance response on the part of adult bats. Since the gates were installed in 1997 and monitoring began in 1998, there have been no obvious changes in numbers of bats seen exiting or entering mines or in activity levels as measured by TM event recorders. Numbers of bats seen in internal surveys have also been consistent. However, the level of monitoring has varied considerably, so the level of uncertainty in regards to population trends remains high. In addition, since species identification is partially dependent on trapping, identification of bats using mines becomes even more difficult. Anabat™ recordings continue to provide a record of bats in the area, but this identification tool is problematic for quiet bats, and bats whose calls are less species distinctive. We have observed, for example, that Townsend's big-eared bats usually do not call as they are seen exiting or entering mines. (These bats may be negotiating the spaces between the gate bars without the use of their sonar capabilities.)

Effect of bat gates on bat activity: Overall circling to in-and-out ratios was much greater ($>5X$) at gated mines than un-gated mines. However, within gated mines, ratios change substantially at different times of the year. This may reflect differences in species behavior and/or developmental difference within species behavior (e.g., sub-adult vs. adult). For example, in May, bats in one gated mine circled only once to every two entrance or exits. This may be due to different species dominating the roost as they are migrating through the area. Ten-fold increases in circling events at gated and un-gated mines with maternity groups in July and August suggested that these later changes were due to sub-adults learning to negotiate the gates or avoiding potential predators. Maternity colonies of Virginia big-eared bats showed bimodal activity around sunset and sunrise in summer until lactation when activity throughout the night increases (Lacki, 1994). As sub-adults become volant, circling may be a way of practicing flight maneuvers, thus may not necessarily reflect gate effects. Adult "tutor" bats may also be contributing to the increase in circling; O'Shae (1977) suggested that adult bats fly close to their young to "coax" them to emerge.

In addition the increase in numbers of bats using the gates may physically impair their ability to navigate through the gate openings. Twente (1955) tested Brazilian free-tailed bats and showed echolocation was not used during emergence events in large colonies.

Learning may play a role in the behavior of all ages of bats, as suggested by the ten-fold increase in circling at the newly gated mine. Early in 2001 after gate installation, bats mostly entered and exited via the crack located above the gated portal, rather than the gate. Later, however, bats started to use the gated portal more than the crack. This suggested that bats over time either learned to negotiate the gate, or grew less wary of a foreign object or predator potential.

In this study, the dramatic increase in circling behavior by bats in gated mines, indicated that gate presence, at least for some species, affects bat behavior. However, several researchers have suggested that since Townsend's big-eared bats circle more than other bats before exiting

their day roosts (P. Brown, R. Sherwin, and S. Altenbach, pers.comm.) this circling might be just reflect normal species behavior. Studies by Twente (1955) showed that Townsend's big-eared bats sampled for light before exiting the roost, by circling to the entrance then roosting on the cave wall and then returning to the entrance until it is dark. However, White and Seginak (1987) documented a significantly higher amount of circling, between gated and un-gated mines, by these bats before evening exits. Thus it appears that even in bats that are known to display circling, gates may increase the amount of circling.

Unfortunately, this increased circling has not been quantified for Townsend's big-eared bat or any bat species. It is not clear if this circling represents a significant energy cost for these bats, based on constrained energy budget and warrants further study. In addition, the potential for added energy costs warrants caution in installing gates with an *a priori* assumption that it will benefit bats. Recent studies for other bat species in Florida and Indiana have identified bat species that are significantly compromised by gated entrances (Ludlow and Gore 2000). Gates may provide bats protection from disturbance thus reducing stress and increasing fat storage retention, but if this is negated by the deleterious effects of expending more energy to get through gates, the net benefit for bats is lost. In addition age specific and species-specific effects may actually affect recruitment rates for populations using these mines. Sub-adults learning to fly must negotiate the gate and thus larger energy costs may be required as they may spend more time circling before exiting the gate. Species such as the Townsend's big-eared bat may rely more on eyesight to exit gates. This may lead to an increase in circling to in-and-out ratios that other bat species may not experience. Echolocation frequency differences between species may also lead to differences in the amount of circling each species may exhibit in response to bat compatible gates. Certain bat species' echolocation frequencies may be better equipped to negotiate gates.

Is there an Observer effect on bat activity? The relationship between observer presence and bat activity appeared to vary between mines. At two gated mines there was no consistent correlation between observer presence and high or low levels of bat activity. These mines showed variation in bat activity during observer presence but the same changes were also noted in the 9-day random sample periods. Observer effects may be reduced at these mines because of the larger numbers of bats attempting to enter/exit through the increased portal clutter caused by the gate. Bats dealing with these distractions may be less sensitive to observer presence.

In contrast, the newly gated mine showed substantial changes in activity during observer presence but the pattern is not consistent throughout the season. Changes seen during and after survey periods were not observed in the random 9-day periods. This may be due to exposure of the mine location. Observers must sit on a narrow hillside with no cover and thus may stand out to bats using the area. Thus differences in observer effect may be due to differences in mine location, bat use of mine, or mine internal structure.

Recommendations

Set up a long term monitoring program

Know what species of bat you have and how gates affect its behavior before you gate. If this information is not available, set up a monitoring program to gather this information and make sure your management actions are appropriate. Consider cooperating with a local University student group to assist your information gathering.

Use of equipment

Because of the different data gathered from each type of equipment, it is apparent that a combination of equipment needs to be used at each mine to provide the greatest amount of information.

TMs are ideal for collecting daily and seasonal bat activity data within the mine and can be used for up to two to four weeks without human interference. These may be the singlemost efficacious tool for monitoring on a low budget. However, TMs only record the number of hits as bats (or other animals such as birds and rodents) pass through the vertical beam, but do not record the type of activity (entering, exiting, circling, flyby). TM's need to be elevated off the mine floor or may be mounted in the side position across the mine opening to minimize rodent activity effects on event numbers. Continuous power to the event recorders is a problem and batteries must be replaced monthly or loss of power will cause a loss of data. Due to the bats' apparent "curiosity" regarding changes in the mine environment, dummy event recorder cases should be installed in each mine to habituate bats to their presence. In addition, statistical data analysis will require additional computer programs specially designed for your analysis needs. We use a SAS macro program designed by Susan Durham, Utah State University. Finally, these event recorders are easily stolen (and impossible to recoup) if adequate security is not available. 2002 Unit Cost (Trailmaster 550™) \$200.

Night vision scopes are necessary to record bat activity outside the mine entrance, especially entering, circling in front of the mine, and flybys. Night vision scopes need to be available for use at all mines simultaneously. Unit Cost \$2000-5000 depending on quality of scope desired.

IR video camcorders provide reliable, permanent record of bat activity at mine entrances and decrease effects of observers near mine entrances. However, maximum recording time is one to two hours with Sony Hi-8 tapes, and data must be analyzed at a later date. Approximate Unit cost for camcorder (Sony night vision™ e.g., model TRV340 handycam) \$850 with accessories, infrared spotlight (Sony HVL-IRH2™) \$75.00, tapes (Sony Hi-8™) \$10.00.

Eye-spy™ IR cameras also provide information about bat activity at mine entrances, to observers stationed more than 20 meters from the mine. This distance may decrease observer disturbance effects and allow observers to monitor more than one mine simultaneously. However, radio wave transmission distance limits the receiver position, and at close distances the monitor light may be a disturbance to bats. The small camera lens with its infrared light source is quite inconspicuous, but an additional infrared spotlight is needed to effectively observe bat activity. Eye-spy™ camera units are somewhat fragile and bulky which makes them more difficult to transport than other IR equipment. 2001 Unit cost was \$200.

Red lights can be used to facilitate the collection of data at mine entrances. However, this is the least reliable of all methods. At distances which decrease effect of observer presence, visibility of mine entrances is low, increasing the potential for observer error in accurately estimating bat entrance/exit counts and other behaviors. Unit cost was \$5.00.

Anabat™ recordings in conjunction with mist-netting/harp trapping provide limited information on species identification of bats using mines and in the surrounding area. Using recordings to identify all species in the area and those using the mines is limited. Technical difficulties include distortion of ultrasound recording by the physical rock structures at and around the mine and by an inability to accurately determine exact direction and distance of a calling bat to recording equipment. In addition, lack of vocalization by bats entering or exiting

mines is sometimes a problem. Bat species such as *C. townsendii* are known as whispering bats, that is their calls may be too soft or directional to be picked up by Anabat™. Thus Anabat™ recordings are not equally effective for all species of bats which may be using these mines. Similarly, not all bat species (and individuals) are subject to mist-net or harp trapping, thus both techniques probably provide only partial information on species identification for the Silver Reef Area. In addition we believe our resident Silver Reef bats may also be learning to evade these nets as a result of past experiences. Netting once per year would limit disturbance to bats and maximize species use information. Cost for netting should include nets, poles and/or harp trap but also include the need for trained personnel with rabies shots. Cost for Anabat™ detection likewise should include equipment (Anabat™ detector and laptop computer) plus training costs for interpretation of data.

Despite the inherent drawbacks of each of these sampling techniques, the combination of these techniques has improved our knowledge of bat use of these mines. However, observer effect continues to be a question in our data collection. In 2002 we changed our protocol to include a small “bullet” camera lens plus infrared spotlights at the mine entrance connected to a power source and the camcorder located 30 meters from the mine entrance. Thus we can change video tape AND monitor bat activity through the camcorder with a substantial reduction in human disturbance. The data from this field season is still being collected.

Finally, none of these techniques accurately measures changes in bat population numbers using each mine. Future studies in this area should involve radio-telemetry and banding of bats to address these questions

Acknowledgement

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REVEGETATION OF NINE SQUARE MILES OF COPPER TAILINGS

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ABSTRACT

The permanent closure of approximately 5,500 acres of copper tailings at the White Pine Mine Tailings in the upper peninsula of Michigan was performed over a four-year period. The most important component of the closure plan in terms of cost and meeting water quality criteria was the design and implementation of a revegetation plan that would control wind and water erosion on the tailings by establishing a low/no maintenance, self-sustaining vegetative cover without the use of imported topsoil. This component saved the owner over \$100,000,000 over importation of topsoil. To meet these requirements the revegetation approach employed included extensive site examination, selection of locally available sources of organic amendments, design and execution of greenhouse trials and on-site revegetation trials, development of reclamation specifications, full-scale implementation, and revegetation performance monitoring. By incorporating a paper mill sludge/wood chips mixture, balancing inorganic fertilizer additions, identifying effective erosion control techniques and selecting adapted plant species a highly extensive revegetation plan was developed and implemented on site.

INTRODUCTION

A mine closure program was initiated to permanently close 5500 acres of copper tailings at the White Pine Mine (WPM) Tailings in the upper peninsula of Michigan. The most important component of the closure plan in terms of cost and meeting water quality criteria was to design and implement a revegetation plan which would control wind and water erosion on the tailings and establish a self-sustaining vegetative cover without the use of imported topsoil and long-term maintenance. The existing regulatory approved method of closure included placement of a minimum of two feet of topsoil over the tailings. In reality, at least three feet of cover would need to be placed to bridge over the soft tailings. This equates to over 26 million cubic yards. At a minimal cost estimate to excavate, load, haul and place this material at \$4.00 per cubic yard, the cost would have been over \$100,000,000. Therefore, the costs related to developing a direct tailings revegetation approach were justifiable. The technical approach for the direct revegetation of the tailings included:

- Review of existing data
- Collection of soils and vegetation data

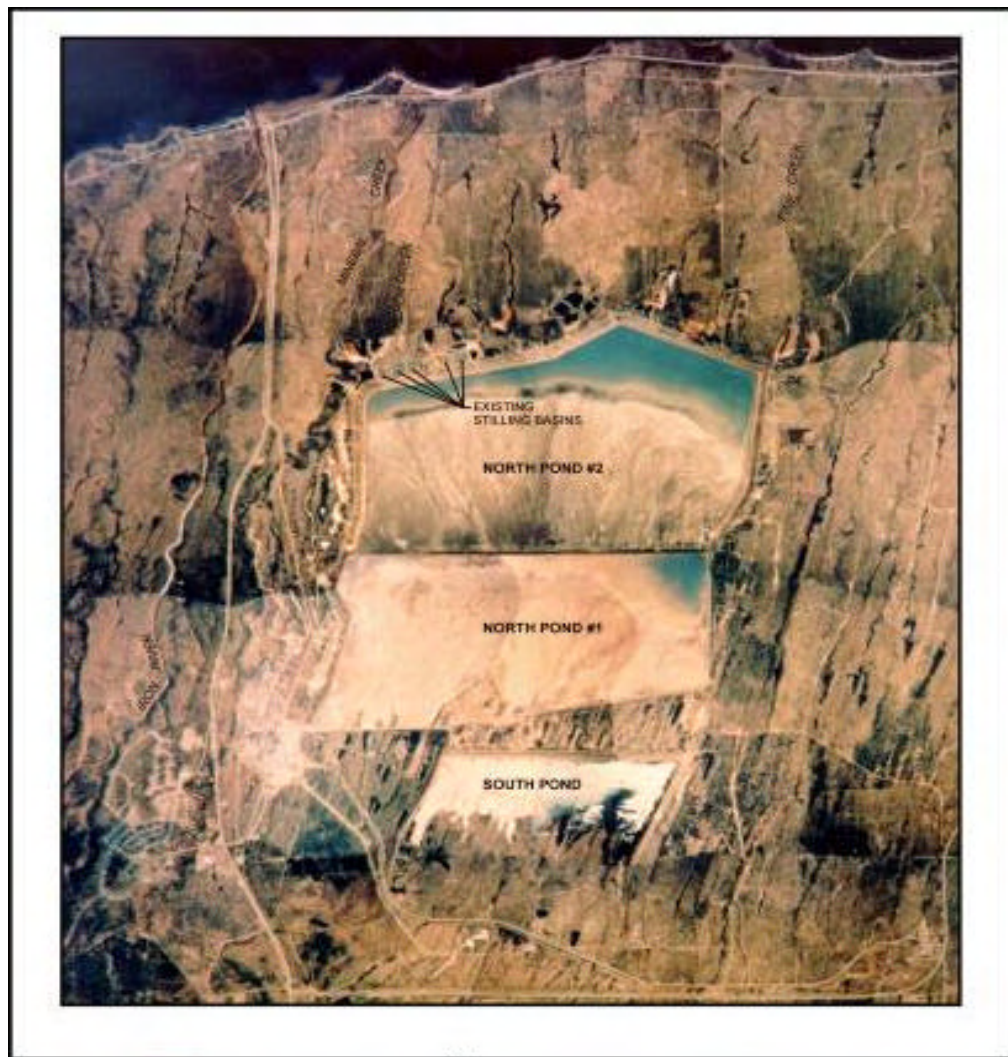
- Identification of local sources of soil amendments (e.g. paper mill sludge, wood waste, composted bark, etc.)
- Performance of greenhouse trials designed to test organic amendment strategies, plant species performance, plant metal tolerances and micronutrient deficiencies.
- Establishment of on-site revegetation trials to test the effectiveness of erosion control methods and the field performance of organic amendments and plant species selected in the greenhouse trials
- Provision of specifications for revegetation of the site
- Provision of quality assurance of the revegetation work
- Monitoring of the field trial and full-scale revegetation performance and modification of subsequent full-scale revegetation efforts.

The technical approach to the revegetation of the WPM Tailings proved successful due to the significant reduction in design development time, improved potential for revegetation success and the reduced risk of failure. This rational approach to reclamation and closure provided the continuity and organization essential for meeting the established success criteria at the lowest possible cost. Considering the size of the WPM Tailings, small changes in revegetation methods would significantly affect the total overall cost of tailings revegetation. Therefore, while research and development costs seemed onerous initially, long-term cost-benefits realized due to the ability to systematically diagnose the cause(s) of reclamation success and failure and rapidly modify and improve reclamation techniques during full-scale implementation.

BACKGROUND INFORMATION

The White Pine Mine located in Ontonagon County, Michigan (at approximate 47° North Latitude) commenced operation in 1953 and operated through 1995. Approximately 300 million tons of copper ore (chalcocite {Cu₂S}) from the Nonsuch Shale formation were mined underground and processed (crushing and sulfide flotation). Tailings were discharged during the operations into three separate impoundments identified as North Pond 1, North Pond 2, and South Pond. The tailings were deposited by direct slurry discharge with surface pools maintained against the dams. The total amount of tailings deposited within the impoundments was estimated to be approximately 186 million tons. The total area covered by the ponds is approximately 5,500 acres. The climate in the region is characterized by a short growing season (June-Sept.), seasonal high winds and annual precipitation approximately 38 inches that mainly falls in the form of snow.

An aerial photograph of the three tailings impoundments of the WPM Tailings is provided below.



A tailings revegetation field trial program was initiated in the 1970's with limited success and data collection. Approximately 60 percent of North Pond 1 and 10 percent of North Pond 2 tailings support vegetation that naturally invaded the inactive and dry portions of the tailings impoundments over a 25-year period. The vegetation was primarily composed of Redtop (*Agrostis alba*) and Horsetail (*Equisetum spp.*) with infrequent and widely scattered stands of aspen/poplar (*Populus tremuloides*, *P. balsamifera*, *P. grandidentata*), yellow birch (*Betula alleghaniensis*) and willow (*Salix spp.*). However, it is believed that the redtop was the only species surviving entirely on the tailings and the other species may be rooted, in part, in native soils beneath the tailings. The remaining portions of North Pond 1 and 2 and the South Tailings supported no vegetation.

COLLECTION OF SOILS AND VEGETATION DATA

A site investigation was performed to:

- Identify revegetation issues
- Develop a list of potential plant species for the revegetation of the tailings
- Identify candidate species for the greenhouse trials
- Evaluate the suitability and variability of the tailings matrix as plant growth medium
- Identify tailings physiochemical characteristics which could limit plant growth

Plant available copper (AB-DTPA extractable) was found to be well above levels considered in excess of critical levels for normal plant growth and substantially greater in the tailings than in “native” soils. Based on literature review porphyrin is present (approximately 2-5%) in the Nonsuch Shale. Porphyrin is a heterocyclic organic with a central metallic ion that forms the structural component of chlorophyll. Based on the concentrations of copper in water, weak acid and chelate extracts it is believed that porphyrin largely controls the plant availability of copper in the WPM tailings.

The range of geochemical characteristics of the tailings based on the sampling performed during the field survey are provided in **Table 1** below.

TABLE 1

pH (s.u.)	7.5-8.5
Electrical Conductivity (dS/m)	0.2-17
Base Saturation (%)	100
Total Sulfur (wt/%)	<0.01
Pyritic Sulfur (wt/%)	<0.01
Acid Generating Potential (Kg CaCO ₃ /ton)	<0.03
Acid Neutralization Potential (Kg CaCO ₃ /ton)	30-60
Copper (SPLP)	0.002-0.012 (mg/L)
Copper (AB-DTPA)	118-1295 (mg/Kg)
Lead (SPLP)	ND-0.01 (mg/L)
Lead (AB-DTPA)	ND-0.87 (mg/Kg)

TABLE 1

Zinc (SPLP)	ND-0.038 (mg/L)
Zinc (AB-DTPA)	ND-3.28 (mg/Kg)
Arsenic (SPLP)	ND
Arsenic (AB-DTPA)	ND
Mercury (SPLP)	ND
Mercury (AB-DTPA)	ND
Cadmium (SPLP)	ND
Cadmium (AB-DTPA)	ND-0.91 (mg/Kg)
Nickel (SPLP)	-
Nickel (AB-DTPA)	0.38-2.84 (mg/Kg)

ND = Not detected

- = not analyzed

The high levels of plant available copper shown above are known to adversely impact plant growth and development. Numerical thresholds for heavy metals in soils above which phytotoxicity is considered to be possible have been suggested. The copper levels promulgated by the United Kingdom are 140-280 mg/kg EDTA extractable (UK DOE-1987). H.J.M. Bowen (1979) suggested that soil concentrations above 250 mg/kg of total copper may result in phytotoxicity. Neuman, *et.al.*, 1987 suggested that AB-DTPA (ammonium bicarbonate-diethylenetriaminepentaacetic acid) extractable copper levels between 50-210 mg/kg in mine soils from selected western coal mines were phytotoxic to plants.

Based on available literature, the plant availability of copper should be reduced by the addition of organic matter (OM) amendments. Solid-phase ligand formation is the mechanism responsible for decreases in copper toxicity to plants through the addition of peat and other sources of organic matter in high copper substrate (Soltanpour and Schwab, 1977). McLaren and Crawford (1973) showed that organic matter may form stable ligand complexes with soluble copper and maintain them in non-mobile forms. Baker (1990) indicated that organically bound copper is retained to the greatest degree in soils. In the presence of high levels of OM, humic materials and fulvic acids, the plant availability of copper is reduced through the formation of strong complexes with the OM and humates, resulting in slow dissociation rates (McBride, 1978, and Davies and Mertz, 1987). Stevenson (1982) found the stability constants of metal complexes with soil humic acid followed the order: copper > lead > cadmium > zinc. As a result of these previous findings the greenhouse study included an evaluation of the effectiveness of OM amendments on plant growth as well as the plant availability of copper and the influence of tailings born copper on plant growth and development.

The major revegetation issues identified as a result of the site investigation included:

- High Plant Available Copper Concentrations
- Low Organic Matter Content
- Nutritionally and Microbiologically Impoverished
- Moderate to High Salinity (No. 1 Tailings Impoundment)
- Wind Blown Tailings and Dune Formation
- Rill and Gully Erosion

- Surface Crusting
- Poor Infiltration and Aeration
- Clay and Silt Textures
- Inaccessible Tailings

IDENTIFICATION OF ORGANIC AMENDMENT SOURCES

High rates of inorganic fertilizers applied to a biologically inert material such as tailings typically do not facilitate the long-term plant nutrient cycling necessary to meet the goal of a self-sustaining vegetation cover. Over time with no OM incorporation the plant availability of inorganic fertilizer will decline and the supply of plant essential nutrients will be habitually reliant on continued fertilizer application. Therefore, one of the major tenants for the revegetation of WPM tailings was to control organic matter, nutrient inputs and species composition during reclamation to provide rapid nutrient cycling leading to improved ecosystem stability, ground cover and erosion control. As such, sources of OM amendments for the revegetation of the tailings were evaluated. The selection of OM was based on the following:

- Cost
- Distance from Site
- Regulatory Restriction
- Available Quantities
- Quality
 - a. Metal Concentrations
 - b. Particle Size Distribution
 - c. Organic Carbon and Nitrogen Content (C:N ratio)
 - d. Density
 - e. Ash and Moisture Content
 - f. Inorganic N, P and K
 - g. Handling Requirements/Restrictions

The potential sources of OM included:

- Logging Waste
- Sawmill Waste
- Municipal Sewage Sludge
- Agricultural Waste
- Alfalfa or Straw Hay
- Wood Pulp Waste
- Commercially Available Organic Amendments

The approach to the amendment of the WPM Tailings was to provide a wide particle size range of OM, some of which decompose and supply nutrients quickly and others that decompose and supply nutrients more slowly. Therefore, woodchips were selected as an OM source that would provide the slowly available (long-term) nutrient source, while

wood pulp sludge was selected to provide the readily available (short-term) source of nutrients for plant growth. Research has generally shown that application of fresh woodchips and other wood residues may result in the immobilization of nitrogen and subsequent nitrogen deficiency in plants grown on the amended material. Therefore, woodchips were supplemented with inorganic nitrogenous fertilizers according to its carbon:nitrogen ratio and the quantity applied to the tailings.

GREENHOUSE TRIALS

A twelve-week greenhouse study was implemented at Michigan Technical University. A four-way, randomized, complete block, factorial design was employed. This statistical design was utilized to assure the results were adequate for predictive purposes. Four levels of tailings, four levels of amelioration, 14 plant species, and five replicates resulted in 1,120 cells (or units). The soil amelioration categories included a control and three levels of organic matter additions. The organic matter amendment chosen was a mixture of paper mill sludge and wood chips. The species originally identified as having the necessary attributes for growing on tailings were narrowed down to 14 species. Statistical procedures were utilized to assure the results were adequate for predictive purposes.

Major Findings of the Greenhouse Study

The major findings of the greenhouse study were as follows

- Based on the performance of species evaluated in the greenhouse study the full-scale field trials seed mixture was formulated. The eight plant species with the greatest biomass production (**Table 2**) were selected for the trials.

TABLE 2
ABOVE GROUND BIOMASS BY SPECIES OVER ALL
TAILINGS TYPES AND OM TREATMENTS

Species	Above Ground Biomass (g)
Alfalfa	0.35 (A)*
Hairy vetch	0.35 (A)
Orchardgrass	0.30 (A)
Volga mammoth wild rye	0.30 (A)
Smooth brome	0.21 (B)
Timothy	0.19 (BC)
Common reed	0.17 (BC)
Red fescue	0.14 (BCD)
Birdsfoot trefoil	0.12 (CDE)

TABLE 2
ABOVE GROUND BIOMASS BY SPECIES OVER ALL
TAILINGS TYPES AND OM TREATMENTS

Species	Above Ground Biomass (g)
Redtop	0.07 (DEF)
American vetch	0.05 (EF)
American beachgrass	0.04 (EF)
Colonial bentgrass	0.04 (EF)
Queen Anne's lace	0.03 (F)

* Values with the same letter are not statistically different at the 0.05 level.

- Overall plant response increased as OM amendment addition increased (**Table 3**) and the minimum organic amendment rate which resulted in improved plant growth was determined.

TABLE 3
ABOVE GROUND BIOMASS
BY ORGANIC MATTER (OM) AMENDMENT LEVEL
AVERAGED ACROSS ALL TAILINGS TYPES AND
SPECIES

OM Level (%)	Above Ground Biomass (g)
5	0.19 (A)*
0	0.18 (AB)
3	0.16 (AB)
1	0.14 (B)

- Values with the same letter are not statistically different at the 0.05 level.

As organic matter amendment addition increased mycorrhizal infection increased (Table 4).

TABLE 4
EFFECTS OF ORGANIC MATTER (OM) AMENDMENT LEVEL ON MYCORRHIZAL INFECTION RATES AVERAGED ACROSS ALL SPECIES AND TAILINGS TYPES

OM Level (%)	Mean Infection Rate	Significance*
5	1.30	A
3	1.06	B
1	0.88	C
0	0.41	D

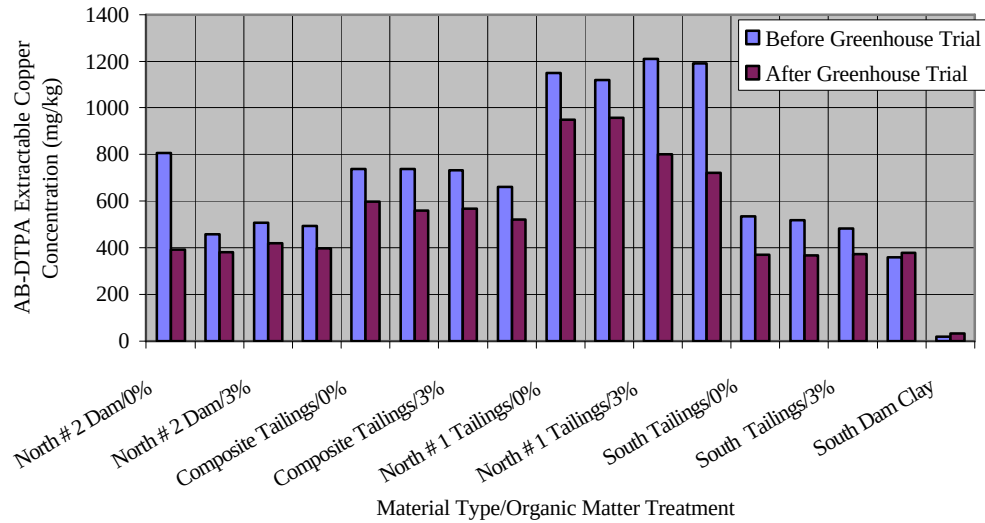
- Values with the same letter are not statistically different at the 0.05 level.
- The relative plant growth potential of each of the tailings types was identified (Table 5).

TABLE 5
ABOVE GROUND BIOMASS BY ORGANIC MATTER (OM) AMENDMENT LEVEL AVERAGED ACROSS ALL TAILINGS TYPES (EXCLUDING SD) AND SPECIES

Average of Foliage Wt	Tailings			
Organic Matter Percentage	Barren	Vegetated	Coarse Sand Embankment	Grand Total
0%	0.1325	0.0540	0.1326	0.1063
1%	0.0648	0.0322	0.0544	0.0505
3%	0.0772	0.0398	0.1262	0.0811
5%	0.1327	0.0618	0.2170	0.1371
Grand Total	0.1018	0.0469	0.1326	0.0937

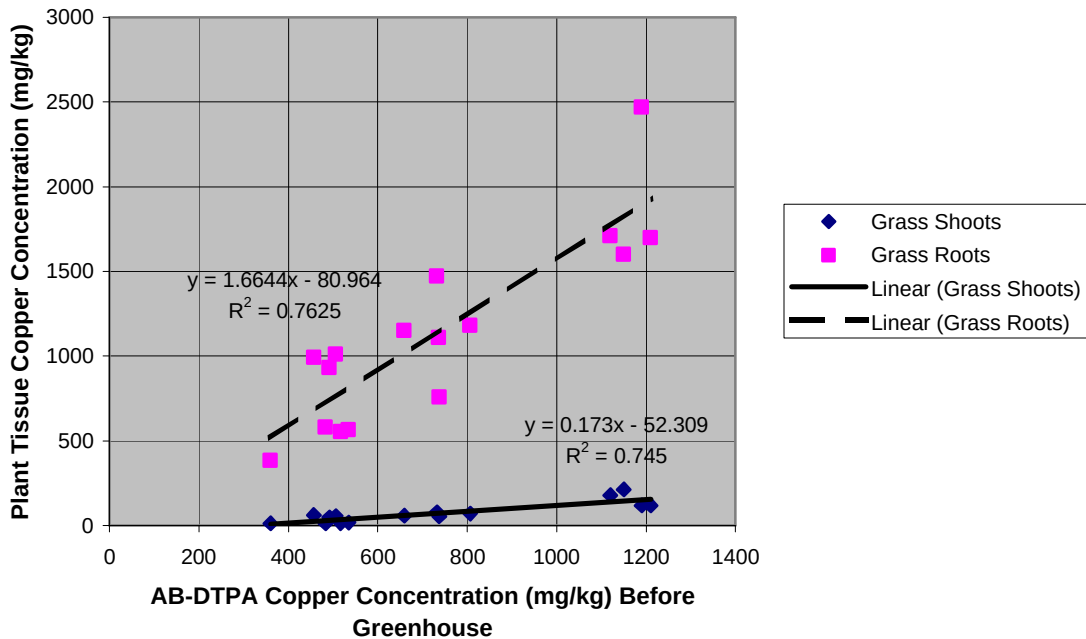
- Within the short time frame of the greenhouse trial (i.e., 12 weeks), additions of the organic amendments tested were not statistically demonstrated to significantly reduce plant available copper in tailings. However based on the general trends in the data provided in **Figure 1** it was believed that over time OM would form stable complexes with plant available copper and maintain them in non-mobile forms thereby reducing plant available copper in the tailings.

FIGURE 1. CONCENTRATIONS OF AB-DTPA EXTRACTABLE COPPER IN TAILINGS AND NATIVE SOIL BEFORE AND AFTER THE GREENHOUSE TRIAL



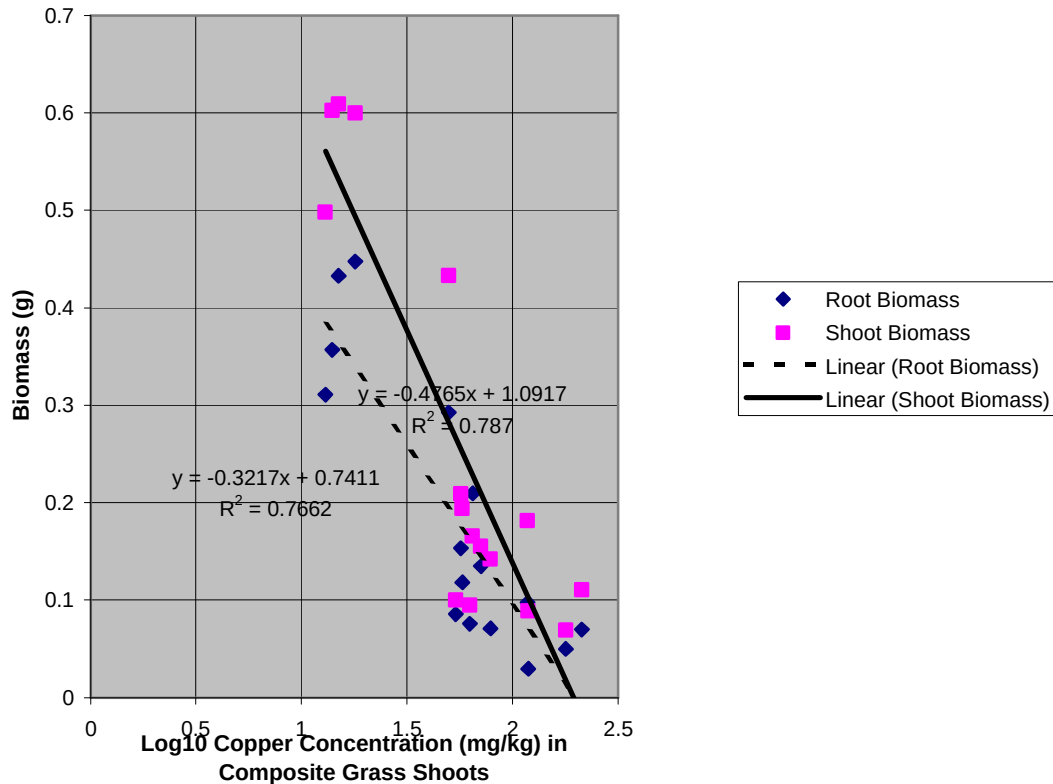
- Demonstrated the ability to predict plant metal uptake levels according to the “plant available” concentrations of copper in tailings (**Figure 2**).

FIGURE 2. RELATIONSHIP OF AB-DTPA COPPER CONCENTRATIONS IN TAILINGS TO COPPER CONCENTRATIONS IN COMPOSITE GRASS ROOT AND SHOOT TISSUE



- Demonstrated the effects of elevated copper levels found in the tailings on plant growth (**Figure 3**).

FIGURE 3. RELATIONSHIP OF COPPER CONCENTRATION IN COMPOSITE GRASS SHOOTS TO THE BIOMASS PRODUCTION OF COMPOSITE GRASSES



- Identified the deficiencies and application rates for the following plant-essential micronutrients and macronutrients:
 - a. Boron
 - b. Manganese
 - c. Nitrogen
 - d. Phosphorus

The findings from the greenhouse were incorporated into the large-scale revegetation field trials described below.

REVEGETATION FIELD TRIALS

The results of the greenhouse study, various erosion control measures and the recognition of all of the factors discussed above were incorporated into the design and implementation of large-scale revegetation field trials. The field trials were sufficiently sized to test the actual revegetation methods that would be used on-site. This effectively eliminated “edge effect” and eliminated the variable of installation method.

Considering the size of the tailings, small changes in the addition of OM and fertilizer resulted in substantial reductions in the cost of the tailings revegetation. Therefore, the rate of OM amendment decomposition in the tailings were evaluated during the field trial to further optimize and possibly reduce the required amount of OM and fertilizer addition.

The large-scale field trials were successfully installed on-site and thoroughly documented. All construction activities were performed under the direction and supervision of the designers of the revegetation plan. Trial designs are summarized below.

- Number of Plots – 162
- Plot Size – 1.0 and 0.5 acres
- Tailing Type –
 - Inaccessible –Wet
 - Inaccessible-Vegetated
 - Inaccessible-Barren,
 - Accessible –Barren
 - Coarse (Cyclone)Sand Embankment
- OM Rates - 0, 2, & 3%
- OM Type - Biosol, woodchips, wood pulp sludge, composted bark
- Erosion Control-
 - crimped straw
 - furrows
 - imprinting
 - dozer basins
 - slag & bark piles
 - incorporated slag
 - soil stabilizer

As part of the revegetation trials the relative rate of organic amendment decomposition was evaluated. The organic amendment decomposition evaluation was performed to refine the quantity and mixture of organic matter amendments applied to the tailings and identify the minimum amount of nitrogen fertilizer needed to prevent nitrogen immobilization. The information gained from this study was used to adjust nitrogen fertilization rates and organic amendments applied to the tailings.

The following recommendations resulted from observations made during both the installation of the field trials and full-scale implementation, as well as from a review of the project data. These recommendations are provided to demonstrate the level of difficulty encountered while working on mine tailings and to help future projects of this nature.

Major Findings from the Field Trials Recommendations

The major findings and recommendations resulting from the implementation and three years of monitoring of the field trials are provided below. Following each year of monitoring and based on experience gained during full-scale implementation modifications were made to the revegetation specifications for the next years revegetation activities.

- The vegetation frequency and overall species diversity of the 2 percent OM plots performed almost as well as the 3 percent OM plots.
- In comparison to the 3 percent OM plots, the 2 percent OM plots had a slightly greater total number of species, a higher frequency of volunteer species, and a higher number of species occurring in all plots.
- The composition of vegetation in woodchip and paper mill sludge plots was primarily timothy, smooth brome grass and hairy vetch. Typically the greater species diversity on the reclaimed lands leads to greater site protection from climate extremes and disease. Therefore, the dominance of a reclaimed vegetation community by one or two species was not considered desirable.
- No single erosion control measure on the plots was substantially superior in terms of erosion protection. Therefore, the lowest cost method, crimped straw at 2 tons/acre, was considered the best erosion control method.
- Surface roughening of any type caught seed, fertilizer and moisture and was of benefit on inaccessible tailings when compared to no surface treatment.
- Based on the results from the OM decomposition study the following generalizations were made:
 - a. Two years following reclamation net nitrogen mineralization (which increases the plant available nitrogen status of the soil in the short-term) was dominant.
 - b. Based on the average loss of mass (on a dry weight basis) within litter bags filled with OM amendments the estimated decomposition rates over the two year monitoring period of woodchips, woodchip/paper mill sludge mixture, composted bark, paper mill sludge, and woodchips/composted bark mixture were 46.0%, 40.9%, 40.0%, 38.4%, and 29.4%, respectively. Based on the decline in the total organic carbon content of the organic amendments, which appeared to be more consistent and less variable than decomposition based on loss of mass, the estimated decomposition rates of paper mill sludge, woodchips/paper mill sludge mixture, woodchips, composted bark and woodchips/composted bark mixture lost were 83.3%, 77.3%, 70.3%, 67.5% and 54.2%, respectively.
 - c. Following two growing seasons the majority of the added nitrogen fertilizer was depleted by plant uptake and microbial sequestration.
 - d. The carbon: nitrogen ratio (C:N) of the organic amendments tested were below or near the ratio that is typically considered to result in net nitrogen mineralization (i.e. 25:1)
 - e. The rapid decomposition of woodchips and composted bark was likely due to the high amount of inorganic fertilizer added to the trial and likely resulted in a

large production of microbial biomass with a low C:N ratio (active nitrogen pool).

- f. A slight decrease in Total Kjeldahl Nitrogen (TKN) of woodchips and composted bark between 1999 and 2000 was observed. This was estimated to be the result of the mineralization of nitrogen contained in microbial biomass (active nitrogen pool) produced in previous years from the application of fertilizer nitrogen and a relatively high C:N ratio carbon source (i.e. organic amendment). Therefore, the majority of nitrogen mineralization in subsequent years will likely be the result of the mineralization of soil microbial biomass rather than the decomposition of OM amendments.
- Vegetation production in the 2 and 3 percent OM plots and the tailings reclaimed in 1999 was extremely high. Based on visual observations it was estimated that vegetation production was between 4,000 - 5,000 lbs/acre (dry weight basis). In addition, plant litter accumulation was extremely high in the plots. It was anticipated that litter accumulation in areas reclaimed in 1999 areas would also be extremely high. While this provided erosion protection it would likely not be sustainable. As a result, revisions to the fertilizer recommendations and seed mixture specifications, were recommended (See below).
 - Based on the performance of tall fescue (tested on other plots performed on site) and mammoth wildrye it appeared that these species may compete well with dominant redtop on the vegetated portions of No. 1 Tailings.
 - Surface applications of woodchips and/or crimped straw appeared to be an effective method of reducing the dominance of redtop on the vegetated portions of No. 1 Tailings.
 - It appeared that low water holding capacity was the main reason for poor vegetation performance on the coarse (cycloned) sand embankment plots.

Recommended Revegetation Modifications Based on Field Trial Monitoring

Based on the conclusions listed above, modifications to the next year's revegetation activities were provided. These modifications were as follows:

- Incorporate woodchips/paper mill sludge as a rate of 2% and eliminate the application of inorganic fertilizer.
- Apply woodchips that have a coarse particle size distribution
- Remove timothy from the seed mixture if the straw mulch crimped into the surface of the tailings has a high percentage of timothy.
- Apply the seed mixture provided below in **Table 6**

TABLE 6
NO. 2 TAILINGS
RECOMMENDED
STANDARD SEED MIXTURE
FOR FULL TREATMENT AREA IN
2001

Scientific Name	Common Name	Pounds Of PLS¹ Per Acre²
Forbs		
<i>Medicago sativa</i>	Alfalfa	1.87
<i>Vicia villosa</i>	hairy vetch	5.0
<i>Trifolium hybridum</i>	alsike clover	0.48
<i>Trifolium pratense</i>	Red clover	5.0
<i>Trifolium Repens</i>	White Dutch clover	5.0
Graminoids		
<i>Dactylis glomerata</i>	orchardgrass	2.17
<i>Bromopsis inermis</i>	smooth brome grass	1.3
<i>Elymus racemosus</i>	mammoth wild-rye	7.5
<i>Phleum pratensis</i>	timothy	0.6
<i>Festuca arundinacea</i>	Tall fescue	4.0
<i>Festuca rubra</i>	creeping red fescue	1.07
<i>Festuca trachyphylla</i>	hard fescue	0.59
<i>Deschampsia caespitosa</i>	Tufted hairgrass	0.31
<i>Arctagrostis latifolia</i>	polargrass	0.44
<i>Agrostis alba</i>	redtop	0.14
TOTAL		35.16

¹PLS - Pure Live Seed.

²Pounds PLS/acre may vary depending upon actual seeds per pound for each seed lot.

- Cut and bale vegetation from previous years revegetation and for use as a surface mulch for the next years revegetation activities.
- For the cycloned sands tailings embankments of No. 2 Tailings the following recommendations were made:
 - a. Incorporate paper mill sludge and woodchips to the coarse (cycloned) sands embankments at a rate of 4% OM or 36.8 and 94.7 tons/acre, respectively.
 - b. Apply the standard fertilizer recommendation plus 60 lbs elemental nitrogen /acre (preferably ammonium nitrate).
 - c. Apply 2 tons/acre straw mulch and crimp into the surface of the coarse (cycloned) sands embankments.
 - d. Apply the seed mixture as shown below in **Table 7**.

TABLE 7
CYCLONED SANDS TAILINGS
EMBANKMENT
RECOMMENDED
STANDARD SEED MIXTURE IN 2001

Scientific Name	Common Name	Pounds Of PLS ¹ Per Acre ²
Forbs		
<i>Medicago sativa</i>	alfalfa	1.87
<i>Vicia villosa</i>	hairy vetch	10.89
<i>Trifolium hybridum</i>	alsike clover	0.48
Graminoids		
<i>Dactylis glomerata</i>	Orchardgrass	2.17
<i>Bromopsis inermis</i>	smooth brome grass	2.61
<i>Elymus racemosus</i>	mammoth wild-rye	5.06
<i>Phleum pratensis</i>	timothy	1.27
<i>Festuca rubra</i>	creeping	1.07

TABLE 7
CYCLONED SANDS TAILINGS
EMBANKMENT
RECOMMENDED
STANDARD SEED MIXTURE IN 2001

Scientific Name	Common Name	Pounds Of PLS ¹ Per Acre ²
	red fescue	
<i>Festuca trachyphylla</i>	hard fescue	0.59
<i>Deschampsia caespitosa</i>	Tufted hairgrass	0.31
<i>Arctagrostis latifolia</i>	polargrass	0.44
<i>Agrostis alba</i>	redtop	0.14
<i>Secale cereale</i>	cereal rye	22.53
<i>Hordeum vulgare</i>	barley	46.67
TOTAL		96.1

¹PLS - Pure Live Seed.

²Pounds PLS/acre may vary depending upon actual seeds per pound for each seed lot.

- e. Pockmark the surface of the cycloned sands embankments. Pockmarks should be approximately 25% the size of the dozer basins on the Coarse (cycloned) Sand Plots. Pockmarks should be irregularly placed and cover the entire surface of the embankment.
- For the voluntarily vegetated tailings areas the following recommendations were made:
 - o Apply the recommended revised seed mixture for the No 2 Tailings as shown above.
 - o Apply paper mill sludge and woodchips on the surface at a rate of 1% OM or 9.2 tons/acre and 23.75 tons/acre, respectively.
 - o Straw mulch the areas at a rate of 2 tons/acre and where inundation is likely, crimp the straw into the surface of the tailings.

Equipment and Implementation Recommendations

- Use low ground pressure tractors such as Caterpillar Challengers to pull various implements. Retrofit tractors and implements with wide tracks or flotation tires.

- Ensure that machine balance is appropriate for the implement being pulled by the tractor. Use front mounted counterweights when appropriate to shift loads away from the rear axle.
- Use side-cast manure spreaders for OM application to avoid traffic over inaccessible wet tailings.
- Prescreen and inspect OM amendment for debris and foreign objects to avoid jamming and breaking of augers on spreading equipment.
- ATVs may be used for an assortment of tasks in rough and boggy terrain typical of tailings facilities.
- Inform equipment operator of potential trouble spots and the methods to avoid getting equipment stuck in the tailings.
- Sharply turning Cat Challengers equipped with spreaders or other implements at the start or end of runs created imbalance. This was the most common reason for getting equipment stuck. Avoid this problem by performing wide gentle turns.
- Once equipment becomes trapped in tailing methodically consider and evaluate extraction methods to avoid getting more equipment stuck.
- Immediately mulch areas following seeding to avoid seed loss.
- Plan and layout operation areas and sequence to meet QA/QC and time objectives.

FINAL REVEGETATION SPECIFICATIONS/QUALITY ASSURANCE AND SUCCESS MONITORING

Based on the results from the field trials, financial constraints and mine management, specifications for the revegetation of the site were developed and modified according to field trial monitoring and experience gained during full-scale implementation. The specifications included methods of ameliorating the tailings to address the chemical and physical issues identified in the tailings analyses, greenhouse study and field trials. Plant species and rates (including specific varieties) proven to be successful in the greenhouse study and based on performance in the field trials were specified for use. Cultural techniques, which address meteorological constraints such as wind blown tailings, precipitation, planting times, etc., were also specified.

Revegetation plan designers performed oversight of the revegetation installation . Oversight included preparation of bid specifications and requests for proposals, identification of revegetation materials such as seed, fertilizers, soil ameliorants, mulches and erosion control products, selection of contractors, supervision of the installation and the monitor of revegetation success over time.

CONCLUSIONS

Through the systematic approach discussed above the key factors that ultimately dictated revegetation success at the White Pine Mine Tailings were identified. As a result reclamation techniques were formulated, evaluated, revised and improved upon. The greenhouse study demonstrated the benefits of OM amendments and identified soil analytical methods that are capable of predicting critical copper levels in plants. Plant tissue analysis accomplished during the greenhouse study emphasized the need to

identify, procure, and propagate copper-tolerant plants that were adapted to the local climate conditions. The field trials identified equipment limitations including the maximum ground pressure tolerated on the tailings and payload capacity. Overtime, information from the field trials enable the selection of the most appropriate erosion control methods, eliminated the use of inorganic fertilizers and confirm the performance of OM treatments and plant species selected for the site.

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VEGETATIVE COMMUNITY ANALYSIS OF BIOSOLIDS TEST PLOTS AFTER FIVE YEARS OF GROWTH

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ABSTRACT

The application of municipal biosolids during reclamation has been gaining acceptance in recent years. A series of reclamation test sites were established at the Bingham Canyon Mine in Utah during 1995 and 1996. These test sites were established on the tailings impoundment surface, on capped waste rock surfaces and on a gravel-borrow area. At each site, biosolids were applied to plots at rates of between 10 and 30 dry tons/acre, and control plots received identical treatments with the exception that biosolids were not applied. Vegetative community surveys were conducted at seven of these paired plots in the summer of 2001. After five to six years of growth, the biosolids plots generally contained a higher percent cover, ~75% of which was provided by volunteer weed species. On average, cheat grass (*Bromus tectorum*) alone accounted for over half of the total cover at the biosolids plots. The control plots, where biosolids were not applied, generally had less total cover, but weedy species accounted for less than 20% of the cover that was present. On average, the absolute cover provided by non-weedy species at the control plots was about twice as high as at the biosolids plots. The species diversity of non-weedy species at the control plots was also higher than at the biosolids plots. Forbs and woody shrubs were most common on the control plots. Most differences between biosolids and control plots were found to be statistically significant at a 0.05 significance level using an ANOVA analysis. The application of biosolids at these rates may favor the growth of weedy species and inhibit the establishment of favorable species. These study results suggest that depending upon the reclamation objectives, biosolids application may not always be beneficial, and that application rates of less than 10 tons/acre may be optimal at reclamation sites.

INTRODUCTION

The Bingham Canyon Mine is located in the Oquirrh Mountains near Salt Lake City, Utah. Several reclamation test sites were established at the mine in 1995 and 1996. These sites were designed to test the effect of biosolids (composted municipal sewage sludge) application during the reclamation of tailings, waste rock and gravel-pit surfaces. Biosolids have been used at many other reclamation sites because they can improve the physical and chemical characteristics of the soil and may act as a slow release fertilizer. The study area has a semi-arid climate and average annual precipitation varies between about 15 and 20 inches/year. The test plots are located between 4400 and 6200 feet above mean sea level.

At each of these test plots, biosolids were applied at rates that varied between zero and thirty dry tons/acre. The biosolids were usually disked into the surface soil before the sites were planted. Data collected from these sites after the first one to two growing seasons generally indicated that the plots where biosolids were applied had produced much more biomass than the

control plots that received no biosolids. In these early surveys, weedy species were not observed to dominate any of the test plots (Marrs, 1997b; McNearney, 1998).

During the summer of 2001, seven of these paired test plots were revisited and new vegetative community analyses were performed. Two of the paired test plots were located on the tailings impoundment embankment, three were located on top of sulfide-bearing waste rock surfaces and two were located on a gravel-borrow area.

METHODS

Test plots were selected for analysis if they met the following criteria: 1) documentation was available that detailed the treatments each plot received when it was established, 2) the plots were more than five years old, 3) the plots had not been disturbed since establishment, and 4) the location and boundaries of the plots could be confidently identified in the field.

Vegetation community analyses were performed at each test plot according to the relevÉ, or "sample stand" method (Barbour et al., 1987). Plant identification and nomenclature generally follows Welsh et al. (1993) while exotic species were identified from Whitson et al. (1992). Using the relevÉ method, variable-sized quadrats (sub-sites) were sampled at representative locations within each test plot area. The number of individual quadrats sampled at each test plot varied from one to five, depending upon the size of the plot. Each quadrat was sized to contain at least 90-95% of the dominant plant species identified within the community during the general site reconnaissance. Within each quadrat, three parameters were measured: the absolute % cover of each species present, the sociability of each plant species, and the vigor class of each plant species (Tables 1 through 3). Percent cover estimates were visually estimated within cover classes defined by the Braun-Blanquet cover scale (Mueller-Dombois and Ellenburg, 1974). The cover for each observed species was measured as a category (a number between zero and seven denoting 0-100% cover, respectively) rather than a precise number. An exact estimate of percent cover is thought to give a false sense of precision and cover estimates from multiple observers rarely agree. Although some precision is lost, categorical classification has good repeatability.

Species diversity was approximated with the number of species observed within each test plot. Even though simple diversity based on species counts can be undesirable because it fails to consider the relative abundance of the species present, in conjunction with the percent cover data, the relative abundance can be inferred.

The data from the relevÉ surveys were used to investigate the effects of biosolids application on the revegetation efforts. Percent cover, species diversity, and weed composition were compared between the biosolids and control plots. Weeds were identified by referencing the following three texts:

Noxious Weed Field Guide for Utah, J. Merritt, N.D. Belliston, and S.A. Dewey, 2000
Weeds of the West, T.D. Whitson et al., 1992
Common Weeds of the United States, USDA, 1971

Table 1.
Cover Classes of Braun-Blanquet

Class	Range of % Cover	Median
1	75-100	87.5
2	50-75	62.5
3	25-50	37.5
4	2-25	15.0
5	1-5	3
+	<1- 0.5	0.75
R*	Rare	*

* R=Individuals occurring seldom or only once; cover ignored and assumed to be insignificant. SOURCE: Mueller-Dombois and Ellenburg 1974

Table 2.
Sociability Scale of Braun-Blanquet

Value	Meaning
5	Growing in large, almost pure stands
4	Growing in small colonies or carpets
3	Forming small patches or cushions
2	Forming small but dense clumps
1	Growing singly

SOURCE: Barbour et al. 1987

Table 3.
Vigor Class

Class	Meaning
E	Excellent
G	Good
F	Fair
P	Poor

In general, weedy species that were observed on the test plots were not part of the reclamation seed mixes that were applied. In most cases the weeds are volunteers on the plots. However, four species that are listed as weeds in one or more of these texts were included in some of the seed mixes applied to the test plots. Rubber Rabbitbrush (*Chrysothamnus nauseosus*) is a dominant native species on undisturbed slopes of the Oquirrh Mountains and was included in some of the seed mixes. Yellow and White sweet clovers (*Melilotus officinalis* and *Melilotus albus*, respectively) and Orchard Grass (*Dactylis glomerata*) have also been historically included in revegetation seed mixes. During the analysis of weed content in the test plots, these four species were considered to be non-weedy because they were intentionally seeded onto many of the test plots.

Average Absolute Cover for each test plot was calculated by averaging the median-point of the Braun Blanquet cover classes for each species at each of the quadrats (sub-plots). These average absolute cover values for each species was totaled and reported as total absolute vegetative cover at each plot. The total absolute vegetative cover for any one plot can exceed 100% as there could be several layers of vegetation contributing to the total (grasses, forbs, shrubs).

PAIRED TEST PLOT RESULTS

Table 4 presents the 2001 survey results for each of the paired test plots. The results presented below characterize the vegetation cover at a single point in time five to six years after the plots were established. The character of the vegetation has likely changed since the initial surveys were conducted immediately after planting and it is anticipated that the character of the vegetation will continue to change in the future.

Table 4.

Comparison of Absolute Cover and Species Diversity between Paired Plots

Test Plot	Absolute Cover of Weed Species (%)		# of Weed Species Observed		Absolute Cover of Non-Weed Species (%)		# of Non-Weed Species Observed	
	BSA	NBS	BSA	NBS	BSA	NBS	BSA	NBS
01-04	88	21	2	2	0.2	90	1	5
01-05	54	41	2	2	46	64	2	3
01-06 Tailings Cap	92	6	4	3	0.4	16	2	2
01-06 Soil Cap	101	17	6	7	7	62	7	14
01-07	99	8	8	5	29	120	8	14
01-09 No Treatments	59	1.5	7	6	60	33	6	15
01-09 All Treatments	85	0.7	7	4	25	48	3	14

Note: BSA = Biosolid Application

NBS = No Biosolid Application

The results for the individual sites are detailed below.

Site 01-04

Site 01-04 is located on the east side of the tailings impoundment embankment at an elevation of approximately 4400 feet above mean sea level. This area corresponds to Test Plot 7, set up in 1996 as a demonstration project for biosolids application (McNearney, 1996). Biosolids were applied at rates of between 20 and 30 dry tons/acre to one set of plots and a series of control plots were also established where no biosolids were applied. All of the plots were then drill seeded. When the site was revisited in 2001, the plots that received biosolids were dominated by Cheatgrass (*Bromus tectorum*) (absolute cover equaled 88%). Non-weed species had an absolute cover of less than one percent on the biosolids plots. At the control plots that received no biosolids, the absolute cover provided by non-weedy species, predominantly Western Wheatgrass, Sheep Fescue and Tall Wheatgrass, was about 90%. Weedy species at the control plots had an absolute cover of 21%.

Site 01-05

Site 01-05 is located on the northwest side of the tailings impoundment embankment at an elevation of approximately 4400 feet above mean sea level. This area corresponds to Test Plot 1, set up in 1995 as a demonstration project for biosolids application (McNearney, 1996). At

the site, a series of plots were established where biosolids were applied at rates of 0, 10, 20 and 30 dry tons/acre. About 6 tons/acre of slaked lime was also added to all of the plots to raise the pH of the acidic soils that were present. All of the plots were drill seeded. The 2001 survey results show that the plots that received biosolids had an average absolute cover of 100%. About half of this cover was provided by Cheatgrass and the other half was provided by Tall Wheatgrass. The control plot that received no biosolids had an absolute cover of 41 % provided by weedy species and about 64 % provided by non-weed species, predominantly Tall Wheatgrass.

Site 01-06 Tailings Cap

Site 01-06 is located at an elevation of 6150 feet on the Eastside waste rock disposal area at the Bingham Canyon Mine. This area corresponds to the 6190 Test Plot, established by Kennecott Utah Copper in 1995 to test various waste rock caps with and without biosolids application (Marrs, 1997a). The waste rock beneath the cap material is acidic and will not support vegetation. Two sets of paired plots were compared at Site 01-06.

An 18-inch thick tailings cap was used with and without biosolids in one set of paired plots. The 2001 survey found that the tailings cap that received 30 tons/acre biosolids had an absolute cover of 92% provided by weedy species, predominantly Cheatgrass. Non-weedy species contributed less than one percent to the absolute cover. The tailings cap that received no biosolids had an absolute cover of 22%. The majority of the cover was provided by Sheep Fescue and Western Wheatgrass and about six percent of the cover was provided by weedy species.

Site 01-06 Soil Cap

A second set of paired plots at Site 01-06 was constructed with a manufactured soil composed of alluvial sediments mixed with pond sludge. One plot received an 18-inch thick cap without biosolids, and the other plot received a 2 to 12 inch cap with 30 dry tons/acre biosolids. Weedy species, predominantly Cheatgrass and Claspig Pepperweed, had an absolute cover of 101% on the biosolids plot in 2001. Non-weedy species, predominantly Four-wing Saltbush, had an absolute cover of seven percent. The plot that received no biosolids had an absolute cover of 17% provided by weedy species, predominantly Cheatgrass. Non-weedy species had an absolute cover of 62%. The most common non-weed species observed were Western Wheatgrass, Rubber Rabbitbrush, Utah Sweetvetch, Yellow Sweetclover and Four-wing Saltbush.

Site 01-07

Site 01-07 is located at an elevation of 6050 feet on a reclaimed portion of the Eastside waste rock disposal area at the Bingham Canyon Mine. The site is on an east-facing slope that was capped with 18 inches of mixed sludge and alluvium. In 1994 one half of the slope was drill seeded without biosolids application and in 1995 biosolids were applied at 30 tons/acre to the other half of the slope before it was drill seeded (Marrs, 1997a). The 2001 survey indicates that the portion of the slope that received biosolids had an absolute cover provided by weedy-species, predominantly Cheatgrass and Claspig Pepperweed, of 99%. Western Wheatgrass and Slender Wheatgrass were the dominant non-weed species providing 29% of the absolute cover. The

portion of the slope that did not receive biosolids had an absolute cover of 128%. Non-weedy species provided 120% of the absolute cover. The dominant species on this portion of the slope were Yellow Sweetclover, Western Wheatgrass, Palmer Penstemon, Utah Milkvetch and Slender Wheatgrass.

Site 01-09 No Treatments

Site 01-09 is in an old gravel borrow area located at an elevation of about 5400 feet above mean sea level at the foot of the Eastside waste rock disposal area. This site corresponds to the Triangle Borrow Test Plots established by Kennecott Utah Copper in 1996 (Marx and Cordell, 1996). At the Triangle Borrow area a series of plots were set up to test the effects of biosolids, mycorrhizae, seed coating gels and soil gels on plant establishment. Two sets of paired plots were compared at Site 01-09.

Biosolids were applied at 0, 15 and 20 tons/acre at one set of test plots. No other treatments were made before the plots were drill seeded. In 2001 when the site was revisited, the absolute cover on the biosolids plots was 119%. Weedy species, predominantly Cheatgrass and Tumble Mustard provided about half of the cover and Intermediate Wheatgrass provided the other half. Non-weedy species provided about 33% of the absolute cover on the control plot and weedy species provided about 2%. The dominant species on the control plot were Slender Wheatgrass and Utah Sweetvetch.

Site 01-09 All Treatments

The second set of paired test plots at Site 01-09 received treatments with mycorrhizae, seed coating gels and soil gels. Biosolids were then applied to the plots at rates of 0 and 15 tons/acre. The biosolids plot had an absolute cover of 110% in 2001. Weedy species, predominantly Cheatgrass provided about 85% of the absolute cover and non-weedy species provided 25%. The dominant non-weed species were Slender Wheatgrass, Intermediate Wheatgrass and Shadscale. Non-weed species had an absolute cover of 48% on the plot that did not receive biosolids and weedy species covered less than one percent. The dominant species on this plot were Big Sagebrush, Slender Wheatgrass, Shadscale, Lewis Blue Flax and California Poppy.

DISCUSSION

Figures 1 and 2 are graphs that average the percent absolute cover provided by each species observed in the seven paired plots. The control plots that were planted without biosolids had an average absolute cover of 76% in 2001. Non-weedy species provided 62% of this cover and weedy species provided 14%. A total of 30 non-weedy species and 11 weedy species were observed growing on the control plots. The dominant species that were observed in order of decreasing abundance were: Tall Wheatgrass, Cheatgrass, Yellow Sweetclover, Western Wheatgrass, Slender Wheatgrass, Sheep Fescue, Palmer's Penstemon, Utah Milkvetch, Utah Sweetvetch, Rubber Rabbitbrush, Big Sagebrush and Claspings Pepperweed. Generally, all of these species except Cheatgrass and Claspings Pepperweed were in the seed mixes that were originally applied to the test plots.

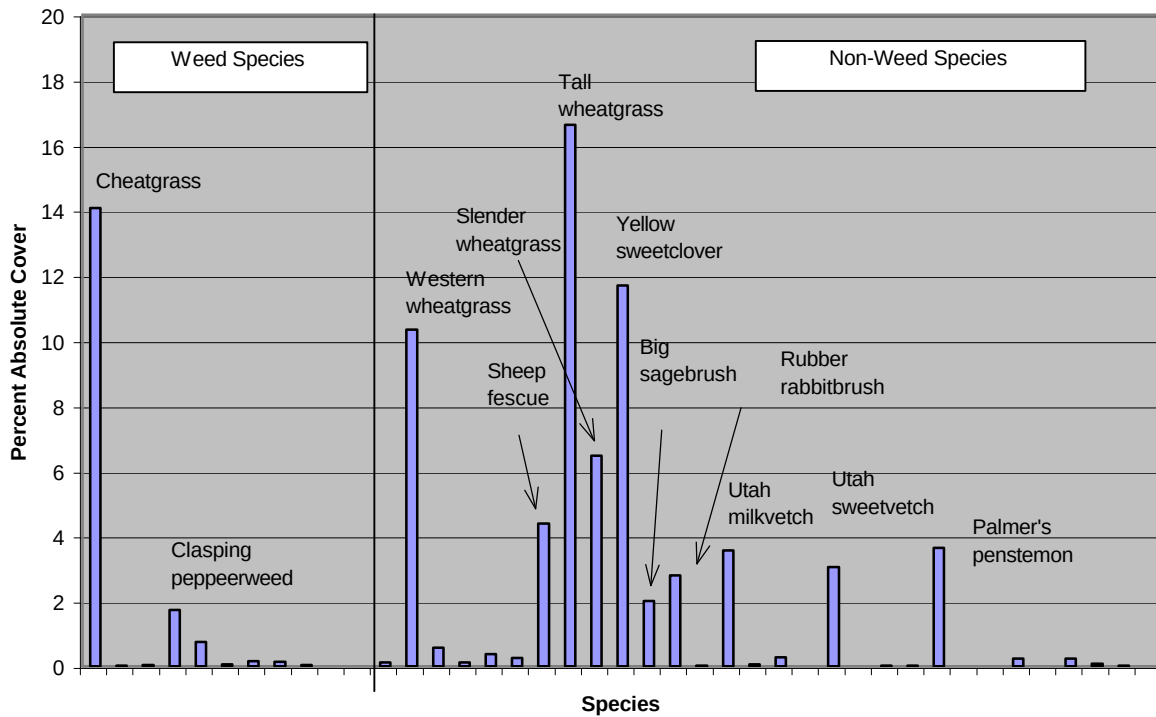


Figure 1. Average Absolute Cover by Species for Paired Plots with NO Biosolids Application

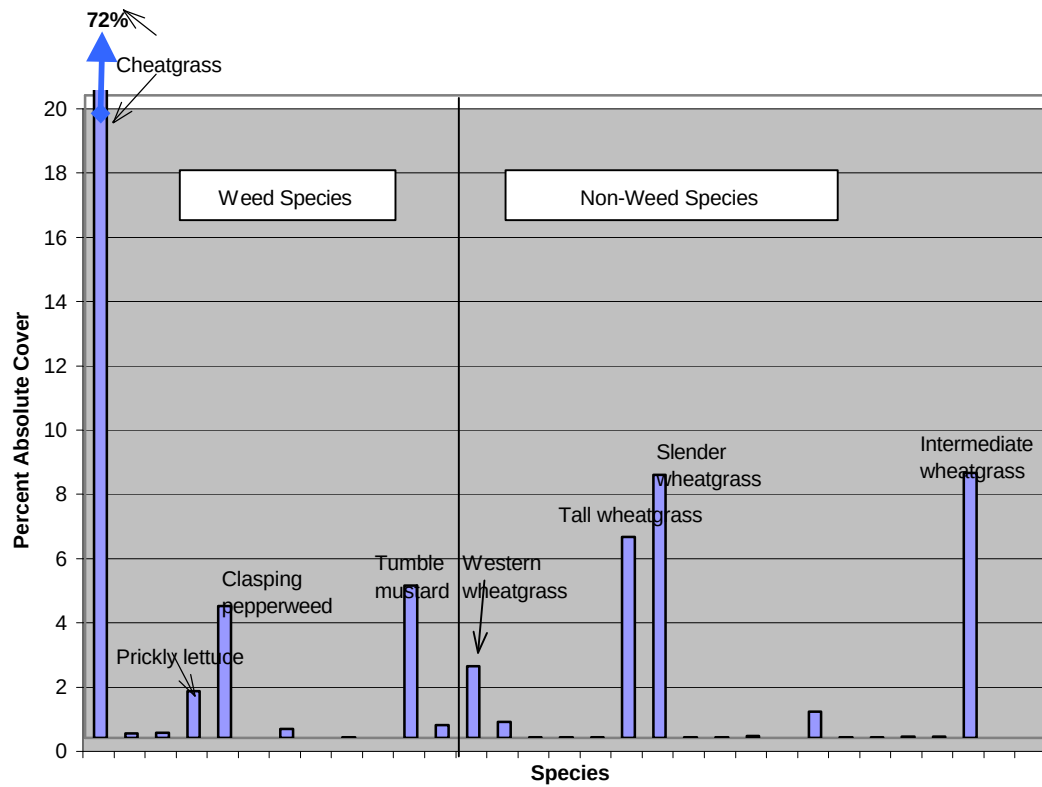


Figure 2. Average Absolute Cover by Species for Paired Plots with Biosolids Applied at 10 to 30 Dry Tons/Acre

During the 2001 field investigation, it was observed that the plots that were planted after biosolids were applied at rates of between 10 and 30 dry tons/acre had an average absolute cover of 107%. Non-weedy species provided 24% of this cover and weedy species provided 83%. A total of 19 non-weedy species and 12 weedy species were observed growing on the biosolids plots. On average, the absolute cover provided by Cheatgrass on the biosolids plots was 72%. No other species had an average absolute cover above 10%. Secondary species observed in order of decreasing abundance were: Slender Wheatgrass, Intermediate Wheatgrass, Tall Wheatgrass, Tumble Mustard, Claspig Pepperweed, Western Wheatgrass and Prickly Lettuce. Only the wheatgrass species were included in the original seed mixes that were applied to these sites.

In general the test plots that received biosolids had a higher total absolute cover than the control plots that received no biosolids. As shown on Figure 3, there is a weak positive correlation between the amount of biosolids applied to a plot and the absolute cover growing after five years ($R^2 = 0.20$). However, biosolids application appears to favor the establishment of weedy species on the test plots (Figure 4). There is a strong positive correlation between the biosolids application rate and the fraction of the total cover that is provided by weedy species ($R^2 = 0.85$). As shown on Figure 5, this results in a moderate negative correlation between the rate of biosolids application and the absolute cover provided by non-weed species ($R^2 = 0.40$). In most cases, the higher the biosolids application rate, the lower the absolute cover of the species that were intentionally seeded onto the site. On average, the control plots had more than twice as much cover provided by non-weed species than the plots that received 10 to 30 dry tons/acre biosolids. Species diversity, as measured by the number of species observed, was also higher on the control plots. An average of 9.2 species were observed on each of the biosolids test plots, but only 4.1 were non-weedy species. An average of 13.7 species were observed on each of the control plots, of which 9.6 were non-weed species.

An ANOVA analysis was performed on the seven paired plots for several of the measured parameters (Table 5). The differences in the absolute cover provided by non-weedy species was found to be statistically significant at a 0.05 significance level using an ANOVA analysis ($p=0.03$). The differences in total absolute cover provided by all species was also found to be statistically significant ($p=0.05$). However, total species diversity between plots that did and did not receive biosolids was not statistically significant at a 0.05 significance level ($p=0.24$).

Table 5.

Statistical Analysis of Differences between Treatments (Biosolids versus Non Biosolids) using an ANOVA analysis

Absolute Cover of Non-Weedy species Total Cover Identified for all Non-Weedy Species						
Treatment	Mean	St. Dev.	95% C.I.	F-value	d.f.	p-value
Biosolid	24	23	22	5.71	12	0.03
Non	62	35	35			
Biosolid						

Species Diversity Total Number of Species Identified						
Treatment	Mean	St. Dev.	95% C.I.	F-value	d.f.	p-value
Biosolid	9.2	5.7	5.3	1.53	12	0.24
Non	13.7	8.0	7.4			
Biosolid						

Total Absolute Cover Total Number of Species Identified						
Treatment	Mean	St. Dev.	95% C.I.	F-value	d.f.	p-value
Biosolid	107	12	11	4.41	12	0.05
Non	76	40	37			
Biosolid						

The application of biosolids at rates of between 10 and 30 dry/tons acre appears to favor the growth of volunteer weedy species at the expense of non-weed species. In most cases the application of biosolids ultimately inhibited the establishment of species that were intentionally seeded onto the test plots at the Bingham Canyon Mine. These study results suggest that depending upon specific reclamation goals, biosolids application may not always be beneficial, and that application rates of less than 10 dry tons/acre may be optimal at reclamation sites. Unfortunately, these study results cannot be used to estimate the optimum biosolids application rate between 0 and 10 dry tons/acre that may aid in initial vegetation establishment without favoring the dominance of weedy species in the longer term.

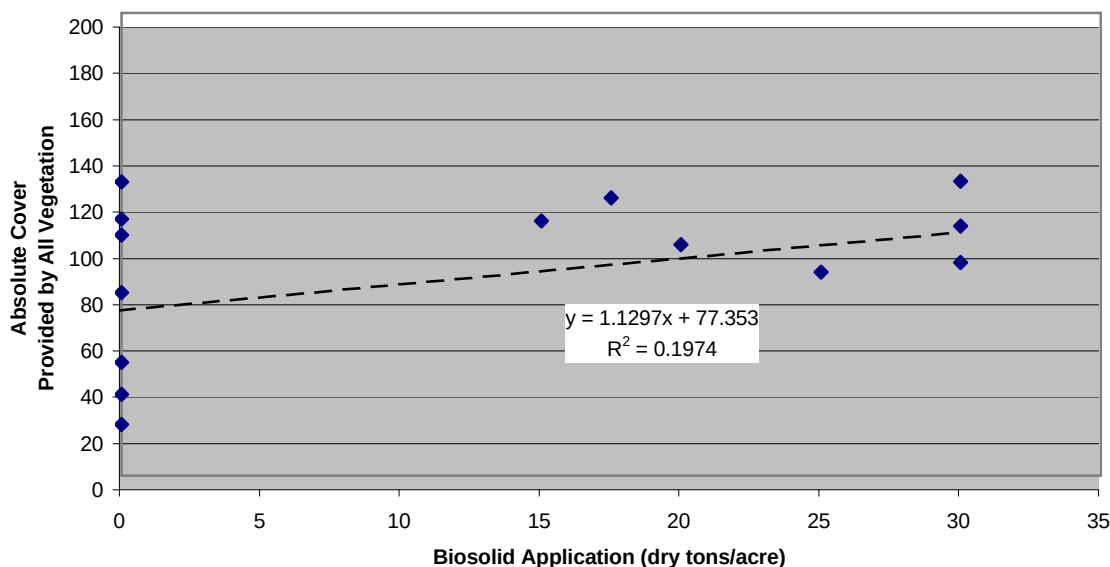


Figure 3. Absolute Cover Provided by All Species versus Tons of Biosolids Applied

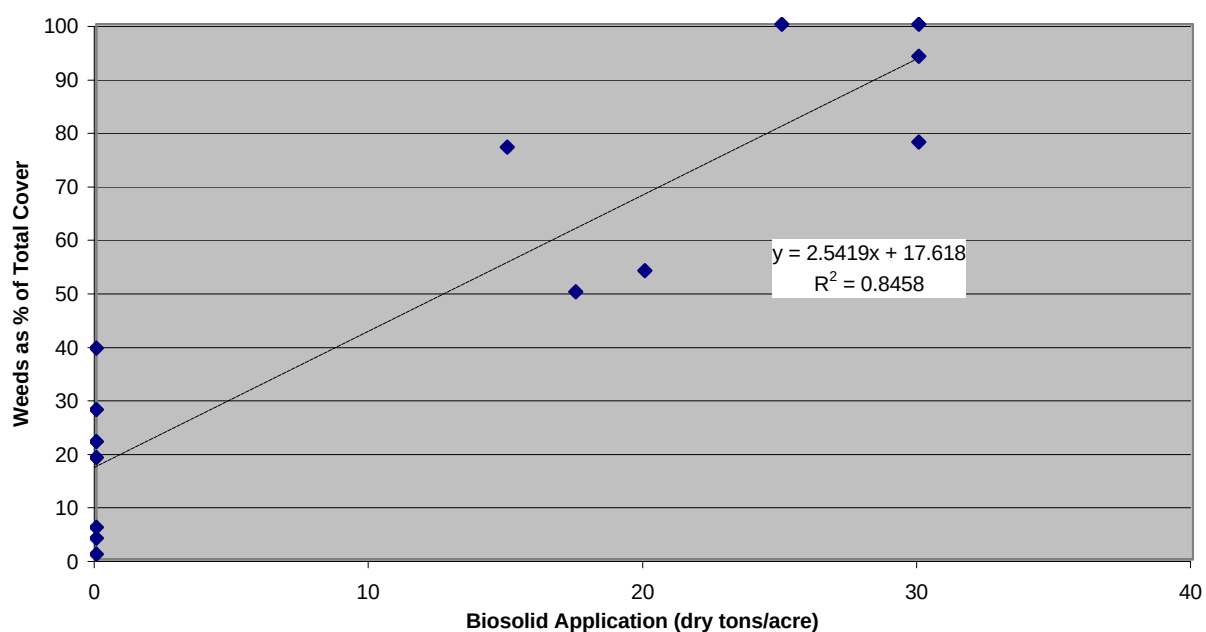


Figure 4. Percent of the Total Cover Provided by Weedy Species versus Tons of Biosolids Applied

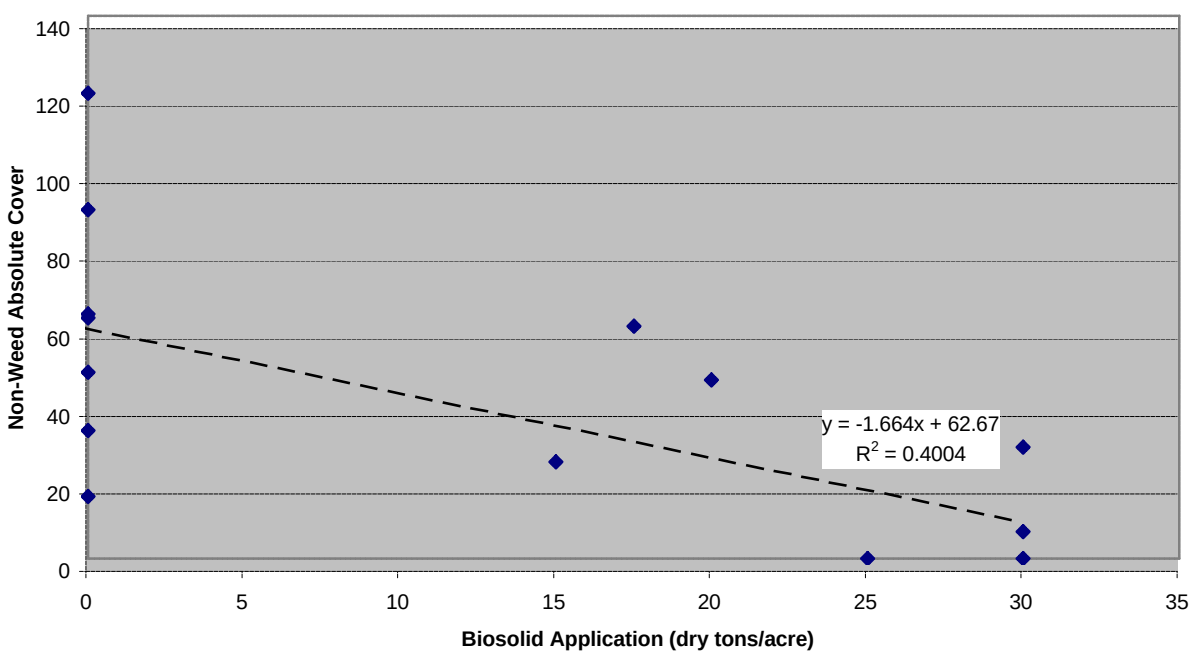


Figure 5. Absolute Cover Provided by Non-Weedy Species versus Tons of Biosolids Applied

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ROOTING CHARACTERISTICS OF VEGETATION ESTABLISHED ON A REFUSE PILE

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ABSTRACT

Established vegetation growing on a reclaimed refuse pile at the Starpoint Mine was compared with vegetation growing on a subsoil stockpile. Both were seeded in 1983. Soil cover over refuse varied from two inches to eighteen inches. Five pits were excavated in the refuse pile and five pits in the subsoil pile adjacent to shrubs common in both locations. Root sizes and quantities were estimated based on the 1998 NRCS publication, Field Book for Describing and Sampling Soils.¹ Soil texture, coarse fragment content, and structure were noted. Representative samples of field measurements of soil pH and electrical conductivity were taken. Resistance to penetration was measured with a pocket penetrometer.

Taproots of all shrubs, except *Eriogonum corymbosum*, dramatically turned to grow along the soil/refuse interface before eventually descending gradually, but not vertically, into the refuse. A mat of fine roots formed at the soil/refuse interface. Medium and coarse roots were limited to the top two feet of the subsoil-covered refuse. At the subsoil pile, all shrub taproots were quite robust and grew straight downwards into the subsoil stockpile as did medium and coarse roots. The subsoil was impenetrable when dry, similar to the refuse. However, when it was moist, resistance to penetration was much lower than the refuse. Avoidance of the refuse by the taproots was likely due to compaction of the refuse and enhanced water availability of the subsoil stockpile.

Root growth into refuse would be enhanced by ripping of the surface prior to soil cover placement. The recommended depth of ripping is inversely related to the depth of cover, so that a less compacted root zone of four feet is achieved. If the refuse is combustible then the recommended soil cover depth should be four feet to allow for a rooting zone, while protecting against combustion. Working the soil cover into the refuse surface to avoid an abrupt boundary layer is also recommended.

¹ Schoeneberger, P.J. Wysocki, D.A., Benham, E.C., and Broderson, W.D. 1998 Field Book for describing and sampling soils. Natural Resources Conservation Service, USDA, National Soil Survey Center, Lincoln, NE.

INTRODUCTION

Refuse piles are a significant component of mined land reclamation in Utah. While the coal refuse in Utah is generally considered non-toxic, it is unknown whether it provides a suitable root growth medium. Evaluation of rooting depths on coal refuse piles was selected as an evaluation topic to investigate the suitability of coal refuse as a plant growth medium.

The evaluation was conducted at the Star Point Mine refuse pile on the ridge above the test plots. The test plots were established in 1983 to evaluate varying depths of topsoil, subsoil, and fertilizer on vegetative cover. The vegetation is now 17 years old and has established, well-developed root systems.

A backhoe was used to excavate five pits in the refuse pile and five pits in the subsoil pile. The pits were dug no deeper than five feet because of safety concerns. Pit locations were based on the presence of three shrubs common to each location and equipment accessibility. We anticipated that this would enable us to make paired comparisons, where the only variable was the presence of refuse or subsoil below the topsoil.

Root size and quantity was estimated based on the 1998 NRCS publication, Field Book for Describing and Sampling Soils (Schoeneberger et al, 1998). Soil and refuse conditions were assessed similar to a soil survey. Estimates of the soil texture, coarse fragment content, and structure at different depth intervals were taken. Representative samples of field measurements of soil pH and electrical conductivity were taken. Each pit was photographed.

Field reconnaissance work was completed in May and August of 2001. We compared the rooting depths and distributions found in the refuse and subsoil areas. We also compared these patterns and depths with rooting depths reported in the literature. Any differences in root growth patterns and physical differences between the refuse and subsoil were noted.

SITE DESCRIPTION AND LITERATURE REVIEW

Typical root growth characteristics are summarized in Table 1 below. Munshower (1995) states that root growth is strongly influenced by the soil in which the root is growing. For instance, *Artemisia tridentata* may be a deep taproot with a wide lateral spread or a short taproot with many branches.

Table 1. Typical root growth characteristics*

Species	Root type	Depth (ft)	Height (ft)
<i>Artemisia tridentata</i>	One or more tap roots. 1/3 of roots in top foot of soil	6	2-4
<i>Atriplex canescens</i>	Branching tap root	6.5 – 20	1-7
<i>Chrysothamnus nauseosus</i>	Branching tap root	deep	1-7

<i>Ephedra</i>	Several deep tap roots subdivide at intervals	deep	0.75 – 5.0

*Munshower, 1995; Brown and Wiesner, 1984; USDA Fire Sciences Laboratory, July 2001.

The Star Point Mine annual reports indicate that the mine weather station recorded an average of 13.78 inches precipitation for the years 1984 to 1991. The highest annual precipitation recorded was 21.07 inches in 1985; the lowest annual precipitation recorded was 8.97 inches in 1989. The weather station was located at an elevation of 8550 feet until July 1989 when it was moved to 7560 feet elevation. Information specific to Star Point Mine is not available after 1991, as the weather station was disabled by a lightening strike (Personal communication, 2001).

In a 1977 report, Dames and Moore described the Star Point refuse as waste from the wash plant and mine composed of mudstone, shale and coal. The refuse was classified as a well-graded, silty, fine-to-coarse sand with fine and coarse gravel and occasional cobbles (Dames & Moore, 1977). They recommended a compaction of 75 pounds per cubic foot for the refuse material when it was placed in the test plot area of the refuse pile sometime between 1976 and 1982. A 1982 photograph of the refuse prior to installation of the test plot shows a two-track road going up the ridge of the pile. Our rooting depth study pits were in the same approximate location as the road.

The Star Point Mine refuse pile test plots test plots were planned to evaluate topsoil and subsoil replacement depths necessary for successful plant growth. The test plots and surrounding area were seeded in 1983 and the following seed mixture was reportedly used.

Table 2. Seed mixture reported used on the refuse pile.

Species	Lbs. PLS/Acre
Slender wheatgrass	3
Western wheatgrass	3
Tall fescue	2
Great Basin wild rye	3
Bluebunch wheatgrass	3
Scarlet globemallow	.5
Penstemon	.5
Cicer milkvetch	1
Yellow sweet clover	1
Rubber rabbitbrush	.5
Big sagebrush	.1
Green ephedra	2
Fourwing saltbush	1
Total	20.6

Table 3 summarizes the characteristic of the refuse and subsoil as reported in the Star Point Mining and Reclamation Plan. As Table 2 illustrates, the average refuse pH was 7.1 with a high of 7.9 and a low of 6.6. The average electrical conductivity (EC) was 3.76 (high of 8.8 and low of 1.2). The average sodium adsorption ratio (SAR) was 1.61, with a high of 5 and a low of 0.3. On the average, particle fractionation was 59% percent sand, 23% silt, and 18% clay, placing the refuse texture in the sandy loam category. The average nitrogen level was 3.76. Overall, the refuse had a higher salt content than the subsoil, but not sufficient to affect plant growth. The refuse was also coarser textured than the spoil.

Table 3. Comparison of subsoil and refuse chemical and physical parameters as reported in the MRP.

Parameter	Subsoil	Refuse
PH (units)	7.9	7.1
EC (mmhos)	0.54	3.76
Ca (Meq/l)	399	38
Mg (Meq/l)	67	16
Na (Meq/l)	1	7
SAR (units)	0.22	1.16
Sand (%)	38	59
Silt (%)	31	23
Clay (%)	31	18
Texture (Average)	Clay loam	Sandy loam

In the year 2001, the refuse pile was well vegetated and was growing species which were not seeded, such as the Sego Lily. The Utah Regulatory Program Evaluation Year 2000, Evaluation Topic: Reclamation Success on Refuse Piles, dated 10/18/2000, reported that the average vegetative cover on the reclaimed refuse test plots was 32.3% and met the 90% standard

of the designated reference area cover. Shrub density was 3,261 shrubs/acre, exceeding the 2,000 shrubs/acre standard. With a MacArthur's Index value of 5.65, the reclaimed test plots came close to, but did not meet the 6.45 MacArthur's Index value of the diversity standard of the reference area. Erosion was reported to be moderate on the north-facing, steep (40%) slope. The report notes that in addition to the steepness of slope, there were few coarse fragments on the surface to stabilize the slope.

METHODS

This study was conducted on June 12, 2001. Five test pits were located on the top of the refuse pile, easily accessible by a track hoe. The concept of placing pits according to subsoil and topsoil cover depth placement was abandoned and replaced by the concept of locating pits immediately adjacent to shrub species of interest. An attempt was made to create corresponding pits in the subsoil storage area adjacent to the same shrub species. In some cases, pits were excavated between the roots of two different shrubs so, five pits yielded information on more than five shrub roots.

Refuse pits numbers 1 through 4 were located on level ground at the top of the refuse pile, within several feet of the test plot. Pit number 5 was on the outslope. Subsoil pits were located on a gentle slope with the higher pit numbers at the base of the slope.

Penetrometer resistance information was gathered from the pits on August 23, 2001. On that date, the refuse pits were either damp and muddy or had six inches of standing water in the bottom. The same was true for the subsoil pits, except that the subsoil pits at the base of the slope were completely submerged. This moisture proved fortuitous for the measurement of compressive strength of the soil.

The definitions of the descriptive terms used to quantify the roots and place them in a size class followed the procedures found in Schoeneberger et al, 1998. A copy of the Schoeneberger nomenclature has been included in this report as Appendix 1. In short, to describe the frequency of roots, the following terms are defined: "common" means 1 to < 5 per unit area; "few" means less than one per unit area; and, "very few" means less than 0.2 per unit area. The unit area evaluated depends upon the root size. To describe root size, the following terms are described: "very fine" roots are less than one millimeter in diameter; "fine" roots are between one and two millimeters in diameter; "medium" roots are between 2 to 5 mm in size; and "coarse" roots are 5 to 10 mm in size.

DISCUSSION

Refuse Pile

At the refuse pile, taproots of the following shrubs were exposed: three four-wing saltbushes (*Atriplex canescens*); four whitestem rubber rabbitbrushes (*Chrysothamnus nauseosus* var. *albicaulis*); one green stem rabbitbrush (*Chrysothamnus nauseosus* var. *consimilis*); one big sagebrush (*Artemisia tridentata*); one Mormon tea (*Ephedra viridis*). All taproots of the shrubs,

except *Eriogonum corymbosum*¹, dramatically turned to grow along the soil/refuse interface before eventually descending gradually, but not vertically, into the refuse, see Picture #1. These tap roots were very gnarled, see Picture #2 versus Picture #3.



Picture #1, Refuse Pit #2. Taproot growing sideways. (The red portion of the Sharpshooter shovel is 18 inches long.)



Picture # 2, Refuse Pit #2. Gnarled roots.



Picture #3, Subsoil Pit #1.
Normal roots

The soil and refuse were very dry and very hard to dig. The roots formed a mat of fine roots at the soil/refuse interface at Pit #2 south side, Pit #3 east and west sides, and Pit #4 north and south sides, for example see Picture #4. Within the refuse, root growth was noted in mats

¹ *Eriogonum corymbosum* was not seeded. It is a volunteer. It is often seen growing in coal outcrops.

underneath a large coarse fragments at Pit #2 south side and Pit #3 east and west sides and pit #5 south side. Few to very few medium and coarse roots were noted growing in the top two feet of the soil covered refuse at Pit # 1 east and west sides, Pit #2 south and north sides, Pit #4 south and north sides, and Pit #5 south side. Below two feet only few to very few medium and few to very few fine to very fine roots were noted in the refuse. (Very few medium roots were noted between 17 and 55 inches in Pit #2 north and south sides. There was no notation made to indicate whether the medium roots were located in the 17 to 24 inch zone or below 24 inches.)

Soil cover over the refuse varied from two inches on the slope at Pit #5 to eighteen inches at Pit #4. Soil field parameters were measured for the first two refuse pits (Pits #1 and #2) and the averages are reported in Table 4 below. Field measurements were hindered by variable saturated paste standing time and difficulty in drawing the filtrate off with suction.



Picture #4, Refuse Pit #2 south side
Mat of fine roots at the soil/refuse interface.

Table 4. Average field measurements for two refuse pits.

	Soil Cover	Soil/Refuse Interface	Refuse Composite
Estimated Texture	Clay loam	Loam	sand
Average pH	7.8	7.35	4.9 (ranged from 3.5 to 6.4)
Average color	Light brown	Peach/orange	black
Structure	Granular/platey	platey	massive
Resistance (dry)	3.0 Tons/sq ft		impenetrable
Resistance (moist)	1.2 Tons/sq ft		4.1 Tons/sq ft

Coarse fragments in the refuse were stained with iron and sulfur precipitates at four out of the five pits, suggesting some acid formation (see Picture #5). In response to testing with hydrochloric acid the refuse showed no effervescence, indicating that there are no carbonates present and it has no buffering capacity for any acidity it produces.



Picture #5, Pit #1 west side
Iron and Sulfur precipitation.



Picture #6, Pit #4 south side
Compacted Refuse

Refuse structure was massive and difficult to dig even with the trackhoe (see Picture #6, Pit #4 south side). The compaction of the refuse was noted by measuring the resistance to penetration with a pocket penetrometer. When the refuse was dry, it was impenetrable. When moist, it still presented a very hard surface requiring four times as much pressure to penetrate as the subsoil above it.

Subsoil Pile

At the subsoil pile, taproots of the following shrubs were exposed: two four-wing saltbushes (*Atriplex canescens*); two whitestem rabbitbrushes (*Chrysothamnus nauseosus* var. *albicaulis*); and two greenish rabbitbrushes (*Chrysothamnus nauseosus* var. *consimilis*). All shrub taproots were quite robust and grew straight downwards into the subsoil stockpile (see Picture #7)

Whereas roots growing into the refuse were generally fine to very fine in size, medium to coarse roots of plants were noted growing into the subsoil. At Pit #1 east side, very few, very coarse roots were noted and very few medium roots were noted. At Pit #3 east side, very few medium roots were noted. At Pit #4 south side, medium roots were common and coarse roots were few. At subsurface depths in Pit #5 east side, few medium to very few medium roots were noted. In fact, at Pits # 4 and # 5 at the base of the slope where moisture was encountered with depth, more roots of all sizes were noted at a depth of four feet.

At Pits #1 and #3 in the subsoil very few fine to very fine roots were noted clustered around a large rock (see Picture #8). This is similar to what was noted in the refuse.



Picture #7, Subsoil Pit #3
Taproot growing straight down into subsoil.



Picture #8, Subsoil Pit #
Roots clustered under rock in the subsoil.

Measured soil field parameters for the subsoil pile are reported in Table 5 below. At depths of seven to ten inches below the surface, the massive structure of the subsurface subsoil was encountered. Increasing moisture was noted with depth for pits at the base of the slope. However, at the top of the slope, hand digging of taproots was very difficult in the compacted, dry subsoil. The subsoil was impenetrable when dry, similar to the refuse. However, when it was moist, resistance to penetration was much lower than the refuse (2.16 tons/sq ft versus 4.1 tons/sq

ft). The entire subsoil profile had a strong effervescent reaction indicating the presence of carbonates.

Table 5. Subsoil pile field measurements taken from Pit #3

	Surface	Subsurface
Estimated Texture	Clay to clay loam	Clay loam
Average pH	8.0	8.0
Average color	Brown	light brown
Structure	Fine platy	massive
Resistance (dry)	2.91 Tons/sq ft	impenetrable
Resistance (moist)	1.33 Tons/sq ft	2.16 Tons/sq ft

Volume measurements (length x width x height) were taken of shrubs at both the refuse and subsoil pit locations. The average volume for each site is reported in Table 6 below. No conclusions can be drawn from this information due to the extremely small sample size, the variation in topographic position, and the differential effects of grazing on growth at the sites.

Table 6. Average Above Ground Shrub Volumes in Cubic Feet

Shrub Volume	Refuse (sample size)	Subsoil (sample size)
<i>Atriplex canescens</i>	29.7 (2)	122 (2)
<i>Chrysothamnus nauseosus</i> var. <i>albicaulis</i>	49.8 (2)	21.4 (2)
<i>Chrysothamnus nauseosus</i> var. <i>consimilis</i>	68.3 (1)	42.0 (2)

CONCLUSIONS

The study of two plant growth medium types: coal refuse covered by substitute topsoil (or subsoil) and stockpiled subsoil (the same material used to cover the refuse) conducted at the Star Point Mine in central Utah provided the following facts:

- Rooting growth characteristics varied between refuse and subsoil.
- None of the shrub species in the study had a taproot that penetrated vertically into the refuse. Conversely, all the sampled shrub species in the subsoil pile had taproots that went vertically into the subsurface layer.
- The refuse was drier than the subsoil.
- The subsoil did not drain as freely as the refuse.
- Refuse had lower field pHs than the subsoil and higher ECs.
- When moist, refuse was more difficult to penetrate (almost twice as difficult) than the subsoil.
- Both subsurface subsoil and refuse were impenetrable when dry.
- Fine and very fine roots were observed at the four to five foot depth in

both subsoil and refuse.

- More coarse and medium roots were noted at comparable depths in the subsurface subsoil profile than the refuse profile.

Woody plant species became established in both growth mediums, but the roots reacted differently in each medium. Roots appeared to be better developed in the subsoil stockpile, including the development of well-defined taproots. In the refuse pile, roots grew straight downward until they came to the interface of the soil and refuse where they moved laterally before finally entering the refuse material. The research team concluded that the growth of taproots into refuse was atypical compared to growth of taproots into an adjacent subsoil stockpile of the same age or the available literature.

Compaction and moisture may have played a role in the differences. Compaction of refuse piles is required under Mine Safety and Health Administration regulations at 30 CFR 77.215 as a strategy to avoid combustion. As discussed earlier, Dames and Moore recommended a compaction of 75 pounds per cubic foot for the refuse material when it was placed in the test plot area of the refuse pile sometime between 1976 and 1982. A 1982 photograph of the refuse prior to installation of the test plot shows a two-track road going up the ridge of the pile. Our rooting depth study pits were in the same approximate location as the road. As demonstrated by the penetrometer readings the refuse remains well compacted, even when moist.

The difference between the penetration resistance of the refuse and subsurface subsoil, coupled with the location of the subsoil stockpile in a topographic position where precipitation run-on is likely (enhancing water availability), may well have accounted for the vertical taproot penetration into the subsurface subsoil compared to the refuse and the limited growth of medium and coarse roots into the refuse. The National Soil Survey Center (1996) advises that compacted soils can be identified by “platy or weak structure or a massive condition, greater penetration resistance, higher bulk density, restricted plant rooting, flattened, turned, or stubby plant roots.” All of these conditions were noted in this study, with the exception of bulk density which was not measured.

Medium and coarse roots grew four to five feet deep in the subsoil stockpile, whereas medium and coarse roots were limited to the top two feet of the subsoil-covered refuse. Above two feet, the refuse would have been subject to freeze thaw forces which would reduce the bulk density and decrease compaction, creating a more conducive environment for medium and coarse root growth. To a lesser degree the ability of very fine roots to penetrate the refuse was also limited.

Although iron and sulfur staining was noted in most of the refuse pits, it is unclear if the lower pH had any effect on plant root growth, but the presence of fine and very fine roots in the refuse would indicate that they were not adversely affected by the refuse pH.

Root growth into soil-covered refuse would be enhanced by ripping of the surface prior to soil cover placement. The recommended depth of ripping is inversely related to the depth of cover, so that a less compacted root zone of four feet is achieved. If the refuse is combustible then the recommended soil cover depth should be four feet to allow for a rooting zone, while protecting against combustion. Working the soil cover into the refuse surface to avoid an abrupt boundary layer is also recommended.

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APPENDIX 1

Root Quantity and Size Description

from

Schoeneberger, P.J., Wysocki, D.A., Benham, E.C., and Broderson, W.D. 1998 Field Book for describing and sampling soils. Natural Resources Conservation Service, USDA, National Soil Survey Center, Lincoln, NE, Page 2-53

ROOTS

Record the **Quantity**, **Size**, and **Location** of roots in each horizon. **NOTE:** Describe **Pores** using the same **Quantity** and **Size** classes and criteria as **Roots** (use the combined tables). A complete example for roots is: Many, fine, roots In Mat at Top of Horizon or 3, f (roots), M.

ROOTS - QUANTITY (Roots and Pores) - Describe the quantity (number) of roots for each size class in a horizontal plane. (NOTE Typically, this is done across a vertical plane, such as a pit face.) Record the average quantity from 3 to 5 representative unit areas. **CAUTION:** The unit area that is evaluated varies with the Size Class of the roots being considered. Use the appropriate unit area stated in the *Soil Area Observed* column of the "Size (Roots and Pores) Table". In NASIS and PDP, record the actual number of roots/unit area (which outputs the appropriate class). Use class names in narrative description.

Quantity Class ¹	Code Conv NASIS		Average Count ² (per unit area)
Few	1	#	< 1 per area
Very Few	-		< 0.2 per area
Moderately Few	-		0.2 to < 1 per area
Common	2	#	Common 1 to < 5 per area
Many	3	#	= 5 per area

¹ The Very Few and Moderately Few sub-classes can be described for roots (optional) but do not apply to pores.

² The applicable area for appraisal varies with the size of roots or pores. Use the appropriate area stated in the *Soil Area Assessed* column of the "Size (Roots and Pores) Table" or use the following graphic.

ROOTS - SIZE (Roots and Pores) - **See** the following graphic for size.

Size Class	Code Conv NASIS		Diameter	Soil Area Assessed ¹
Very Fine	vf	VF	< 1 mm	1 cm ²
Fine	f	F	1 to < 2 mm	1 cm ²
Medium	m	M	2 to < 5 mm	1 dm ²
Coarse	co	C	5 to < 10 mm	1 dm ²
Very Coarse	vc	VC	= 10 mm	1 m ²

¹One dm² = a square that is 10 cm on a side or 100 cm²

TECHNICAL PAPER SESSION 6 PARTNERSHIP / PROJECTS

Title: [Pennsylvania's Efforts to Address Operation, Maintenance and Replacement of AMD Passive Treatment Systems](#)

Authors: [Pamela J. Milavec](#)*, Water Pollution Biologist 3, PA Department of Environmental Protection, Bureau of Abandoned Mine Reclamation and **Daniel R. Seibert***, Resource Conservationist, USDA – Natural Resources Conservation Service

Title: [Interagency/Industry Coordination to Respond to Selenium Contamination at Phosphate Mines in Southeast Idaho](#)

Authors: **Brian Buck**, Geological Engineer, JBR Environmental Consultants, Inc. and [Jeffrey L. Jones](#)*, Minerals Management Specialist/Geologist, USDA, Forest Service

Title: [Ohio DNR and Cuyahoga Valley N. P.: A Partnering Success Story](#)

Authors: [Mark Smith](#)*, Environmental Specialist/ Project Officer, Ohio Division of Mineral Resources Management-AML Section and **Kim Norley***, Landscape Architect, National Park Service

Title: [Watershed Coalition Power in Appalachia - Keepers of the Land and Water](#)

Authors: [Kelley Sponaule](#)*, Assistant State Conservationist, USDA – Natural Resources Conservation Service and **Patrick C. Park**, AML&R Liaison, West Virginia Office of Abandoned Mine Lands & Reclamation

PENNSYLVANIA'S EFFORTS TO ADDRESS OPERATION, MAINTENANCE AND REPLACEMENT OF AMD PASSIVE TREATMENT SYSTEMS

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ABSTRACT

An increasing number of watershed groups, as well as many Federal, State and local agencies, have become active in watershed restoration over the past several years. As a result, a large number of restoration projects are being funded and constructed. In Pennsylvania, a total of nearly \$93 million of public money has been spent on all types of watershed restoration projects since 1988. A portion of this funding has gone to construct 153 AMD passive treatment systems statewide. Funds have come from a variety of sources, including the Office of Surface Mining's Title IV program, the Natural Resources Conservation Service's (NRCS) PL-566 program, Pennsylvania's Growing Greener program and the Environmental Protection Agency's 319 Non-Point Source program. Water quality and aquatic habitat improvements are occurring as these projects are implemented. The need for long-term operation, maintenance and replacement (O, M & R) has been increasingly recognized as a requirement to ensure the success of watershed restoration projects. The failure to maintain the systems being constructed could have detrimental impacts to watersheds that are beginning to support an increasing number of stream uses. As a result of growing concern over this issue, the PA Department of Environmental Protection (DEP) established a workgroup to provide recommendations to address this need. The workgroup consisted of individuals from Federal, State and local governments, as well as private consultants and watershed group officials. All had extensive experience in the operation and maintenance of watershed restoration projects, both mining and non-mining related. Recommendations were finalized by late 2001.

The NRCS and DEP have taken a lead role in implementation of these recommendations, including the development of maintenance plans and agreements, working with local watershed groups to provide routine maintenance and trouble-shooting to solve problems that arise. Their experiences are providing a greater understanding of the efforts needed to keep systems functioning properly.

INTRODUCTION

In Pennsylvania, watershed groups and various government agencies started constructing passive treatment systems to treat abandoned mine drainage (AMD) in the early 1990's. The design of these systems has evolved from simple, aerobic wetlands to complex vertical flow alkalinity generating systems with mechanisms to flush accumulated metals. While the design improvements have resulted in the ability to treat highly acidic discharges, the resulting systems have required significantly more effort to keep them operating effectively. Early vertical flow systems that did not have adequate flushing mechanisms have started to fail due to plugging by metals. Additional problems have surfaced at older systems, including leaks, short-circuiting

and metals accumulation. All these experiences have pointed to the need to address long-term operation, maintenance and replacement (O, M & R) of AMD passive treatment systems.

The need to address O, M & R became even more pressing as additional funding was made available to build these types of systems. Early on, funds were provided by the EPA 319 Non-Point Source program, the Natural Resources Conservation Service (NRCS) Rural Abandoned Mine Program and P.L. 566 program and the Federal Office of Surface Mining's Ten Percent Set Aside and Appalachian Clean Streams Initiative (ACSI) programs. These funds continue to increase, while significant additional funding has surfaced with the establishment of Pennsylvania's Growing Greener program in 1999.

In June 2000, State Representative Sam Smith provided remarks at a statewide AMD conference that emphasized the need to address O, M & R in watershed restoration work. Many others working in the AMD treatment field were recognizing the same need. As a result, the PA Department of Environmental Protection (DEP) established a workgroup in early 2001 to develop recommendations to address this problem. The workgroup met throughout 2001 and finalized recommendations to DEP Secretary David Hess in November, 2001. These recommendations are provided in Attachment A. Since that time, much effort has gone into implementation of the recommendations. The DEP and NRCS have been leaders in that effort, along with several strong watershed groups and knowledgeable consultants.

IMPLEMENTATION

A major focus of implementation of the workgroup's recommendations has been the educational aspect. Members of the workgroup spoke at various conferences and Growing Greener training workshops in order to develop an awareness of the need to address O, M & R. Also, several changes were implemented in the Growing Greener program (the single most significant funding source) as a result of the recommendations. They included: developing an O, M & R fact sheet, providing detailed information in the application packets about the need to address O, M & R in the application, changing project score sheets to emphasize the need for O, M & R on implementation projects, and requiring the development of an O, M & R plan for all construction projects. In addition, a separate funding category has been developed to address funding of O, M & R projects with significant costs, starting with the 2003 round. The State Legislature passed Legislation in late June that continues Growing Greener through 2012 and provides a permanent funding source for the program.

The development of O, M & R plans has become a major focal point for projects constructed by the NRCS, under their P. L. 566 program, and the DEP's Bureau of Abandoned Mine Reclamation (BAMR), which uses OSM and Growing Greener funds to construct treatment facilities. These plans emphasize the partnerships with local watershed groups that are needed to provide for necessary O, M & R. O, M & R plans are developed for all NRCS projects and all new BAMR projects. The NRCS requires local sponsors in counties where the projects are located to accept the responsibility for all O, M & R needs. Operation and maintenance agreements and plans are prepared for the sponsors. NRCS staff provides consultation and technical input when significant maintenance is needed. BAMR looks upon the local groups to provide for routine monitoring, operation and minor maintenance requirements. Training is provided to the local groups where needed. BAMR is responsible for more significant maintenance needs and for eventual system replacement.

A major issue with regard to O, M & R is monitoring, particularly water sampling and laboratory analysis. Monitoring of the treatment system efficiency is very important – it provides feedback for future design improvements and signals when systems are not operating properly and may need maintenance. Typically, local groups and BAMR staff collect the samples and DEP's laboratory provides the analysis. This has proven to be a significant portion of the expenses involved with O, M & R. Determining how best to deal with this cost is an ongoing issue within DEP that has yet to be resolved. The DEP has recently convened a small workgroup to address this.

TECHNICAL ISSUES

A number of difficult technical issues have arisen with regard to the long-term operational efficiency of AMD passive treatment systems. The most complex issue deals with metals precipitation within the systems, particularly vertical flow systems that treat net acid water. Vertical flow systems typically consist of a layer of standing water over organic material (usually mushroom compost), which is underlain by limestone with a pipe collection system below the limestone. In theory, vertical flow systems are expected to keep ferrous iron in the ferrous state and to reduce existing ferric iron to a ferrous state as a result of a lack of oxygen in the system (the compost layer strips oxygen present in the water as a result of the biological oxygen demand of the compost). Ferrous iron is expected to pass through the limestone and precipitate in a subsequent settling basin. Aluminum, which comes out of solution as the pH increases, whether or not oxygen is present, is expected to precipitate within the compost and/or limestone layer. Flushing is expected to remove precipitated aluminum. However, field evidence indicates that most systems retain some iron within the limestone. In a few cases, iron has precipitated on top of the compost layer, causing the system to plug. While flushing these systems provides visual evidence of both iron and aluminum removal from the systems, a recent study has indicated that only a small percentage of retained metals is being flushed from the system in two systems studied (Watzlaf, 2001). The long-term implication of this is unknown, but efforts are underway to determine the best way to design the flushing systems to maximize removal from the limestone.

A less frequent problem occurs when ferric iron precipitates on top of the compost in vertical flow systems, as the pH starts to increase. When this occurs, it eventually reduces the permeability of the compost until water cannot flow vertically through the system. Since the solubility of iron is pH dependent and precipitation occurs more rapidly as the pH increases (Hem, 1992), the pH of the raw water that is being treated must be carefully considered when designing systems with high iron levels. Creating larger precipitation ponds and wetlands before the vertical flow systems can reduce the amount of ferric iron reaching the vertical flow system.

Accumulation of aluminum in the top 6 inches of the rock layer in vertical flow systems can create hydraulic conductivity problems within the limestone. As mentioned earlier, oxygen is not needed to precipitate aluminum - there only needs to be an increase in pH to above 4.5 (Hem, 1992) for precipitation to occur. In many systems, this pH increase occurs in the upper areas of the limestone rock column, or even within the compost. The initial precipitation of aluminum creates a very loose, jelly-like precipitate ($2\text{Al}(\text{OH})_3$) that is easily dislodged and flushed from the rock. This precipitate is easily flushed from the system when aggressive flushing systems are initially designed in the system. Frequent flushing is recommended, at least quarterly, to keep the aluminum purged from the system. Field observations indicate that if the

aluminum is allowed to accumulate in the rock to point where hydraulic conductivity is reduced, the flushing of aluminum becomes more difficult. Also, aluminum precipitate seems to harden and take on a paste consistency with time and becomes harder to flush.

Other problems encountered with vertical flow systems include short-circuiting caused by the development of preferential flow paths through the compost layer. This has especially been evident on several systems where the compost was washed out immediately below the influent point to the system. Dispersing the inflow through a manifold rather than at a single, point-source location seems to help this. The configuration of the piping system underlying the limestone rock can also impact short-circuiting through the system. Long narrow systems that have continuous pipes running along the longitudinal axis of the system seem to short circuit through the piping system. This apparently results from the water entering the piping near the influent end of the system and traveling through the piping rather than through the limestone. Segmenting can alleviate this, or zoning the piping system by designing incremental breaks in the pipes to force the flow of water into the limestone (Danehy et al., 2002). Consideration of a system with a lower length to width ratio during the design phase also may be important in reducing short-circuiting.

The most frequently used source of organic material in vertical flow wetlands is spent mushroom compost. The function of the compost is to reduce ferric iron to ferrous iron and provide a medium for biological activity. When new systems are first put into service the mushroom compost can create very high biological oxygen demands (BOD) on the stream receiving the treated water. If aquatic life is present in the stream at the time the system goes on line, the BOD may kill much of the aquatic life present in the stream. To manage this potential problem, it is best to install a valve on the inflow pipe to the system and limit the amount of water entering the system. This allows for a slow flushing of the BOD out of the system and prevents an aquatic kill on the receiving stream.

OVEN RUN CASE STUDY

Stony Creek is a historically AMD impacted watershed located primarily in Somerset County, PA. The first major source of AMD to Stony Creek was a tributary known as Oven Run. The Oven Run AMD Abatement Project was developed under an NRCS PL-566 plan, the first in the country approved to address AMD. Six project areas were identified for abatement in the plan. Five of the six project sites required passive treatment using vertical flow systems. With completion of the first five projects by the fall of 1999, the Stony Creek turned from net acidic to net alkaline for a distance of 22 miles. The project has been very successful and has restored a recreational fishery in a stream long considered to be dead. The amazing success of this project has occurred even though three of these systems have had O & M related problems, which will be discussed below. Although the Somerset County Commissioners signed an agreement to be the responsible O & M entity under the PL-566 Plan, both BAMR and the NRCS have taken the lead role in addressing the technical problems that have arisen.

Oven Run Site A, the sixth and final site to be constructed, was just completed in the spring of 2002 using NRCS and Growing Greener funds. It consists of a passive treatment system that incorporates many design features developed as a result of lessons learned from the sites constructed earlier. Specifically, aerobic wetlands and limestone filter dams were used to remove as much ferric iron as possible prior to the vertical flow wetland. Also, an aggressive flushing system was constructed. Initial indications are that this site is functioning as designed.

Routing water sampling of the system is planned starting in the fall of 2002, after the system has stabilized.

Oven Run Site B was completed in 1999 by BAMR, using OSM ACSI and Ten Percent Set Aside funds. BAMR has continued to provide all monitoring, operation and maintenance at this site, although turning routine operation and maintenance to the Somerset Conservation District is a future possibility. Site B has a design flow of 350 gpm, although the system has successfully treated flows as high as 450 gpm. The influent has acidity between 500 and 600 mg/l, total iron between 55 and 85 mg/l and aluminum between 35 and 45 mg/l. The system consists of a deep mine drainage collection trench, a vertical flow wetland, settling pond, second vertical flow wetland and second settling pond. Until spring of 2000, the system effluent was net alkaline, with very low metals concentrations. After flows increased in the spring of 2000, effluent quality degraded to the point that net acid water was being discharged with a pH in the low 4's and elevated iron and aluminum. This situation continued, even after flows subsided. Site inspectors had observed an opening in the compost directly below the point of influent discharge into the first vertical flow system. BAMR's construction crew was brought in to construct an inflow manifold system to spread influent over a larger area and prevent the development of preferential flow paths through the compost. The expected water quality improvements did not occur, although this vertical flow system is generating about 200 – 250 mg/l of alkalinity, which is about all that can be expected. Now, concerns are being directed to the second vertical flow pond, which has steadily lost the ability to generate the additional alkalinity needed to fully neutralize the raw water. Both vertical flow systems are scheduled to be drawn down in the summer of 2002 to evaluate the development of preferential flow paths and take remedial action. One possibility is that the very aggressive flush system has actually pulled compost down into the limestone, causing the compost layer to be too thin above the pipes and allowing the development of preferential flow paths. The aggressiveness of the flush system is due to the large head differential between the system and the flush discharge point and the separation of the flushing system into 3 cells, allowing greater velocities when each is flushed individually. There is no evidence of metals plugging in either vertical flow wetland and the system continues to remove over 90% of the iron, 70 to 80% of acidity and about 60% of the aluminum (see Figure 1).

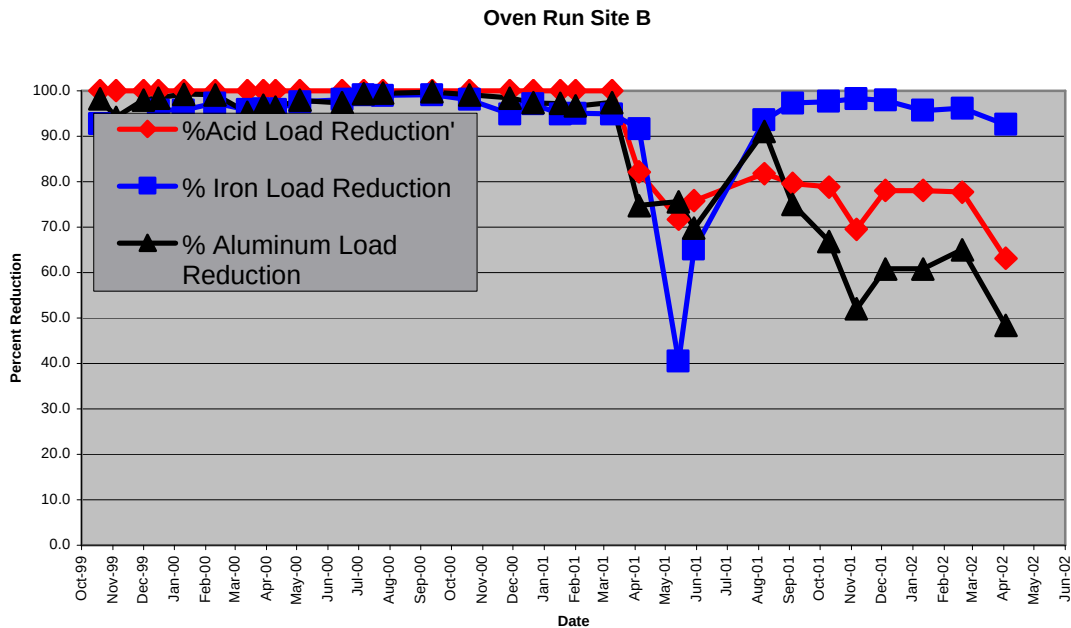


Figure 1

Oven Run Site C was completed in 1997 and consisted of backfilling a 5,000 foot long highwall using OSM Title IV funds. A small, but highly acidic, discharge from the open pit was largely eliminated. A minor seep that remains is directed to the Oven Run Site B system. Since backfilling this highwall, which was hydrologically connected to the deep mine discharge at Site B, maximum flows at Site B have been no more than half the flow measured prior to completion of this project. This flow reduction is a very important secondary benefit to completion of the backfilling project.

Oven Run Site D was completed in September of 1995 by NRCS, using PL-566 and section 319 funds. Site D treats approximately 100 gpm of moderately acidic deep mine drainage. Since beginning operation as the first completed system on Oven Run, the system worked well. In sequential order the system is composed of an initial settling pond, aerobic wetland, vertical flow wetland, settling pond, aerobic wetland, vertical flow wetland and a final settling pond. A rise in the water level in the first vertical flow wetland was noticed after the second winter of operation.

A limited flushing system in this system allowed for some flushing of accumulated metals from the system. Initially, the limited flush lowered the water level back to original levels. In subsequent years, the water level raised every winter when flow rates increased. Each time the system was flushed, the effectiveness of the flush decreased. A layer of iron was accumulating on top of the compost in the vertical flow ponds that limited the flow through the system. The system continued to treat the water flowing through it, but the quantity of water flowing through the system was controlled by the permeability of the iron on top of the compost. In the winter of 1999, some of the water began to flow through the emergency spillway and was not treated in the vertical flow wetland. This condition continued through the spring of 2002. At this point in time, approximately 50 GPM would pass through the system; any flow above this amount would bypass the system through the emergency spillways.

To remedy this situation, the Somerset County Conservation District applied for and received a DEP Growing Greener grant in the spring of 2002. To limit the iron accumulation on the compost, 3 rock filter dams were placed in the wetlands preceding the vertical flow ponds. The rock filter dams will eliminate short-circuiting of flow through the wetland and will increase the detention time in the wetland. An aggressive bottom flushing system was also installed to eliminate inert materials left behind by limestone dissolution and to remove metal accumulation in the rock layer. As part of the bottom flushing system, piping was extended to the surface of the compost and capped with threaded pipe caps. These vertical pipes will act as ports to flush accumulated iron from the surface of the compost. The caps will remain on the vertical pipes during normal operations of the system and be removed prior to flushing for surface iron removal.

Oven Run Site E was completed in 1997 with NRCS funds, and treats two moderately acidic deep mine discharges with a configuration very similar to Site B (two vertical flow wetlands and two settling ponds). Plugging of the vertical flow wetlands started to occur relatively soon after commencement of operation, which was very puzzling to the system designers. The problem was eventually determined to be the result of the limestone used in the vertical flow wetlands. While technical specifications called for a required calcium carbonate percentage, they did not specify rock meeting soundness standards as specified by the PA Department of Transportation (PA DOT, 2000). Initially, the rock produced good water quality, but the rock quickly began to deteriorate. After 4 years, hydraulic conductivity through the system was lost to the point that the system is not providing treatment. Designs have been prepared to replace the degraded rock and install an aggressive flushing system. Late summer of 2002 construction is planned for the upgrading of this system.

Oven Run Site F was completed in September of 2000 with NRCS funds. The design of this system was completed with much more knowledge about the operation and maintenance concerns of vertical flow wetlands. Experience at site D taught us that routine flushing from the bottom of the vertical flow wetland was necessary to keep the systems functioning over time. This system treats 300 GPM of acid mine drainage and consists of a vertical flow wetland, settling pond, vertical flow wetland and a final settling pond. A very intensive flushing system was designed for the vertical flow wetlands at this site. The vertical flow wetlands have a grid of 6 inch, perforated pipes on 11 foot centers, under the limestone. These pipes outlet to two, 12 inch pipes that are at opposite ends of the vertical flow wetland. The flow out of the system when these two pipes flow is approximately 5000 GPM per pipe, at the beginning of the flush. Experimenting with the sequencing of opening valves and the duration of flushes has provided some empirical observations of the flushing events at this site.

Observations were made while opening only one valve at a time, with alternate opening and closing, after 30 minutes of flow, and opening both valves at the same time until the vertical flow wetland was drained. With both flushing scenarios, the flush water was initially very turbid. With the alternate opening and closing of valves, the effluent water began to clear and become less turbid after 30 minutes of flushing. The amount of turbidity decreased with each successive alternate opening and closing of valves. When both valves were opened simultaneously and the water was allowed to flow until the system was drained, the effluent water remained very turbid during the entire time of the flush, approximately 3 hours. Since this system was constructed with an aggressive flushing system in 2000, quarterly flushing has been completed. There has been no indication of rising water levels in this system as were noted at Site D, where only a limited flushing system was designed. These empirical observations need

to be followed by more controlled flushing experiments that involve water quality testing during the flush to calculate quantities of metals flushed from the system.

CONCLUSIONS

The future of passive treatment of AMD is dependent upon resolution of the long term O, M & R issues related to these systems. Implementation of the DEP Workgroup recommendations is underway and starts to resolve these issues, particularly from an administrative standpoint. However, resolution of many of the technical concerns may be more difficult. One of PA's leading AMD treatment consultants, Hedin Environmental, received a Growing Greener grant to evaluate design and operation of flushing facilities. This work was initiated with a workshop attended by a number of government and consulting personnel to gather and organize existing data on vertical flow systems in order to design the most efficient systems (Workshop Proceedings, 2002). The technical issues fall under several general categories that are discussed below.

Use of Mushroom Compost:

The use of mushroom compost in vertical flow wetlands to promote biological activity and facilitate the conversion of ferric iron to ferrous iron is a widely accepted practice (although, more recent thinking is that this conversion is not a complete one; ferric iron is observed being flushed from these systems). Mushroom compost is also used in anaerobic wetlands to encourage sulfate reduction reactions and in aerobic wetlands to promote plant growth. When AMD systems are constructed using mushroom compost, sample analyses have shown a significant biological oxygen demand (BOD) present during the first week to 3 months the system is in operation. This BOD can present devastating impacts on receiving streams if any aquatic life is present. Frequently, the acid water being treated has already devastated aquatic life to the level that there is little need for concern. However, in situations where aquatic life is present or where there are downstream municipal water supplies, the management of the outflow of BOD from the system is imperative. The simplest method to control the initial flow of BOD is to strategically place piping and valves in the system so that the majority of the AMD can be bypassed around the system while a small flow is allowed to move through the system. The small flow will, with time, reduce the BOD to levels that are not harmful to aquatic life. Once this condition is reached, the flow of AMD through the system can gradually be increased until all of the AMD is flowing through the system. Recent trends have been toward a reduction in compost from early designs, where compost thickness was as high as two feet. Experience on the NRCS Oven Run sites indicates that 6 inches of compost is adequate to promote biological activity and facilitate conversion of ferric iron to ferrous iron. Larger quantities of compost take longer to dissipate the BOD and long-term odor problems can be a concern in residential areas. Another consideration, however, is that too little compost may contribute to short-circuiting, as well as possible rapid depletion of fine limestone within the compost and a possible loss of biological activity once the pH drops. BAMR has recently dropped compost specifications from 2 feet to 1 foot to reduce BOD generation while still providing adequate compost to address the other concerns.

Short Circuiting:

In Oven Run, we have learned that the flow through systems with under draining flush capabilities may short circuit in a number of ways. Preferential flow patterns may develop as a result of shifting compost below inflow points and possibly even above flush pipes on systems with aggressive flushing. Other short circuiting may occur directly through the flushing pipes. In long, narrow systems, with flush piping extending the full length of the system, there is a high potential for water to enter the flush pipes at the inflow end of the system and travel through the pipe instead of through the rock. This short-circuiting does not allow adequate detention time in the limestone rock for treatment of AMD. Short-circuiting can be reduced using a couple different methods. Distribution manifolds that evenly distribute the water throughout the vertical flow wetland prevent water from entering at one point and entering the flush system. This also keeps compost from being shifted immediately below the inflow point. Another method of preventing short-circuiting is to incrementally cap the longitudinal flush pipes so water is forced to leave the flush pipes and flow through the limestone rock (compartmentalizing the flush systems). On larger flow discharges, the use of both of these techniques is recommended to maximize water to rock contact. Minimizing the length to width ratio also should be considered during design.

Flushing:

Experience in Oven Run and other watersheds over the last seven years has clearly shown that vertical flow wetlands treating highly mineralized AMD that are not designed and operated with an aggressive flushing system will experience plugging with time. In vertical flow wetlands that treat acid mine drainage with dissolved iron and aluminum, the accumulation of precipitated metals in the rock will fill the rock voids, eventually plugging the system, and cease to treat the mine drainage. Bottom flushing of vertical flow wetlands has proven to be an effective way of removing accumulated precipitates from these systems. Long duration, high volume flushing performed on a regular schedule has maintained hydraulic conductivity through the Oven Run Site F system. The system has continued to produce high quality water since construction. Figure 2 illustrates how the water quality improves as it moves through the system.

Some system designers have recommended limiting the number of holes in the perforated pipe to increase the velocity of flow through each perforation in the pipe. The number of perforations in the pipe is the limiting factor determining the quantity of water leaving the system. There are some concerns with this type of design. One concern is that the distance between holes in the pipe becomes too great and the area of influence of the perforation is less than the distance between perforations. In this case, there potentially could be "dead areas" between perforations where little flow occurs, which would eventually cause the rock to plug with metal precipitate. Another concern is that limestone rock placed directly on the perforated pipe could greatly reduce the capacity of the perforations if a rock lodges in a perforation. If this happens, the distance between perforations becomes even greater, increasing the potential for "dead" areas. Other designs currently being evaluated include those using multi-tiered flush piping and those that do not use compost at all. Determining the best design for these systems is an ongoing process. Hedin Environmental has retained an engineer to evaluate current system designs and make recommendations for future designs. A draft paper, currently being circulated for comment, recommends increasing flush velocities to assist in the removal of retained solids by dividing the under drain systems into multiple cells and designing the header pipes for gravity flow to provide for even flow distribution (Langese, 2002).

Rock Quality:

The quality of the limestone rock used in vertical flow wetlands is somewhat dictated by the local commercially available sources of limestone. In western Pennsylvania, there are several sources of limestone that perform well over long periods of time. It is important to specify stone that is durable and will not deteriorate when exposed to acid. Specifying rock that meets the soundness standards specified by the Pennsylvania Department of Transportation (PA DOT) should ensure the integrity of the system with regard to ability to transmit water. Early in the implementation of the Oven Run Site E project, the soundness of the limestone was not specified by NRCS. Rock was provided that met the specified chemical standards, but was not from an approved PADOT quarry. This is believed to have caused the system to fail.

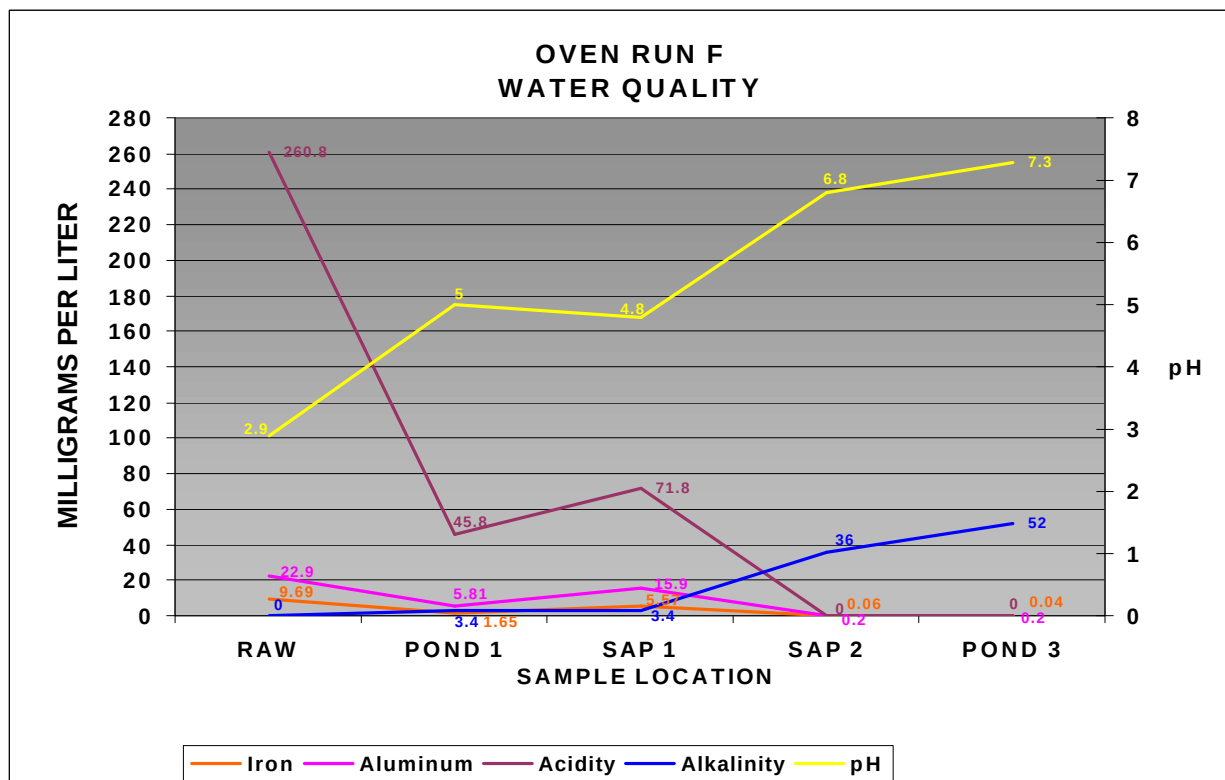


Figure 2

It is also important to specify a minimum of 80% calcium carbonate as determined by ASTM C-114. It is important to note that calcium carbonate equivalent (CCE) is not specified but elemental calcium carbonate is. Also, the maximum content of elemental magnesium should not exceed 2% and inert material (e.g. silica) should be less than 15%.

The above discussions should help to emphasize the need to have a knowledgeable, reliable entity to provide for long-term O, M & R. The failure to do so will result in the eventual failure to adequately treat AMD and the loss of millions of dollars worth of public investment. Gains in the restoration of aquatic habitat will also be lost. The design of these systems is expected to continue to evolve as more is learned about long-term operation. Passive treatment

of AMD is expected to be an important aspect of watershed restoration into the foreseeable future. O, M & R improvements will ensure the continued success of this restoration work.

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Attachment A

DEPARTMENT OF ENVIRONMENTAL PROTECTION

FINAL RECOMMENDATIONS OF THE LONG TERM OPERATION, MAINTENANCE AND REPLACEMENT WORKGROUP

November 15, 2001

An increasing number of watershed groups, as well as many Federal, State and local agencies, have become active in watershed restoration over the past several years. As a result, a large number of restoration projects are being funded and constructed. Water quality and aquatic habitat improvements are occurring as these projects are implemented. The need for long-term operation, maintenance and replacement (O, M & R) has been increasingly recognized as a requirement to ensure the success of watershed restoration projects. In Pennsylvania, a total of nearly \$93 million of public money has been spent on these projects since 1988 (see attachment A). The establishment of the Growing Greener grant program has greatly accelerated this effort. The failure to maintain the systems being constructed under these projects could have detrimental impacts to watersheds that are beginning to support an increasing number of stream uses. As a result of growing concern over this issue, the Department's Greener Team established a workgroup to provide recommendations to address this need. This workgroup consists of individuals from Federal, State and local governments, as well as private consultants and watershed group officials. All have had extensive experience in the operation and maintenance of watershed restoration projects.

It is important to note that, for the purpose of defining needs and determining costs, the workgroup defined long-term O, M & R as system operation and maintenance, plus one system replacement at the end of the design life of the project. Also of note is a decision by the group to include all publicly funded watershed restoration projects constructed through 2001, when determining costs associated with existing systems.

O, M & R Plan

An O, M & R Plan, developed by the project sponsor, is an integral part of providing for operation and maintenance of watershed restoration projects. The basic elements of an O, M & R plan include: a written agreement with the entities responsible for O, M & R, identification of tasks to be completed, development of a schedule and determination of responsible parties and costs. Plans must become a "deliverable" of all new implementation grants. For existing projects that have no O M & R plan, site-specific plans will need to be developed prior to receiving funds to address O, M & R.

Operation, maintenance and replacement concerns should begin at the initial site inventory of a project and continue through all phases of project development. Water quality information, along with flow measurements, should be looked at critically with respect to future operation and maintenance. If a site requires intense operation and maintenance to function, the sponsors of

the project need to understand the intensity and potential cost. Once the decision is made to move ahead with project design, the focus should be to make the operation and maintenance of the system as easy as possible. Prior to project implementation, the sponsors need to understand what it is they need to do and at what frequency. Additional training may need to be provided to facilitate a more detailed understanding of operation and maintenance.

In developing an O, M & R plan, the following should be considered:

Operations - Sponsors need to demonstrate an understanding of, and the ability to perform, routine duties, such as:

- Inspections (including water sampling and flow measurements);
- Litter control;
- Vegetation control;
- Mechanical maintenance (including flushing);
- Insect and vector control;
- Physical stability and erosion control.

Maintenance - Sponsors need to demonstrate an understanding of, and the ability to perform, more intensive items that may take considerable dollars and time to accomplish, such as:

- Removal and disposal of accumulated precipitate or sediment;
- Maintenance of channels;
- Industrial cleaning of pipes;
- Repairing damage after major storm events;
- Repairing cracks or leaks;
- Adding limestone, compost, sand or gravel;
- Repairing vandalism damage;
- Adjusting grade or outlet structures.

Replacement - Systems have a designed life expectancy; once that design life is exceeded, much of the system will need to be recharged or replaced. Replacement will involve much of the same effort originally needed to construct the system. Changes in technology and water quality and quantity will need to be considered to determine if the size and/or design of the system must be changed. Replacement considerations include:

- Estimating BMP (Best Management Practice) design life;
- Determining replacement responsibility, including a successor, in the event of the original project sponsor's inability to carry out these responsibilities;
- Determining approximate costs for the following possible needs: removing accumulated sediments, replacing defective valves, water control structures, re-sizing the system to accommodate changed water quality or quantity, recharging organic matter layer on wetlands, recharging limestone rock.

An O, M & R Plan should include:

- Narrative describing O, M & R needs and identifying responsible parties
- Signed maintenance agreement with all parties, including property owners
- O, M & R Site Map that includes BMP's, flushing points, monitoring points (water sample locations, benchmark cross sections, etc.)
- Site specific instructions
- "As-built" plans

Long-term Cost Analysis

Long-term costs are analyzed in many business and government applications. The starting point for most analyses is a spreadsheet that projects costs over the lifetime of the BMP. Costs are often divided into tasks such as site inspections, sample collection, sample analysis, sludge management, flushing, and reconstruction. A long-term cost spreadsheet should be developed for all projects early in the planning process. The construction of this spreadsheet will help sponsors to recognize long-term responsibilities and also encourage them to identify mechanisms that will legitimately lessen the long-term costs of their projects.

The workgroup collected information on long-term costs of BMPs by reviewing existing policies, interviewing technology experts, and by analyzing current cost data. The workgroup did not find established O, M & R cost estimates for mine drainage treatment systems, so estimates were developed from Department, Natural Resources Conservation Service (NRCS), non-profit and consultant experiences. These data were used to develop spreadsheets that projected long-term O, M & R costs for specific mine drainage BMPs. Development of the spreadsheets required assumptions about the time period over which to project costs and whether to include a BMP replacement in the extrapolation. The workgroup decided to analyze 25 years of costs and to include one replacement in the calculation.

The spreadsheets were analyzed in two ways. The first method was to calculate the present value of the long-term costs. The method requires financial assumptions about rates of inflation and investment return. The result of this calculation is a sum of money that, if the financial assumptions are realized, will yield proceeds adequate to cover all anticipated long-term costs. Our analyses assumed a 3% inflation rate and a 6% rate of return, or a net rate of return of 3%. While this may seem conservative, it is consistent with long-term economic trends in the U.S. It is also consistent with similar analyses of long-term AMD treatment costs being conducted by the Department for permitted mines. The present value analysis yields a sum of money that can be placed into perspective by comparing it to the BMP's original construction cost. On average, the present value of the long-term O, M, & R costs were approximately 60% of the construction costs. Thus, if the Department wanted to fully fund a \$100,000 passive treatment project, it should plan on placing \$60,000 in an interest-bearing account at the time of construction. If the cost projections and financial assumptions are correct, no more funds should be required for 25 years.

A second analytical method calculated the annual costs of an on-going O, M & R program. Instead of paying all the anticipated long-term costs in the first year, only those expenses anticipated for the current year would be paid. Each year, for 25 years (the workgroup's

analytical timeframe), the annual O, M & R costs would be paid. We calculated the average annual cost by summing all anticipated O, M & R costs and dividing by the analytical period (25 years). This average O, M & R cost was related to the construction cost to calculate the O, M & R factor. On average, most AMD passive treatment technologies had an average annual O, M & R factor of 4%. Thus, a \$100,000 project would require an average of \$4000 per year in annual costs. The actual costs would vary widely because major maintenance costs and replacement costs – both high expense items – occur infrequently and generally toward the end of the BMP lifetime. The factor does not account for inflation. Since most watershed restoration projects have been constructed relatively recently, not accounting for inflation shouldn't be a problem at this time. If the Department decides to fund O, M & R using the O, M & R factor, it should regularly adjust the base value of construction to account for inflation in the future.

The estimated O, M & R factors varied with the type of watershed restoration project. Table 1 shows the range in factors. Most of the BMPs being implemented with Growing Greener funds are in the 3-5% range. While the AMD factors were based on actual experiences of several workgroup members, the non-AMD estimates were derived from informal surveys of the following sources: NRCS, the Center for Watershed Protection, the Keystone Stream Team, PA DEP, MD DOE, Universities and consultants. These sources were able to provide good input concerning O & M (particularly the NRCS, which just completed an evaluation of agricultural BMP's by June C. Grabemeyer, Agriculture Economist, East Lansing, MI), but were less certain about replacement costs. The group decided that 4% was a good average O, M & R factor to use in estimating long-term costs for all types of restoration projects, for the purpose of estimating funding needs.

Table 1: Average O, M & R Factor for Watershed Restoration BMP's

Agricultural BMPs	
4%	
Stream Restoration BMPs	4%
Stormwater Management BMPs	3%
AMD Vertical Flow Systems	5%
AMD Anoxic Limestone Drain Systems	4%
AMD Compost Anaerobic wetlands	4%
AMD Pyrolusite© Systems	3%
AMD Open Limestone Channels	1%

The workgroup broke down the long-term O, M & R factor into cost categories. For a passive treatment system that has a 5% annual factor, system reconstruction accounted for 40% of the costs, routine operations (inspections, sampling, flushing) accounted for 20%, water sample analyses accounted for 10%, and general and unscheduled maintenance and repairs accounted for 30%. This breakdown was valuable because it showed that well-organized project sponsors should be able to cover up to 60 % of the estimated O, M & R costs by assuming all or part of the non-replacement responsibilities.

The workgroup decided to use the O, M & R factor method to analyze costs and make recommendations concerning the amount of funds needed to address O, M & R on a long-term

basis. This determination was made based on feedback received from Executive Staff and others that up-front, lump sum funding of O, M & R was not likely to be pursued by the Department.

A difficult issue within the analysis of long-term costs was the cost of lab analyses of water monitoring samples collected. The water sampling cost analysis was based on the Department's cost of \$65 per sample (approximate cost of the Bureau of Abandoned Mine Reclamation's 711 Standard Analysis Code, used for routine AMD samples). Private laboratories experienced with AMD analysis can provide reliable analyses for \$15-35 per sample, although inexperienced private labs sometimes provide inconsistent results. Two possible options were discussed with regard to sample analyses. One is for the Department to consider certifying private laboratories for AMD analysis and encourage watershed groups to use private labs, thereby decreasing long-term costs. Another option is for the Department to develop a regular funding source for analyses of watershed samples currently being collected under Mineral Resource Management's collector numbers. Costs can be reduced by determining a Standard Analysis Code that provides the minimum number of parameters needed to evaluate system performance. The advantages of this option are that lab results would be made available more easily to the Department and the quality assurance issues are addressed. However, it may be possible to address the quality assurance issue with private labs through a certification process. The workgroup has decided to recommend both options so that watershed groups can utilize what works best on an individual basis. The workgroup believes that the Bureau of Mining and Reclamation's existing SOAP/ROAP certification process is the best vehicle to use to certify private labs.

Implementation (Funding Engine)

Various funding options were reviewed by the workgroup to provide for the sustainability of existing and future facilities that benefit the general public and improve the water resources of the Commonwealth.

True sustainability needs local community ownership and involvement. Public-private partnering develops healthy interdependence (working relationship) between state agencies and the watershed residents, including volunteers, students, service groups, private industry, environmental professionals, and other interested parties.

Some project sponsors have developed and are implementing long-term plans; however, many groups currently do not have the means or ability to do this.

The workgroup developed recommendations for a support strategy to enable groups to provide for long term O, M & R. It includes the following:

- Commonwealth: develop a source of funding and create a grant funding category for the O, M & R of existing and future construction projects;
- Sponsor: provide available resources for total or partial O, M & R;
- Other: provide additional O, M & R support by use of the Bureau of Abandoned Mine Reclamation (BAMR) construction/maintenance crews, the 12th Congressional District Equipment Center, and local/private industry.

Funding Options:

The workgroup calculated the approximate initial annual funding needed to address long-term O, M & R at \$1.86 million, using the following method. This amount, discussed in both options below, has been calculated by determining the cost of providing for 50% of the average 4% O, M & R factor of \$93 million for existing projects. This amount is expected to cover major maintenance (10%, or approximately 1/3 of the expected total maintenance costs) and replacement (40%) needs. It is expected that watershed groups and their local partners, Department assistance with lab costs and BAMR and 12th Congressional District Equipment Center assistance with maintenance will make up the remaining 50% of the O, M & R factor.

The following are two alternatives developed by the workgroup as possible solutions to the funding challenges associated with long-term O, M & R. One of these alternatives, or a combination thereof, may ultimately be seen as the appropriate funding solution.

Option 1: Funding O, M & R on an annual-basis (“pay as you go”)

- Up to 10% of Growing Greener funds are earmarked for funding of O, M & R projects; the amount not spent for O, M & R is released to provide additional new project funding.
- The Secretary's approval is needed if demand is such that more than 10% of Growing Greener funds are necessary.
- Some of the 10% is held back for emergency O, M & R projects, with this money released for new project funding at the end of the fiscal year.
- The delivery system would be the existing Growing Greener Grant Center, using an additional funding category on the grant application form.

Advantages:

With this option, if the O, M & R amount is not fully requested, then the balance would be available for funding new projects. At the current Growing Greener funding level of \$50 million per year, it is expected that less than 10% of this amount will cover all major maintenance and replacement needs for the foreseeable future (expected to be about \$1.86 million for existing projects).

Disadvantages:

This option requires the continuation of Growing Greener beyond year five. At this time, continuation is considered likely, but is not a certainty. Also, if Growing Greener is continued, the funding level may be reduced, thereby reducing the amount available for O, M & R. Another disadvantage is that it will take away from money to be spent on new projects, unless the Legislature authorizes increased Growing Greener funding to make up the difference.

Option 2: Funding O, M & R for the long-term (“set aside”)

- The PA legislature provides an annual budget appropriation for long-term needs (or, an existing funding source is found within the Department) at an initial rate of \$1.86 million per year.
- The amount appropriated will need to increase annually based upon the amount spent on

construction projects annually. For example, if \$25 million worth of projects is constructed in 2002, there will be \$93 million plus \$25 million, or \$118 million worth of constructed projects; therefore, \$2.36 million will need to be appropriated for O, M & R the following year (50% of 4% factor multiplied by \$118 million).

- The annual appropriation would be placed in a "set-aside" fund administered and managed by the Commonwealth. Applicants would apply for funds using the established Growing Greener framework. Any money left over at the end of the year would stay in the fund. The fund would be allowed to build up so that, when needs become greater (as systems need replaced or major floods or other catastrophes occur), the funds would be available to cover that need.

Advantages:

This option would leave the current project funding amounts for Growing Greener intact and would not be dependent upon the continuation of Growing Greener beyond year five. It would allow an accumulation of funds to deal with long-term needs that are expected to increase as systems age and need to be replaced.

Disadvantages:

This option would require legislative action to appropriate funds. It would require the establishment and administration of an interest-bearing fund. It would require tracking of implementation projects from all public funding sources in order to know how much new construction takes place on an annual basis, to determine funding amounts.

Actions Needed by the Department for Implementation

- Select a funding option and appropriate funds for O, M & R support of existing and future projects.
- Develop a fund/program management system, including a Growing Greener O, M & R project category and related activities (including changes to scoring and application guidance).
- Require the development of O, M & R plans prior to the provision of O, M & R funds for existing projects and as a deliverable under construction contracts for new projects.
- Provide O, M & R training for watershed groups via Growing Greener workshops and watershed conferences, with assistance from others.
- Improve DEP capacity to assist groups with O, M & R:
 - Provide improved capacity of BAMR's construction crews to assist with major maintenance.
 - Dedicate funds to support Mineral Resource Management sponsored lab analysis for watershed groups and determine an appropriate Standard Analysis Code.
 - Adopt SOAP/ROAP lab criteria and cost guidelines for watershed sample analysis.

Appendix A

Publicly Funded Restoration Projects

	NRCS	319	BAMR	WRPA	OSM	G2	Totals
1988	\$125,000	\$0	\$0	\$0	\$0	\$0	\$125,000
1989	\$150,000	\$0	\$0	\$0	\$0	\$0	\$150,000
1990	\$0	\$75,000	\$0	\$0	\$0	\$0	\$75,000
1991	\$75,000	\$200,000	\$0	\$0	\$0	\$0	\$275,000
1992	\$12,000	\$225,000	\$0	\$0	\$0	\$0	\$237,000
1993	\$0	\$400,000	\$0	\$0	\$0	\$0	\$400,000
1994	\$0	\$675,000	\$0	\$0	\$0	\$0	\$675,000
1995	\$152,066	\$850,000	\$0	\$0	\$0	\$0	\$1,002,066
1996	\$0	\$1,000,000	\$0	\$0	\$0	\$0	\$1,000,000
1997	\$183,959	\$275,000	\$1,502,626	\$0	\$0	\$0	\$1,961,585
1998	\$34,314	\$1,700,000	\$1,664,737	\$0	\$0	\$0	\$3,399,051
1999	\$274,454	\$3,400,000	\$2,470,041	\$688,458	\$262,240	\$25,350,000	\$32,445,193
2000	\$109,284	\$2,700,000	\$643,873	\$296,558	\$567,800	\$21,050,000	\$25,367,515
2001	\$200,000	\$3,700,000	\$1,390,401	\$0	\$321,400	\$20,140,000	\$25,751,801
							\$92,864,211

INTERAGENCY/INDUSTRY COORDINATION TO RESPOND TO SELENIUM CONTAMINATION AT PHOSPHATE MINES IN SOUTHEASTERN IDAHO

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ABSTRACT

Selenium contaminated vegetation and surface water related to phosphate overburden disposal was discovered in southeast Idaho in 1997. Shortly afterward, phosphate mining companies and regulatory agencies joined in response to the potentially widespread problem throughout the phosphate mining area. Five companies with a vested interest in southeastern Idaho phosphate reserves organized as a committee under the Idaho Mining Association. Under this arrangement they commissioned a regional environmental sampling program to characterize the problem in voluntary collaboration with Federal and State regulatory agencies. In 2000, the agencies in cooperation with tribal authorities agreed to coordinate their regulatory responses under a Memorandum of Understanding (MOU) that identified statutory and regulatory authorities and responsibilities; established priorities, and clarified processes for undertaking area-wide and site-specific investigations. Within the agreement, participating agencies and the Shoshone-Bannock Tribes set out frameworks for response actions and regulatory cost recovery. This group of agencies and the Shoshone-Bannock Tribes have since entered into an enforceable Area-wide Administrative Order of Consent (AOC) with the mining companies to conduct area-wide site investigations and risk assessments intended to lead to the development of remedial action objectives, remediation goals, and risk-based cleanup levels for selenium and other contaminants of concern. The U.S. Forest Service and Idaho Department of Environmental Quality, with support from other State, Federal and tribal authorities are cooperating to plan localized site investigations and engineering evaluations/cost analyses at individual mines. Data collected during the course of site-specific and area-wide efforts will eventually result in appropriate remediation of the selenium impacts at all developed phosphate mines in southeast Idaho. The authors describe the inter-agency and industry cooperative efforts in response to the selenium issue, highlighting the complications, successes, and stumbling points encountered along the way.

BACKGROUND

Phosphorous, is an important element for agricultural and chemical industrial uses worldwide. The primary source of phosphorous is phosphate ore that is known to occur in various locations around the world. The United States contains approximately 4.2 billion tons of phosphate ore, about 14 percent of the known world reserves (USGS, 2000). In 1975, the western phosphate field in Southeastern Idaho (Figure 1) was estimated to contain approximately one billion tons, about a quarter of the U.S. reserves (USGS, 1977). The phosphate reserves of Southeastern Idaho are about 80 percent located on Federal land administered by the U.S. Forest Service, Caribou-Targhee National Forest, with smaller amounts on State or Tribal leases and private land. Under authority of the 1920 Mineral Leasing Act, the Bureau of Land Management administers the 84 existing Federal phosphate mineral leases on about 46,000 acres of land and cooperates with the Forest Service, Idaho Department of Environmental Quality, and other Federal and State agencies in evaluating and

mitigating the environmental consequences of the mining.

Phosphate ore has been mined in Idaho since about 1907 with major production commencing in the 1940's. There are four active phosphate mining operations that, in a normal market, produce an aggregate of about six million tons of ore annually. Ore is shipped from the mines by rail, truck, and/or slurry pipeline to fertilizer or phosphorous manufacturing plants operated by the companies in the Soda Springs or Pocatello areas. The region contains 11 major inactive mines along with numerous, small historic orphan sites, primarily of underground design. Various types and amounts of reclamation have been completed at the major inactive mines, depending on the applicable regulations and policies in existence at the time the mining was conducted. The historic, orphaned mines are generally not reclaimed.

Phosphate ore in Southeastern Idaho occurs within the upper and lower parts of the Meade Peak member of the Phosphoria Formation. Interbedded shale and mudstone approximately 170 feet thick have been extensively folded and faulted throughout the region (Figure 2). A typical phosphate mine in the area is developed on dipping ore beds that occur parallel to topographic ridges. Ore is removed by open pit mining methods down-dip to the economic extent feasible and then along the strike of the outcrop to the margins of the lease, or to where the ore beds have been removed by erosion or displaced by faulting. This results in long, relatively narrow open pits, similar to many eastern coal strip mines. Because of the sequential extension of the open pits along strike, much of the overburden from subsequent mine pits is opportunistically backfilled into previous pits although in the initial mine panel development significant quantities of overburden have, and continue to be placed outside of pit back fills in external overburden dumps.

The overburden for the upper ore zone is typically sandy siltstones and limestones of the Triassic Dinwoody Formation, chert of the Rex Chert Member of the Phosphoria Formation, and shales and mudstones of the upper Meade Peak Member. Overburden produced from the lower ore zone includes shales and mudstones of the "Middle Waste Shale" portion of the Meade Peak Member and poorly cemented arenitic limestones of upper members of the Wells Formation. Overburden is moved with trucks from the open pits to the sites of the overburden dumps and then end dumped from various heights in lifts. Historically, this material was placed in a run-of-mine condition with little or no segregation of the different waste rock lithologies. Shale and siltstone from the waste units weather variably into rocky soil-like material that was utilized in the past to support reclamation vegetation with extensive fertilization. Until the early 1990's topsoil was not typically salvaged and replaced during reclamation. However, this has become the norm for the modern mining operations.

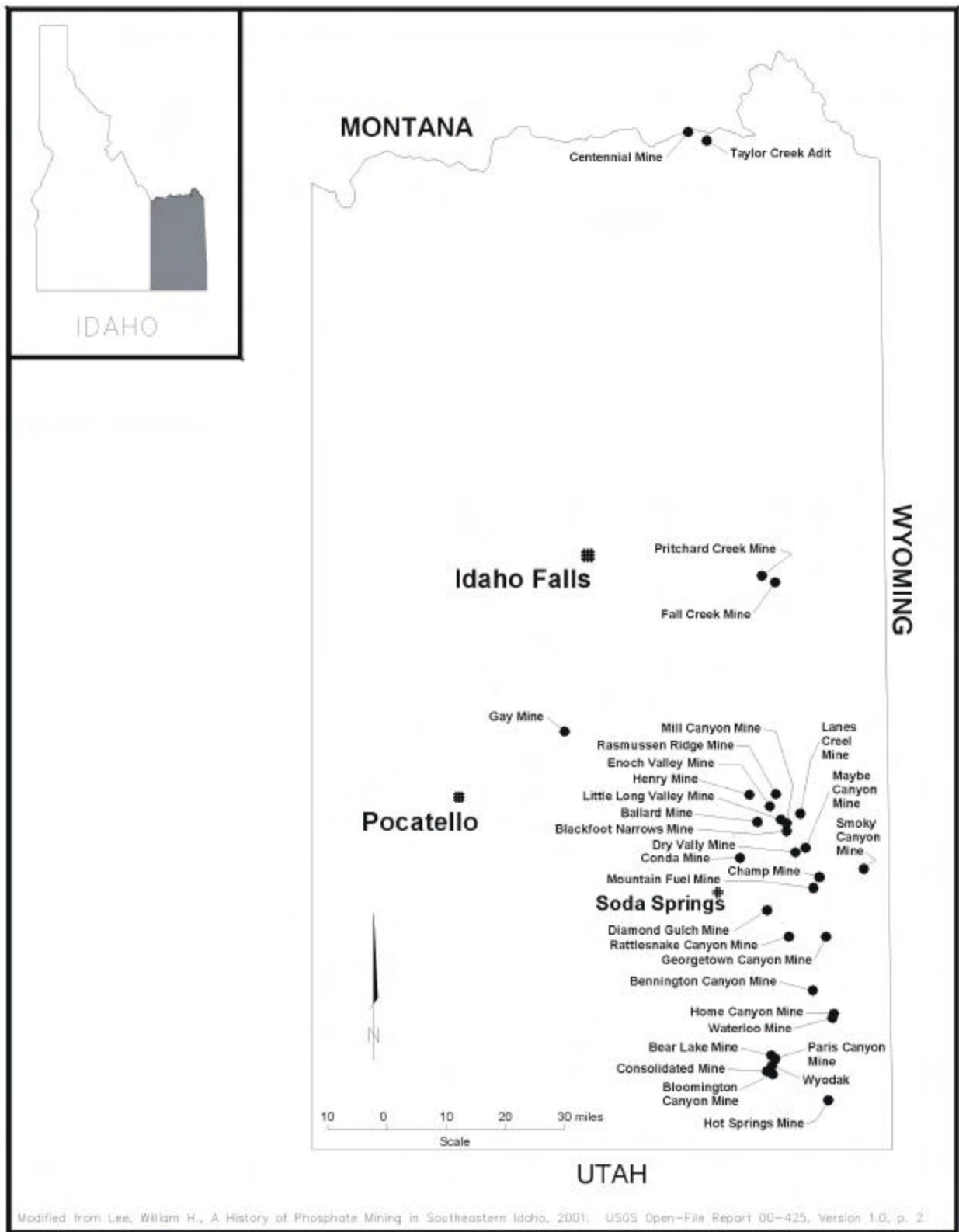


Figure 1. Generalized location map showing phosphate mines in southeastern Idaho

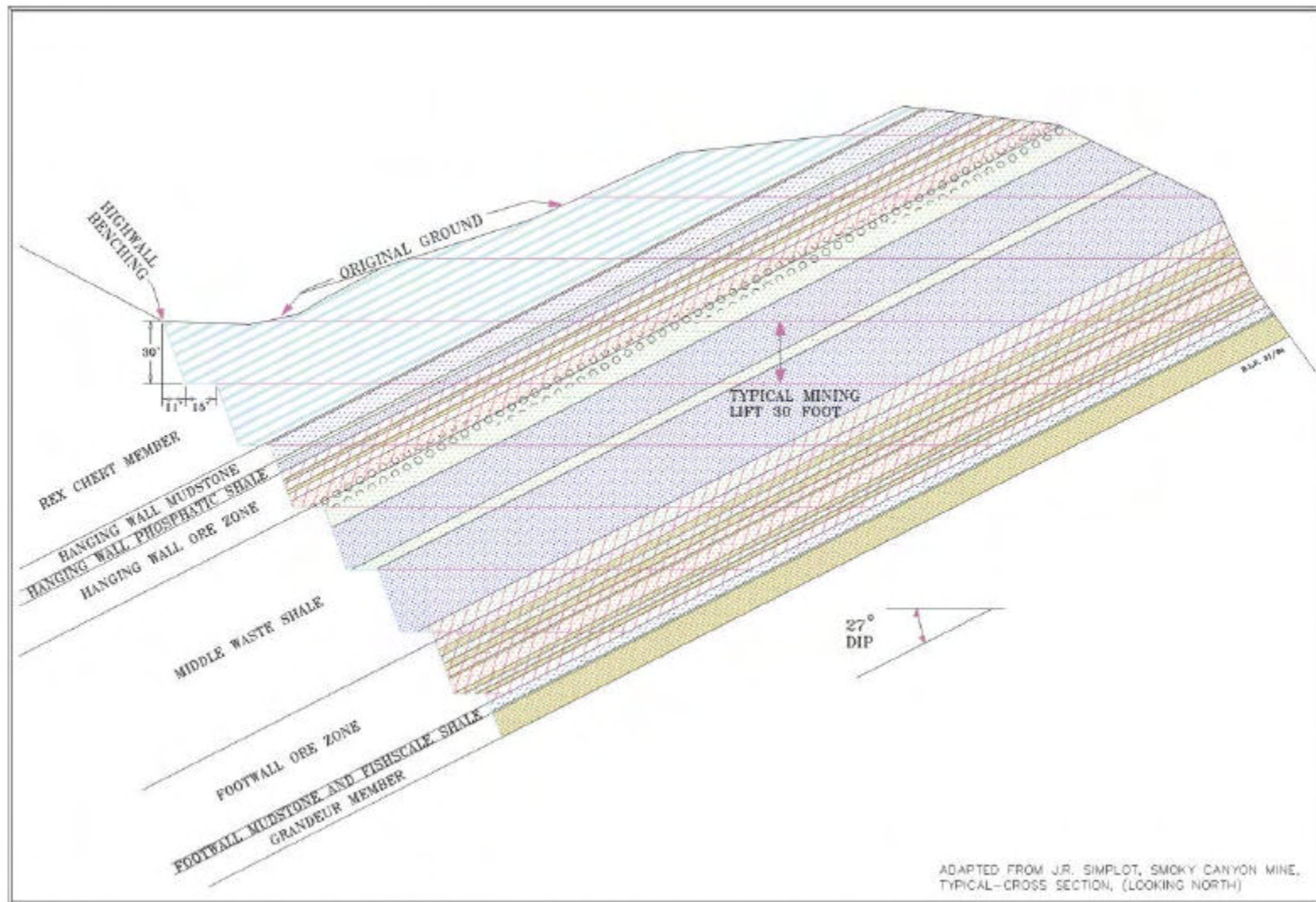


Figure 2. Typical Cross Section of the Phosphoria Formation, Simplot Smoky Canyon Mine Panels B&C

Many overburden dumps constructed prior to about 1990 were reclaimed by regrading slopes to 3h:1v (horizontal: vertical) and drilling or hydroseeding a mix of grasses and forbs directly onto the regraded overburden surface. The relatively moist mountain climate of southeast Idaho is conducive to establishment of vegetation cover on most reclaimed mines in the region.

Mountainous topography in the area led to construction of overburden dumps on hillsides, some of which are close to stream channels. In some cases, overburden was placed in head-of-hollow or cross-hollow fills with rock drains in the former stream channels to carry infiltrating meteoric water and stream flow under the overburden fills. Construction of overburden fills in valleys was a preferred overburden handling technique for a number of years because of convenience, an unobtrusive visual profile, and to reduced the surface area of external overburden fills when compared to placement of overburden on steep mountain slopes.

Runoff from mine disturbances has been controlled through the use of runoff diversion, collection, and settling features common to all types of mining. Precipitation has typically come in direct contact with weathered overburden materials because topsoil was not utilized in reclamation, and older waste dumps were often constructed to rapidly infiltrate meteoric water. Runoff from storm events and snowmelt is commonly collected in settling ponds or silt traps to remove eroded sediment before discharge to local streams. Past environmental impact analyses documented the potential for impacts to surface streams. Impacts were most often attributed to suspended sediment along with lesser amounts of dissolved parameters such as nitrate, metals, and other contaminants (USGS, 1977).

DISCOVERY OF SELENIUM PROBLEM

Selenium has been known to be present in elevated concentrations in Meade Peak Member phosphate rock and mudstone for some time. In 1977, a programmatic EIS developed to analyze universal impacts of phosphate mining in Southeastern Idaho reported that phosphate rock had average selenium concentrations of 30 mg/kg (ppm), with maximum concentrations of 800 mg/kg, while mudstones were documented with average concentrations of 14 mg/kg and maximum concentrations of 1,500 mg/kg (USGS, 1977). Selenium was significantly elevated when compared to an average of 0.23 mg/kg for selenium concentrations in soils in the western United States (Shacklette and Boerngen, 1984). However, this EIS and other environmental impact studies conducted in the area prior to 1996 did not specifically identify selenium found in overburden as being a contaminant of potential concern (COPC).

Selenium in Meade Peak member overburden is present as relatively insoluble selenide (Se-II) and native elemental selenium (Se) that, after weathering and oxidation, can produce soluble forms of selenite (SeIV) and selenate (SeVI). Soluble oxidation products can easily be mobilized from the overburden materials in runoff or infiltration water (Desborough et al., 1999). Selenium in trace quantities is an important nutrient for human health (ATSDR, 1996). Small quantities of selenium are present in many human and livestock food supplements but selenium can also be toxic to humans and animals at higher doses. A number of environmental studies have been conducted in other parts of the United States where selenium concentrations in surface waters have been affected, typically by irrigation drainage (Seiler et. al. 1999, Luoma and Presser, 2000). Mobile forms of selenium bioaccumulate in some plants and animals chronically exposed to the contaminant (Herring et al,

1999). A particularly problematic pathway of selenium exposure can be present where livestock or wildlife feed exclusively on vegetation where selenium has bioaccumulated from growth medium or water. Animals exposed to high doses of selenium can themselves accumulate and biomagnify toxic concentrations of the contaminant and display symptoms of chronic selenium poisoning (selenosis).

In December 1996, six horses grazing on private land downstream from the former South Maybe Canyon phosphate mine became ill and were diagnosed with chronic selenosis. Five of these animals had to be destroyed when it was determined they would not recover their health. Again in the summer of 1997, two horses pastured on the former Conda Phosphate Mine were diagnosed with selenosis and both animals had to be destroyed. In mid-summer 1997, 176 sheep were found dead in the Conda Mine area. The cause of death was not confirmed but selenium poisoning was not ruled out. Since then, other occurrences of multiple sheep deaths have been reported at the Conda Mine and Wooley Valley Phosphate Mine. Forensic examination of samples taken from the dead animals in each case showed elevated selenium concentrations in tissue and rumen although definitive conclusions as to the actual cause of the deaths were not made. Myocardial necrosis, a symptom of toxic selenosis, was found in the Wooley Valley sheep.

Selenosis in the horses pastured in Dry Valley prompted agency and public concern that selenium releases from phosphate mining was apparently an environmental and potential public health concern. A Preliminary Assessment of the South Maybe Mine in 1997 led the Forest Service to exercise their delegated authority to initiate action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA). The current leaseholder was identified as the Potentially Responsible Party (PRP) for that site. In September 1997, the U.S. Forest Service entered into an Administrative Order on Consent (AOC) for the South Maybe Mine with the leaseholder to conduct a Site Investigation (SI) and Engineering Evaluation/Cost Analysis (EE/CA) under CERCLA.

EARLY INDUSTRY AND AGENCY RESPONSES

Five phosphate mining companies in Southeastern Idaho quickly accepted that the selenium contamination problem was a significant concern and could be systemic throughout the phosphate mining region. Agency personnel along with the phosphate mining industry generally recognized that the geology, mineralogy, and physical environmental conditions at all the phosphate mines in Southeastern Idaho were similar enough that known problems at a few mines could easily be indicative of potential conditions at the other phosphate mines in the region. However, site differences in elevation, ecology, and climate indicated that conclusions from a few sites may not be universally extrapolated across the phosphate producing region.

In January 1997, agency and industry representatives were invited, along with citizens in Southeast Idaho, to attend a meeting in Soda Springs where information about the situation was presented. The five mining companies present decided to form an ad hoc committee of the Idaho Mining Association (IMA) in early spring 1997; this “Selenium Subcommittee” consisted of FMC (now Astaris), J.R. Simplot Company, Nu-West Industries (Agrium), Rhodia LLC, and P4 Production LLC (a joint venture between Monsanto Inc. and Solutia Inc.). Members of the subcommittee joined voluntarily with representatives from the land management, environmental, and resource management agencies, as the “Selenium Working Group”, to provide oversight of the

investigative work. Selenium Subcommittee members through the IMA agreed to fund studies intended to identify, on a regional basis, whether selenium was originating from phosphate mines, selenium sources, and the extent of selenium impacts. Industry subcommittee members retained technical experts from the consulting industry who subsequently subcontracted specialists from academia to conduct the necessary studies. Montgomery Watson was hired by the IMA subcommittee as the environmental consultant; the University of Idaho, and University of California-Davis joined them in a contractual arrangement.

The Selenium Working group operated under the auspices that they would direct data collection strategies, identify specific studies, collaterally interpret data, and cooperate with the phosphate mining industry to develop mitigation or management practices to prevent selenium releases from current and future phosphate mining operations. Participating agencies initially included:

- \$ U. S. Forest Service (USFS)
- \$ U. S. Bureau of Land Management (BLM)
- \$ Idaho Department of Environmental Quality (IDEQ)
- \$ Idaho Department of Lands (IDL)
- \$ Idaho Department of Fish and Game (IDFG)

Later in the process several other agencies and sovereign parties joined in the process but remained outside the working group. They included:

- \$ U.S. Fish and Wildlife Service (USFWS)
- \$ U.S. Environmental Protection Agency (EPA)
- \$ U.S. Bureau of Indian Affairs (BIA)
- \$ Shoshone-Bannock Tribes

Additionally, representatives of the public, interest groups, academia, veterinary and agricultural sciences, and the press participated in the open meetings of the Selenium Working Group. Meetings were held regularly to coordinate efforts of the participants in the regional investigations and do the other work of the Selenium Working Group. As this group evolved, sometimes including more than 50 participants, decision making became difficult and at times controversial. In an attempt to improve effectiveness, the “Selenium Steering Committee”, was formed with a single representative from each organization within the Selenium Working Group.

As data from regional investigations in 1997 were received, it became evident that elevated selenium concentrations were being observed throughout the phosphate producing area.

Members of the IMA subcommittee and their consultant produced a number of documents related to regional investigations performed throughout a 2,500 square mile area in Southeastern Idaho including:

- \$ Fall 1997 Interim Surface Water Survey Report, Southeast Idaho Phosphate Resource Area Selenium Project, February, 1998;
- \$ 1998 Regional Investigation Sampling and Analysis Plan, Southeast Idaho Phosphate

- Resource Area Selenium Project, April, 1998;
- \$ 1999-2000 Regional Investigation Sampling and Analysis Plan, Southeast Idaho Phosphate Resource Area Selenium Project, August, 1999;
- \$ Final 1998 Regional Investigation Report, Southeast Idaho Phosphate Resource Area Selenium Project, December, 1999;
- \$ 1999 Interim Investigation Data Report, Southeast Idaho Phosphate Resource Area Selenium Project, October, 2000; and
- \$ 1999-2000 Regional Investigation Data Report for Surface Water, Sediment and Aquatic Biota Sampling Activities, September 1999 Draft, April, 2001.

In addition to these data reports, using field data from the 1998 regional investigations, the consultants to the Selenium Subcommittee prepared a Preliminary Human Health Risk Assessment and a Preliminary Ecological Risk Assessment. Regulatory agencies involved in the Selenium Working Group commented on the risk assessments and essentially rejected them for premature conclusions based on the lack of sufficient data. Comments submitted by the agencies were not sufficiently addressed or incorporated in the assessment. Support of the risk assessments by the regulatory agencies was withdrawn and an agency disclaimer written.

Two reports were produced by the Selenium Subcommittee describing management practices that had been or could be employed at the phosphate mines for control of selenium impacts; they were:

- \$ Existing Best Management Practices at Operating Mines, Southeast Idaho Phosphate Resource Area Selenium Project, March, 2000; and
- \$ Draft Best Management Practice Guidance Manual for Active and Future Mines, Southeast Idaho Phosphate Resource Area Selenium Project, April 2000.

The first of these reports summarized management practices that were already being employed at the mines to control sediment. Practices detailed here had been previously endorsed by the State of Idaho as practices suitable to control erosion and sedimentation impacts.

Final publication of the second document was never accomplished. It was intended to address the release of contaminants from the mine sites in multiple media. However, the scope and detail were not sufficient to provide a broad range of mitigations to address the problem. Most of the methods discussed again focused on control of erosion and sedimentation without addressing water treatment. Compared to the extensive discussion of management practices for surface runoff control in these documents, the regulatory agency reviewers were dissatisfied with the relative lack of objective discussion on the use of more expensive management practices such as: capping the tops or lining the bottoms of overburden fills with impermeable materials, and collection and chemical treatment of seleniferous water.

In addition to what the Selenium Subcommittee was doing, other organizations were conducting separate studies, including:

- \$ With funding provided by J.R. Simplot Co., the University of Idaho conducted graduate project studies to identify or refine environmental and selenium treatments at the Smoky

- Canyon Mine (Simplot, 2002).
- \$ Astaris agreed to conduct independent field studies at their Dry Valley Mine of selenium accumulation in vegetation growth medium and vegetation in response to mitigation employed at their mine.
 - \$ Three of the mining companies conducted multi-media environmental baseline studies at their properties, focusing on the selenium impacts, to support upcoming Environmental Impact Statements (EISs).
 - \$ The USFS Rocky Mountain Research Station is conducting research to identify vegetation species adapted to reclamation purposes that would occlude selenium. Studies are underway that will evaluate potential amendments that could permanently capture selenium within waste products. Mustard species, specifically Canola, are being tested for potential as a phytoremediation tool that would not escape cultivation on waste dumps. Correlations between soil salvaged from the mine sites and bioaccumulation in reclamation vegetation are included in their studies.
 - \$ The IDEQ began Total Maximum Daily Load (TMDL) studies on known impacted watersheds in the region.

The USGS Western Mineral Resources Team, Western U.S. Phosphate Project, began a 5-year study in 1997 that included investigations of the geology, mineralogy, history, stratigraphy, chemistry and environmental characteristics of many phosphate mining locations in Southeastern Idaho. This work has been a collaborative effort between USGS scientists from multiple offices and others from a diverse range of interests including state, federal, tribal, academic, mining, and general public. When all the reports are completed in 2002, there will have been over 50 separate publications, most of them USGS Open-File Reports (USGS, 2002).

Altogether, the studies conducted by the IMA, State and Federal agencies, academia, and individual mining companies in Southeastern Idaho generated a tremendous amount of information in only 3 - 4 years on the source, pathways, and impacts of selenium contamination related to phosphate mining. This was a major accomplishment of industry and agency cooperation. Although the regulatory agencies were appreciative of the phosphate mining industry's voluntary efforts on the regional and other investigations, they questioned the role of the mining industry in interpreting the data and objectively considering mitigation measures for existing and future potential selenium impacts on public lands. Conscious of the scope and implications of the situation, the agencies decided that the completely voluntary efforts to date on the part of the mining companies would have to be replaced with a more traditional, agency-controlled approach using State and Federal authorities.

MEMORANDUM OF UNDERSTANDING

In July 2000, the Federal regulatory agencies participating or overseeing the actions of the Selenium Working Group (USFS, BLM, EPA, USFWS, BIA), the IDEQ, and the Shoshone-Bannock Tribes entered into a formal agreement between them titled, "Memorandum of Understanding concerning Contamination from Phosphate Mining Operations in Southeastern Idaho" (MOU). The stated purpose of this agreement provided a cooperative atmosphere for the regulatory parties to

work together on matters related to the environmental contamination at phosphate mines. Commitments were made to follow specific processes to resolve conflicts between them, minimize duplication of efforts, and communicate a single set of instructions to the mining companies.

Parties to the MOU agreed that an area-wide contamination investigation should be conducted by IDEQ under criteria and a scope of work established in the MOU with a commitment for cost recovery and enforcement within the scope of an “Administrative Order on Consent” (AOC) with the companies principally responsible for the leases in southeastern Idaho. Outlined in the AOC was an agreement that subsequent, site-specific investigations and remedial actions, conducted under CERCLA and other regulatory authorities, would not duplicate efforts conducted under the area-wide investigations. Site-specific investigations would be managed by specific, and agreed upon lead agencies, with identified support agencies. Lead agencies would enter into site-specific, enforceable agreements with the affected companies for each individual mine site. Parties to the AOC also agreed on the general scope of work for the site-specific CERCLA activities.

In signing this MOU, the agencies asserted their regulatory authority under CERCLA to take charge of the regional contamination impact investigations, now called the “Area-wide Investigations” and eventually conduct whatever site-specific studies were necessary to thoroughly investigate all the 15 major operating and inactive phosphate mines in Southeastern Idaho for the release or threatened release of hazardous substances. Site Investigations and Engineering Evaluation/Cost Analysis undertaken will eventually lead to another agreement requiring the remediation of the existing contamination impacts at each of these sites by the responsible companies. Adoption of the MOU changed the former voluntary effort of the Selenium Working Group, that was primarily controlled by the companies who made up the Selenium Subcommittee, to a rigorously regulated process under CERCLA that clearly placed the regulatory agencies in charge of the effort. At first glance, one might think the mining companies would object to this change in management, but this has not necessarily been the case. Involved mining companies supported this change because it offered the promise of more efficient project management and decision-making, with the added benefit of the agencies being able to chart a clear course to some final end for each individual site. Additionally, without a mechanism offering proof that the companies would relinquish their leases in a condition suitable for the management of other sustainable resources, permitting future extractive phosphate operations on public lands would have become impossible.

When the MOU was fully executed on July 15, 2000, the IDEQ took over the former regional investigations calling the new effort the “Area-wide Investigations”, and began planning to do the work. What the IDEQ and the other agencies needed was the financial support of the mining companies, and clearly enforceable authority over the process. Costs incurred in oversight of the process by IDEQ, EPA, F&WS, and the Shoshone-Bannock Tribes are recovered from the phosphate industry participants in the AOC. Cost recovery, negotiated participation, and provided enforcement necessary for the agencies to protect the public interest. Additionally, the AOC was necessary to ensure continued financial support for the investigation and oversight by IDEQ and some of the support agencies.

AREA-WIDE CONSENT ORDER AND ADMINISTRATIVE ORDER ON CONSENT

In concert with the interagency cooperative agreement and CERCLA process described in the

MOU, the parties to the MOU entered into an enforceable Consent Order and Administrative Order on Consent (CO/AOC) for the Area-wide Investigations with the mining companies making up the Selenium Subcommittee. The stated purpose of the Area-wide CO/AOC was to set out the scope of work for the Area-wide Investigation, identify procedures to be used, and ensure cost recovery for the scope of work from the mining companies signing the order. The regulatory authority for the Federal agencies signing the order is CERCLA and the work to be conducted under the order was specified to comply with the requirements of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). IDEQ's authority to participate in the investigation and cleanup of hazardous substances are: the Idaho Environmental Protection and Health Act ("EPHA"), Idaho Code § 39-101 to 39-130, and the Hazardous Waste Management Act of 1983 ("HWMA"), Idaho Code § 39-4401 to 39-4432, and other laws including CERCLA and the Solid Waste Disposal Act, as amended by the Resource Conservation and Recovery Act, 42 U.S.C. § 6901 et seq.

The statement of work under the order included: 1) establishing area-wide remedial action objectives, remediation goals, and risk-based cleanup levels for selenium and other contaminants of concern that will be protective of human health and the environment; 2) develop a monitoring plan that will assess the effectiveness of future remedial activities within the Resource Area; 3) develop Best Available Technologies and Remediation Techniques for use, as appropriate, at sites in the Resource Area; and 4) provide information to support future agency-approved site investigations and remedial actions, and other land use activities on selenium-impacted lands with the Resource Area. The work to be done under the order included a general, area-wide risk assessment, and planning for general remedial action objectives intended to be considered for future site-specific activities. With the signing of the Area-wide CO/AOC in September, 2001 IDEQ was ready to begin work on the Area-wide Investigations.

AREA-WIDE INVESTIGATIONS

IDEQ adopted the Selenium Working Group organizational structure to initiate the Area-wide Investigations. The former Working Group Steering Committee was changed to the "Selenium Area Wide Advisory Committee" (SeAWAC), and the larger Working Group meetings were shifted to a quarterly schedule to distribute information and provide progress reports in a public forum. An Interagency Technical Group, made up of representatives of the parties to the MOU with representatives from Idaho Department of Lands and the Idaho Fish and Game was also developed to provide for regular coordination and planning of the area-wide activities. IDEQ successfully hired an experienced environmental professional with CERCLA project experience to manage the area-wide activities. IDEQ also retained the services of an environmental consultant, Tetra Tech EM Inc., to assist it with the area-wide work.

The Area Wide Scope of Work was developed to utilize the existing information from the IMA regional investigations and continue the work envisioned in the MOU by the signatory agencies to that agreement. After obtaining input from the Interagency Technical Group and the Area Wide Advisory Committee, the Area Wide Scope of Work was defined to include:

- \$ Assess all existing data and prepare a preliminary risk assessment,
- \$ Determine data needs to support an area-wide human health and ecological risk assessment,

- \$ Develop sampling and analyses plans and studies to fill identified data gaps,
- \$ Conduct area-wide investigations as required,
- \$ Complete Area-Wide Population based Ecological and Human Health Risk Assessments,
- \$ Establish remediation goals, remedial action objectives, and risk based cleanup levels,
- \$ Develop a regional water quality and aquatic monitoring plan,
- \$ Develop best available technology and remedial techniques,
- \$ Conduct public involvement and participation activities for the area-wide investigation, and
- \$ Other activities to support area-wide goals.

Each phase of the Area Wide Scope of Work was planned in advance and input was sought from the Interagency Technical Group and the Area Wide Advisory Committee. Deliverable products for each phase of work were documented and reviewed by the Technical Group and Area Wide Advisory Committee. IDEQ was diligent in seeking public input at all major steps in the area-wide process. Several public meetings were held. Notices were published in local newspapers and on IDEQ's internet site to solicit interest from the affected community. Major study plans were published on the IDEQ website for 30-day public comment periods. Most comments are provided by agency representatives and the Idaho Mining Association.

SITE-SPECIFIC INVESTIGATIONS

Site-specific investigations mentioned in the MOU will be conducted at 15 sites by potentially responsible parties using technical contractors approved by the lead agency on each site. With one exception, the Forest Service will be the lead on all mine sites that are located within the boundaries of the Caribou-Targhee National Forest; the IDEQ will lead where the surface is privately owned and intermingled with BLM or State surface ownership, and the BIA will lead where the surface ownership is tribal. Other parties to the MOU will be "Support Agencies" ensuring that lead agencies protect their interests as appropriate for each site. Lead agencies will provide an On-Scene Coordinator (OSC) or Remedial Project Manager (RPM) as appropriate for each site; these individuals will have the duties described in the NCP and will coordinate with a site-specific Project Manager also provided by the lead agency.

The scope of work for each site-specific CERCLA project will include the following major tasks:

- \$ Develop a Project Work Plan,
- \$ Prepare and implement a Community Relations/Public Involvement Plan,
- \$ Oversight of the Site Investigation Work Plan,
- \$ Oversight of the Sampling and Analysis Plan,
- \$ Oversight of the Quality Assurance Project Plan,
- \$ Oversight of the Health and Safety Plan,
- \$ Oversight and approval of the Site Investigation,
- \$ Oversight of the Risk Assessment,
- \$ Oversight of the Engineering Evaluation/Cost Analysis, and remedial alternative selection
- \$ Monitoring Oversight of Selected Alternatives

\$ Analysis of various technical and progress reports typically prepared in a CERCLA project.

The lead agency and the mining company will enter into an enforceable CO/AOC that will refer to a site-specific Project Work Plan and schedule. Responsible parties will coordinate with the lead agency to develop a Scope of Work to be included in the CO/AOC. Detailed work plans will be developed to specifically outline the plans necessary to conduct a NCP Site Investigation. Site investigations will be evolved to fill data gaps about the release mechanisms and pathways by which contaminants are released from operations. Data collection will also be designed to evaluate potential remedial treatments and their effectiveness to reduce releases to concentrations compliant with Applicable or Relevant and Appropriate Regulations gathered by the lead agency.

When alternatives are developed to address site-specific releases, they will be presented to the public according to the instructions listed in the Community Relations/Public Involvement Plan prepared by the lead agency. Subsequent to the public involvement process, the lead agency will publish their decision in a "Record of Decision". Alternative selection will consider the merits of the treatment and its cost effectiveness.

Once the decision is made to proceed with an alternative, negotiations with the responsible party for remediation will result. Negotiations will be undertaken to provide guidelines for the removal of the contaminant, reclamation of the site, and monitoring the performance of implemented treatments.

FUTURE ACTIVITIES

To date, two of the 15 major phosphate mining sites, the South Maybe Canyon and Smoky Canyon mines, have successfully completed AOCs to conduct site investigations and EE/CAs. AOCs for the other sites are scheduled for negotiation beginning in late summer 2002 and are expected to be completed by the end of 2004. Each of the site investigations for these major sites are expected to take from two to three years to complete after which the removal actions themselves will take place. Appropriate removal actions will likely be somewhat different for each site, adjusting for site-specific conditions. At this point, one can only guess at the time frames required to complete all the removal actions but it is safe to say that it will take years to do so. Long-term removal actions and certainly monitoring activities will likely extend decades into the future.

The approach to the orphaned phosphate mine sites will be different than the 15 major sites. Orphan sites are abandoned sites where no viable responsible parties are apparent. Most of these sites were underground operations though some were open pits. Data collected from these sites in 2002 will be evaluated and a Preliminary Assessment prepared for each. Conclusions in the Preliminary Assessments will be used to decide how to proceed. Some sites may not need any further investigation however others may need detailed site investigations. At that time, further efforts may be taken to identify responsible parties or a determination will be made to expend public funds to further detail the extent of any releases and the risks posed to human health and the environment.

CONCLUSIONS

A great deal of information has been generated in an attempt to understand the selenium issue

in Southeastern Idaho and, because the situation is still unclear, more information will be produced . It is hard to keep up on all the new information coming out and definitive determinations on the human health and ecological impacts have yet to be made. Keeping in mind that factual conclusions are still to be made on much of the data, some points of general consensus can be made as follows:

- \$ The general sources and potential releases of selenium from phosphate mining sites in Southeastern Idaho are systemic to some degree at all such mine sites throughout the region.
- \$ While other contaminants of potential concern co-exist with the selenium, they are not as much of a concern as the selenium itself.
- \$ Bioaccumulation of selenium in vegetation growing on seleniferous overburden is the main pathway for exposure of elevated concentrations to foraging animals. Certain plant species are more susceptible to accumulating high concentrations of selenium than others.
- \$ Runoff from seleniferous terrain is the main pathway for release of the contaminant to surface waters.
- \$ Infiltration of precipitation into seleniferous overburden can potentially cause groundwater contamination but a more problematic release pathway for this leachate is through seeps and springs that may occur at the outer edges of overburden fills. These discharges can subsequently result in pathways of selenium to surface waters, vegetation, and animals.
- \$ Impacts appear to be relatively confined to the mine sites or immediately downstream and these impacts may be able to be reduced or eliminated with the proper site-specific mitigation/remediation actions.
- \$ Results to date do not indicate any known immediate or imminent threat to public health.
- \$ Local toxicity threats to wildlife and livestock appear to be the main ecological impacts.
- \$ Some mine engineering designs exacerbate selenium concentrations in vegetation and surface water, while others work to abate contaminant releases.

From 1996 to now, the administrative/regulatory/political process has been very interesting. An obvious good point is that the government and industry representatives are still talking to each other and trying to cooperate as practically as possible, within the constraints of the major financial and legal concerns. A large portion of the credit for this needs to go to the IMA Selenium Subcommittee who proactively accepted responsibility for beginning the expensive work of studying this problem early on when it would have been easy to wait and see what happened from a legal and regulatory approach. Industry cooperation early in the investigative process resulted in a major effort over a 3-year period study covering over 2500 square miles. Products of that effort provided valuable data necessary to permit us to agree on the points of general consensus listed above.

Early industry cooperation was good for public relations and the regulatory agencies because the phosphate industry was able to rapidly provide financial support where government funding would have taken time. Early action in 1997 demonstrated that the companies and their government partners were anxious to address the problem. Delays resulting from endless debate would have been counterproductive and led to public distrust of both the agencies and the phosphate mining industry. Government intentions from the beginning were not to issue citations or to damage the industry but to solve the problem rapidly. Rapid resolution to bring contaminant releases into compliance were considered necessary to protect a critical national resource.

There were obstacles, distrust, and at times adamant disagreements, however, many of those obstacles were set aside to keep the search for the solution moving forward. Most companies mining phosphate today moved forward in their attempts to mitigate contaminated leachates produced from mine wastes. While detailed communications regarding their actions were sometimes weak, agency representatives accepted these efforts as well intentioned. Because some of these mitigations were poorly documented, it now makes it difficult for the agencies to know if a permanent mitigation was developed or if there is a temporary suppression of impacts that may reoccur in the future.

Forty years of what may be interpreted as friendly regulation of the phosphate industry in Southeastern Idaho has led to the impression that an adversarial relationship now exists between the phosphate industry and the agency regulators. However, contrary to this perception, the regulatory agencies are simply following prescribed protocols. As regulators, protection of the public trust has multiple meanings. Environmental protection is legally mandated in many cases but it is also in the interest of the local population.

Releases of contaminants from or onto public lands requires an appropriate response mandated by law. Several factors influenced both agency and industry reactions early in this process. Initial industry control of the early investigative process provided control of the pace that studies and remediation would occur. Voluntary lead with the initial investigations also allowed the industry to control the rate that money was spent. Under regulatory guidance and agency direction industry control was lost but the benefit is that the more structured approach should lead to defensible decisions on site remediation. It's true that site investigations in strict compliance with CERCLA may be more expensive but, when compared to the potential costs associated with unsuccessful remedial activities, these costs are small.

Protection of the public trust is also necessary in the mandated process required by law to implement major actions by the Federal government or on Federally administered lands. Without public trust in both the industry and regulatory managers responsible, the ability to permit continued and future phosphate mining in Southeastern Idaho would become increasing difficult and more costly to both the government and industry. Therefore, agency control and objective, well conceived decisions on the site investigations and remedial activities related to the selenium issue are best for all involved.

Continued success of the phosphate mining industry is dependent on the ability of the agencies and the industry to cooperate within a regulatory framework that provides for maintenance of the public trust. Phosphate production is important not only to the local economy but to the ability of the nation to produce products that sustain a high quality of life. Without this cooperation within a proven regulatory framework, our own laws increase the possibility that opponents of land disturbing activities can successfully delay or prevent extractive industries from operating on public lands.

A tremendous amount of work remains in the effort to continue current phosphate production in southeast Idaho and permit necessary expansions while conducting site investigations and remedial activities at existing mine sites. Agency/Industry relations may continue to be strained at times, but as long as their communications and cooperation continue, an important industry can continue to operate in Southeastern Idaho.

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OHIO DNR & CUYAHOGA VALLEY N.P. : A PARTNERING SUCCESS STORY

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ABSTRACT

Partnering between two diverse government agencies has produced the reclamation of three devastated sites that could not have been accomplished by either agency acting alone. The Cuyahoga Valley National Park (CVNP) preserves 33,000 acres along the Cuyahoga River between Cleveland and Akron, Ohio. Several locations within the Park had been previously disturbed through use as soil and fill material for a ski resort as well as sand and gravel extraction. All of these sites exhibited the same conditions: sparse vegetation and severe erosive soil loss with resultant downstream sedimentation. In 1992 the CVNP approached the Ohio Department of Natural Resources, Division of Mineral Resources Management (ODNR-MRM), about the feasibility of using monies from the State Industrial Minerals AML account to reclaim the sites. Several factors militated against the reclamation of these sites. The IM-AML account did not contain enough money to accomplish the work. Federal National Park Service (NPS) procurement practices required the use of Davis Bacon wage rates, which would place a heavy monetary burden on the State funds. Finally, ODNR had recently undergone personnel cutbacks and lacked the engineering support needed to design the reclamation projects. An agreement was developed between CVNP and ODNR. Parks personnel provided design services to complete the construction plans and specifications with oversight performed by an ODNR engineer. The projects were bid out using the lower State prevailing wage rates. A funding match was provided by the NPS. ODNR provided inspection services and funding to reclaim two sites while CVNP used the 'match' monies to inspect and reclaim a third site. Remaining 'match' monies will be used to perform an extensive stream-cleaning program. The successful completion of these projects has increased the possibilities for future work in the Park.

INTRODUCTION

Many advantages can be derived from 'partnering' on a reclamation project. These advantages can include, but are not necessarily limited to, substantial cost savings, additional sources of funding, more timely implementation of reclamation work, a more accurate and more thoroughly prepared design, more thorough inspection coverage and high public visibility. These advantages accrue from the 'hybrid vigor' that can occur when two or more seemingly disparate entities combine resources to produce the final reclamation product.

Many factors can provide obstacles to the successful implementation and completion of an abandoned mine reclamation project. One of the most troubling obstacles can be the institutional barriers that exist within bureaucracies whenever a proposed project falls outside the purview of 'standard operating procedure'. Other obstacles can be caused by shortages of funds, manpower and time. These obstacles to reclamation can be further compounded when two or more government institutions attempt a venture into partnering. Obstacles that occur in a

'partnering' venture arise from issues such as differing philosophies regarding design approach and project supervision.

This report will discuss a specific 'partnering' venture between the Ohio Department of Natural Resources, Division of Mineral Resources Management and the National Park Service, Cuyahoga Valley National Park that has produced the successful reclamation of several abandoned mine sites. Finally, some strategies that were used to overcome obstacles will be discussed.

CUYAHOGA VALLEY NATIONAL PARK OVERVIEW/HISTORY¹

The Cuyahoga River Valley is situated in the glaciated portion of northern Ohio. It is located between the population centers of Cleveland and Akron, to the north and south, respectively. The Cuyahoga, from the Native American 'Ka-ih-ogh-ha', or crooked, River begins 30 miles east of its mouth in Cleveland. Flowing south, it twists and turns in a great 'U' for 90 miles along the base of the escarpment on which the city of Akron lies before turning north to finally empty into Lake Erie. Sculpting by glaciers and the forces of the river has created a diverse landscape of river floodplain, steep and gentle valley walls, tributaries and their ravines, and upland plateaus.

The Cuyahoga River has long attracted people and wildlife. People have lived here for nearly 12,000 years, and they left a legacy of archeological sites throughout the valley. An important transportation route for native peoples, the area was deemed neutral territory by the tribes, so all might travel on it safely from the cold waters of the Great Lakes to the short portage across the divide to the Tuscarawas River that drained into the Ohio River and the warm waters to the south. European explorers and trappers arrived in the 17th century. The first European settlement in the valley was the Moravian village of Pilgerruh, located near the confluence of Tinkers Creek and the river. In 1786, the Connecticut Western Reserve set aside 3,500,000 acres for settlement. Ten years later Moses Cleaveland, a land agent for the Connecticut Land Company, arrived to plat out the city that bears his name. The Ohio and Erie Canal opened in 1827 between Cleveland and Akron. It paralleled and was partly watered by the Cuyahoga and replaced the river as the primary transportation artery. The surrounding towns and villages boomed with canal-related industry. By the 1860's, railroads had replaced the canal as the major route for commerce, industry and travel. In the early 1960's unchecked development, including logging and minerals extraction, became a major threat to the valley. Citizens joined forces with state and local governments to save the greenspace and historic features. These efforts coincided with the National Park Service, which was then establishing urban recreation areas as a means of bringing national parks to people living in cities. In 1974, Congress created Cuyahoga Valley National Recreation Area as an urban park of the National Park System. The valley attained National Park status in 2000.

The Cuyahoga Valley National Park preserves 33,000 acres along 22 miles of the 'Crooked River'. The National Park Service manages the park in cooperation with others who own property within its boundaries, including Cleveland Metroparks and Metro Parks, Serving Summit County, both of which administer several units within CVNP. Together they protect the natural landscape and preserve remnants of the human history.

The Park surrounds the Village of Peninsula, which attracts visitors with its history, architecture, shops, galleries, and restaurants. Peninsula is also a popular starting point for recreation in CVNP. The Park also contributes to something greater - the Ohio & Erie Canal

Heritage Corridor. CVNP, in the heart of the corridor, unites Cleveland and Akron, which have active corridor preservation programs. The corridor continues south to Zoar, Ohio. It provides continuity and an expansion of the historic connections of natural resources and industry - the lake, river, canal, and railroad - that made this valley and region prosperous.

Wetlands, forests, fields in various stages of succession, and other habitats enable a surprising diversity of wildlife to thrive. Cool ravines provide microhabitats for hemlock, yellow birch, red-breasted nuthatches, and wildlife commonly found in a more northern climate. Covered by mixed deciduous forest and pockets of evergreens, tree species are abundant. Wildflowers and plant varieties range from spring woodland wildflowers, such as hepaticas and bloodroot, to late summer asters and goldenrod in open areas. Yellow and blue irises, cattails, and the American lotus bloom in wetlands in late spring and early summer.

PROGRAM OVERVIEWS

NPS²

The National Park System contains nearly 3,000 sites in 146 parks that are disturbed by previous mineral exploration and development. These sites include 11,000 underground openings, 51 abandoned oil and gas wells, and 33,000 acres of scarred surface area. Resource effects at AML sites include excessive erosion and sedimentation, exotic plant invasion, soil and water contamination, and public safety hazards. The NPS estimates that addressing its priority AML needs would require \$20 to \$40 million. Long-term reclamation costs to deal with all sites could be as high as \$165 million.

The NPS AML program has five objectives: (1) inventory all AML sites, (2) restore degraded natural resources, (3) eliminate safety hazards, (4) protect critical habitat, and (5) preserve and interpret culturally and historically significant resources. To assist in carrying out these objectives, the NPS has entered into agreements with eight states and two federal agencies to conduct site characterizations and aid on-the-ground reclamation.

DMRM³

The Ohio Division of Mineral Resources Management administers both a state-funded abandoned mine lands program and a federal AML program to reclaim those areas disturbed by coal and minerals mining operations for which there is no continuing reclamation responsibility by the mine operator. Both of the programs are funded by severance taxes levied on the mining of coal and minerals.

The State AML program, which provided the funding for the CVNP AML projects, is funded by a share of the seven cents per ton of the state coal severance tax and the two cents per ton of the state industrial minerals (sand & gravel) severance tax. The State AML program focuses on reclamation of: lands that cause pollution of the waters of the state; lands that pollute adjacent property; lands which, when reclaimed, can be used by the public for soil, water, forests, wildlife conservation, or public recreation purposes; lands which, when reclaimed, will facilitate the use or improve the enjoyment of public conservation or recreation lands. The State AML program reclaims lands affected prior to 1972. Projects in the State AML program are typically designed by and inspected by the Division of Mineral Resources Management staff.

SNOWVILLE RECLAMATION PROJECT

In 1992 John Sprouse from ODNR worked with Garree Williamson of the NPS to look into the restoration of the Snowville Quarry Site. By May of 1993, ODNR had reached an agreement with NPS to develop the Snowville Project as a State-funded Industrial Mineral Reclamation Project.

The Snowville site was an old sand and gravel quarry dating back to the 1930's. The 24-acre site was also used as a local dump throughout the years until the site became part of the Cuyahoga Valley National Recreation Area over 25 years ago. There was virtually no vegetation around the quarry site's subsoil piles, water impoundment and steep gullies. Soil eroded directly into two tributaries and, ultimately, the Cuyahoga River less than one-half mile away. In 1982, a report by the Corps of Engineers indicated that the Snowville site delivered about 2,900 tons of sediment per year offsite and an additional 3,500 tons onsite⁴. This sediment caused many down stream problems, blocking and flooding roadways and causing frequent road closings and repairs.

Mapping of the site was completed in 1995, but ODNR was not able to move forward with the project due to lack of engineering support. ODNR could provide engineering oversight, but not design services. The Park offered design services to complete the construction plans and specifications.

In 1997 design work was completed and the project was bid in 1998. Shook Brothers Construction Co., Inc. of Berlin Center, Ohio was awarded a contract for \$177,352.00 to perform the reclamation work. The construction was performed through the summer and fall of 1998 and completed by June 1999.

In the spring of 2001 both NPS and ODNR partnered again to plant native tree species, including blight-resistant American chestnut (*C. dentata*) on the reclaimed slopes of the former Snowville Quarry.

DOVER RECLAMATION PROJECT

Upon the successful completion of the Snowville site, the park subsequently asked ODNR for additional help with three other sites, collectively known as the Dover sites. The Dover sites covered about 20 acres in CVNP where topsoil and subsoil were scalped between 1963 and 1972 to provide fill material to increase the elevation of the slopes of an adjacent ski area. The park subsequently purchased the sites, which were highly eroded and contained virtually no vegetation. The erosion-generated sediments from the sites reached a tributary and the Cuyahoga River less than one-third mile downstream. The 1982 Corps of Engineers study estimated that 7,200 tons of sediment per year was delivered into the Cuyahoga from these 20 acres and its neighboring 40 acres⁵.

The ODNR was, once again, interested in working with the Park to reclaim these sites. At the same time economic downturns caused a decline in the state reclamation funds, which caused a resultant reduction in the ODNR engineering staff. This lack of manpower was further aggravated by a decline in state reclamation funds arising from an economic downturn. While NPS was willing to commit matching funds for the project there was no avenue to allow ODNR to use NPS monies and still follow the state procurement process. ODNR would be required to use the federal Davis-Bacon wage rates of approximately \$27.00 per hour versus the Ohio State prevailing wage rate of approximately \$ 14.63 per hour, on average, for a bulldozer operator.

This difference in construction cost would require ODNR to expend more funds than usual to complete the project, making the project economically unfeasible within the parameters of the State-funded AML program. In 2001 ODNR and NPS reached an agreement; ODNR would handle an 11-acre site with NPS developing the plans and specifications using ODNR engineering oversight, and the NPS would handle the 3-acre site using matching funds. ODNR would provide full-time construction inspection with Park personnel filling in as needed. The ODNR inspector, upon consultation with and approval by the Park, issued field orders and change orders.

The final project specifications were as follows:

- 69,300 cubic yards earthwork
- 40 tons Type 'C' rock channel protection
- 386 square yards temporary channel lining
- 80 linear feet PE/PVC culvert
- 1,160 linear feet silt fence
- 50 tons #1 & #2 stone
- Temporary sediment pond installation and removal
- Permanent pond upgrade
- 140 tons gully drains (# 357 stone)
- 8,800 cubic yards approved resoil
- 4,180 cubic yards alternate organic resoil (residential compost)
- 14.1 acres standard revegetation (Switchgrass, Indiangrass, Chewings fescue)
- 14.1 acres maintenance fertilizer

The final project cost estimate was \$200,000.00. This money was 'matched' by the NPS for use in down gradient stream cleaning and channel reconstruction. After bidding, a contract in the amount of \$173,685.00 was awarded to McMillan Construction Co, Inc. of Wellington, Ohio on August 30, 2001 and actual construction commenced on December 3, 2001. Work proceeded at a steady rate with a shutdown between March and May of 2002 resulting from wet weather. The construction work was 'substantially approved' during an inspection conducted jointly by personnel from the construction firm, NPS and ODNR on June 27, 2002. The final project construction cost was \$180,833.80. The extra costs were derived primarily from the need for more # 357 stone for the gully drains and #1 & #2 stone to stabilize the access/staging area for the alternate organic resoil. Maintenance work, including removal of the temporary sediment pond and removal of the access road, will be completed one year from the substantial completion date.

FUTURE RECLAMATION WORK

The restoration of a remaining severely eroded site, called Site #3, is presently in the planning stages. Both ODNR and NPS are pursuing funding sources and design options for the reclamation of this and other sites. It is hoped that the record of successful projects undertaken in this partnership will enhance the probability of project implementation on this site.

ADVANTAGES OF PARTNERING

In the case of the Snowville and Dover Projects one of the partners, NPS, was also the principal landowner. Parks personnel had great familiarity with the project sites. They knew the sites' histories as well as the nature of the problems. They were within a five minute drive of all the sites, which enabled a much more thorough preliminary design as well as timely inspection back-up, when needed. The plans and specifications created by the NPS incorporated some novel ideas for an ODNR project: revegetation with native plant species (Indiangrass, Switchgrass, Chewings fescue) and leaving untouched the smaller offsite, downslope erosion gullies in order to preserve existing vegetation. Finally, knowledge of the sites' parent material produced an excellent site specific resoiling plan, which required the incorporation of composted yard waste into the graded resoiling material.

ODNR provided the obvious benefit of funding and contracting of the construction work, which produced substantial cost savings. Engineering experience and design oversight by an ODNR professional engineer, when incorporated with NPS design concepts produced a hybrid design of superior quality. ODNR provided full-time project inspection with the obvious benefits. Finally, the use of State-funded AML monies enabled the procurement of a Federal match, which is in the process of being used for further reclamation.

OBSTACLES TO PARTNERING

Obstacles to an interagency partnership often arise from the inherent inertia of the bureaucratic system. Bureaucratic intransigence can have benefits, but it can impede a novel concept like partnering. Existing policies, 'business as usual', can promote resistance to change. Philosophical and procedural differences between disparate agencies can create stasis. Disputes over funding sources ("Who's paying for this?") can produce roadblocks. Finally, the key parties involved in the partnership can lose their enthusiasm while overcoming the many hurdles placed in their path.

PARTNERING STRATEGIES

Some of the above or, perhaps, other obstacles will almost certainly present themselves at some point along the continuum from vision to completed project. The strategies that can be used will be as variable as the obstacles and will often depend on the personalities of the involved parties.

Perhaps the most important strategy is perseverance, staying with the overall objective. When a manager presents objections, ask for an explanation. Persistence in obtaining a logical rationale for the initial denial will often initiate the thought process and produce some positive feedback. If the initial contact person remains negative, consider obtaining other opinions. Approach someone else in the agency with the project idea to build up support.

Sell resistant managers on the project. When success looms on the horizon, even the most reluctant manager can be convinced to take up the gauntlet and fight for his or her 'idea'. A manager who has bought into an idea can be an important ally.

Finally, one needs to stay resilient during the conceptual phases of any partnering project. Maintain an open mind and be empathetic toward the other partnership stakeholders' points of view regarding reclamation concepts. No two agencies do everything the same way. Being aware

of these conceptual differences and adjusting to others' ideas in a positive and open manner will go a long way to producing a successful and, oftentimes, superior product.

SUMMARY

A final accounting of the pros and cons involved in an interagency partnership can be an important predictive tool with regard to the ultimate success or failure of the venture. If the obstacles greatly outweigh the advantages, rethink attempting the project; it will likely waste a great deal of time and resources with little or no resolution and probably fail. However, if the pluses outweigh the minuses, go with the project. The rewards will be many.

A successful interagency partnership can be a wonderful thing. It creates positive feelings among all the participants, including the contractors. The partnership can generate positive economic accounting, i.e. more bang for the buck. The visibility of a successful project will generate positive feedback; partnering is a rare bird and the public will notice. Ultimately, a successful partnering project will engender more of the same, with more 'on the ground' reclamation getting accomplished.

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WATERSHED COALITION POWER IN APPALACHIA – KEEPERS OF THE LAND AND WATER

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The land and water resources of many Appalachian watersheds have been severely impacted by land use, floodplain encroachment and lack of infrastructure. In recent years grassroot coalitions have organized to address local issues of concern. Many of these organizations start as an “anti” group. Opposing some action within the community. Harnessing and utilizing this grassroots energy in positive ways can provide for lasting comprehensive reclamation of watersheds.

Appalachia has a long history of people in conflict with nature resources. The extraction industries historically have owned most of the land. In many mining town the individual ownership of land was non-existent. In the mid-twentieth century most companies sold the company homes with small lots. Today many watersheds are still dominantly owned by large corporations with only a very small percent owned by individuals. The culture was one in which people were controlled by the company. Consequently strong local grassroots leadership did not develop.

These communities were conditioned to except lower standards of the quality of life and nature resources. Mine disasters, floods and poor recreation was accepted as a way of life. Today communities are expecting more, people are organizing in community and watershed coalitions to express concerns and provide leadership for changing and improving their communities. Many of these groups are interested in improving the quality of their nature resources.

The most effective method of managing nature resources is on a watershed basis. This was demonstrated in projects such as the Coon Creek watershed in Wisconsin in the 1930's and has been utilized for countless projects. Over the past decade the development of local grassroots watershed groups has brought new focus and empowerment for action to improved resource management. There is success stories in every state and community of people coming together in organized efforts to work with both private and government organizations to impact concerns.

We all know this process works. What do we do to make them work to improve the quality of life, and resources in communities that have been severely damaged by past mining? That is our challenge as agencies charged with reclamation responsibilities.

Pennsylvania has used this process very effectively in addressing acid mine drainage (AMD) and other water quality issues. In West Virginia, Pat and I are working to create the inter-agency commitments to make this process work. This statement is perhaps worn-out “When we partner we can do more”, however it is as true today as it was the first time it was said.

By utilizing the roles, talents, expertise of various organizations and agencies more can be accomplished with greater holistic benefits. We are currently working on three watersheds. I will discuss who is involved in these watersheds and what are the roles. First an overview of each watershed.

Deckers Creek is located in northern West Virginia. It is an old PL-566 project that has been damaged by excessive sediment in several structures. Various AMD discharges are having severe impact on the water quality. NRCS and WVAML have developed a plan to utilize both AML and PL-566 funds for project installation. Funding for this plan is a combination of NRCS PL-566 funds, WVAML, AMD set-aside funds, (ACSI) Appalachian Clean Streams Initiative and local funds including watershed maintenance funds from the Conservation District. Specific

projects will be funded by each agency. Cost sharing is based on the overall plan and is not by individual practice.

Paint Creek is in south central West Virginia. This watershed has a large acreage of abandon minelands that are contributing to a heavy sediment load and several sources of AMD are restricting fisheries. NRCS has provided an assessment of the minelands in the watershed to AML for developing a watershed plan. In Paint Creek, a wide range of funding will be used to complete fisheries projects, funding has been provided by CVI, WVCA, WVDNR, ACSI, OSM, WVDEP with technical assistance from NRCS and contracting provided by the local conservation district. Reclamation will be completed by a combination of AML and AMD set-aside and ACSI. NRCS utilized RAMP funds to complete the watershed assessment. CVI has provided funding and organizational support to the group.

Pigeon Creek is located in southern West Virginia, Hatfield and McCoy country, along the Kentucky border. Here NRCS working with AML and others and a strong local organization has developed a strategic plan for improvement in the watershed. Currently mine mitigation funds from a local coal company are being used for in-stream fisheries improvements. NRCS has provided technical assistance to complete a watershed assessment and strategic plan. The local watershed coalition has a vista worker provided by an OSM grant. Reclamation projects in the watershed are being funded by RAMP, AML, AMD set-aside programs and ACSI. This watershed group has completed various clean-ups and is currently developing a community park. CVI is providing organizational support to the group.

The common roles within these projects are: 1) Each project has a strong local watershed organization that is committed to improving their resources. They know the local needs and impacts of the existing situation. They also have a vision of what they want, it's often vague and needs defining. Many of these organizations start as "anti" something with conflicting interest and ideas. In many cases, their energy needs focusing and direction. They have tremendous political power for funding when they have well documented and planned projects.

They also bring local ownership to projects. This ownership assures that projects are maintained and have lasting benefits. We all know that many of our reclamation projects have had benefits limited because of misuse from recreation vehicles, etc. The principle is simple: "If it belongs to the government no one cares. If it belongs to the community they care."

These local organizations lack ability to assess, analyze, plan, design, and construct projects.

2) The local conservation district is a critical player. The CD's have the ability to manage funds in a legal, accountable, statutory system. They have co-operative agreements with most nature resource management agencies. Through their ability to handle funds and work with a wide range of agencies they can facilitate the planning and implementation of projects on the local level. The unique delivery system of CD's can supports WS organizations by combining private, state and federal resources for local projects.

State AML agencies are the leaders in reclamation expertise and funding. AMD issues are extremely complex and expensive to treat. Your treatment expertise and funding source is the major resource available. Applying these resources to local watersheds holistically will improve water quality, stream health and peoples lives.

What can NRCS do? One of our strongest talents is working with local groups to assess and analyze resource information and develop plans. We have a long history of success in developing local leadership and plans to carryout projects. In addition to these resources, NRCS has possibilities of funding through various sources such as PL-566, RAMP and special projects.

In West Virginia we have another key player in the Canaan Valley Institute. They are an organization primarily concerned with developing local grassroots leadership in communities and watersheds along with WVDEP stream partners.

There is a host of other agencies and organizations that can contribute services, funds and resources. OSM is a major player with AML agencies. EPA, COE, TVA and others have funds and programs that can be in-cooperated. Corporations and private grant organizations can play major roles.

It sounds so simple, developing leadership, assessing resources, planning actions, funding, designing and installing projects. Each of these activities can be provided by someone who does it best.

Our challenge as leaders within these agencies is to utilize these resources for maximum impacts. The most bang for the buck.

**TECHNICAL PAPER SESSION 7
GEOGRAPHIC INFORMATION SYSTEMS - PART 1**

Title: [GPS for GIS for Applications](#)

Author: [Carma Ingram](#)*, GPS/GIS Specialist, Monsen Engineering

Title: [Abandoned and Inactive Mine \(AIM\) Lands Inventory for the USDA – Forest Service, Region 9, Monongahela and Wayne National Forest](#)

Authors: [Hugo Aparicio](#), P.E., Project Manager; **Michael E Anderson***, GIS Manager, Fuller, Mossbarger, Scott and May Engineers, Inc.; **Pamela M. Stachler**, Forest Hydrologist; **Rebecca R. Ewing**, Forest Biologist, USDA – Forest Service, Wayne National Forest; **Linda L. Tracy**, Forest Geologist, USDA – Forest Service, Monongahela National Forest; **Steve Brewster**, P.G., Project Manager; and **Steve Spagna**, P.G., Geologist, USACE-Huntington District

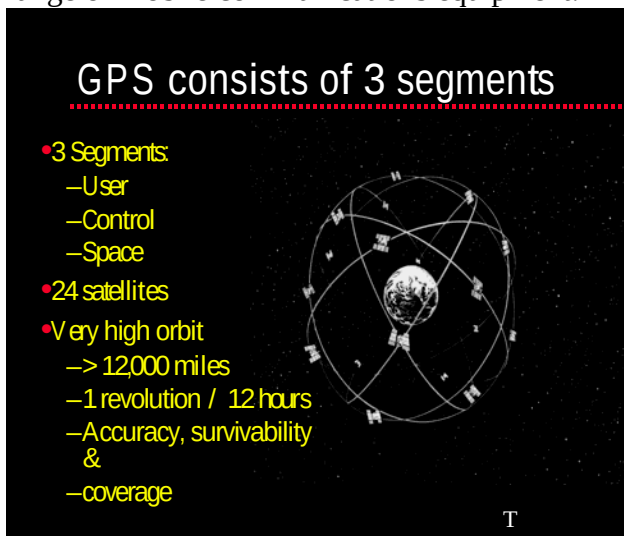
Title: **GIS Analysis of Mine Reclamation: Solving the Problem of Dredge Material and Abandoned Mines**

Authors: [Erica Mignone](#)* and **Matthew Reid***, State University of New York at Purchase College, New York and New Jersey Clean Ocean And Shore Trust (COAST)

Title: [The Characterization of the Kempton Mine Complex, Maryland and Virginia, Using GIS Technology](#)

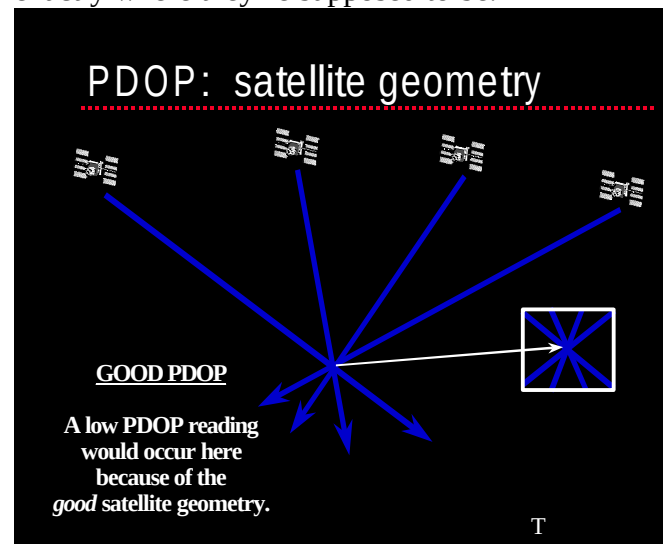
Authors: **Tamara P. Davis**, Natural Resources Planner and GIS Specialist, Research and Development Section, Maryland Department of the Environment, Water Management Administration, Mining Program, Bureau of Mines and [Constance Lyons](#)*, Natural Resources Planner V, Maryland Department of the Environment, Bureau of Mines

Use of the Global Position System – a way of accurately determining positions on the surface of the earth – has grown exponentially since it became feasible for commercial use in the early 1990s. Designed and developed originally for military use only, GPS is now used in mapping, navigation, surveying, agriculture, construction, vehicle tracking and recovery, archaeology, biology—the list goes on and on. In fact, GPS has become so widely used that it has now even found its way into a wide range of consumer products, from cell phones and automobiles to handheld “personal” receivers that have tumbled in cost from around \$2,000 (the 1990 figure) to under \$100. GPS chips are now being heavily used in computer networks, and popping up as well in such unlikely places as ATMs and entire range of mobile communications equipment.



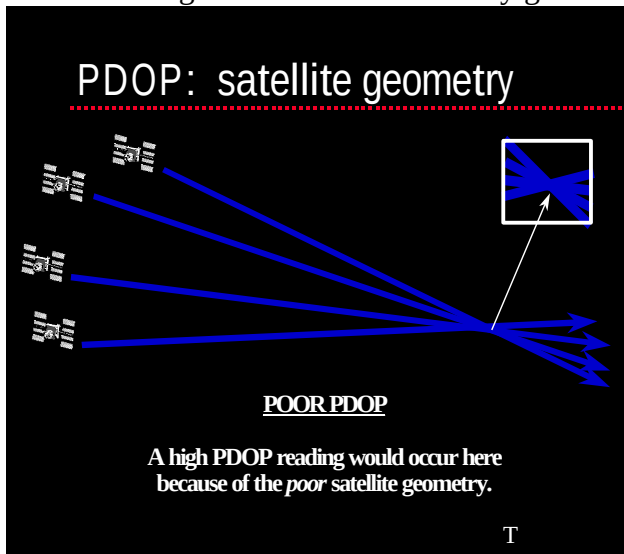
The Global Position System is a constellation of twenty-seven NAVSTAR satellites orbiting the earth at a height of 12,600 miles; five monitoring stations (in Hawaii, Ascension Island, Diego Garcia, Kwajalein, and exotic Colorado Springs); and individual receivers. By reading the radio signal broadcast from as few as three of these satellites simultaneously (a process known as trilateration), a receiver on earth can pinpoint its exact location on the ground. This location is expressed in latitude and longitude coordinates.

Fortunately for people who wish to use GPS to fix locations, they need not even think about the satellites or the monitoring stations. Just like radio or broadcast television signals, GPS signals are available to anyone who has the proper equipment and knowledge. The twenty-four active satellites (there are currently three spares up there, too) have been deployed in six evenly distributed orbits, at speeds that have each satellite passing over a monitoring station once every twelve hours. That means there are always more than four visible in the sky everywhere on the planet. The satellites continuously transmit signals on two L-band frequencies, and the monitoring stations send correctional data to keep the satellites trim and exactly where they're supposed to be.



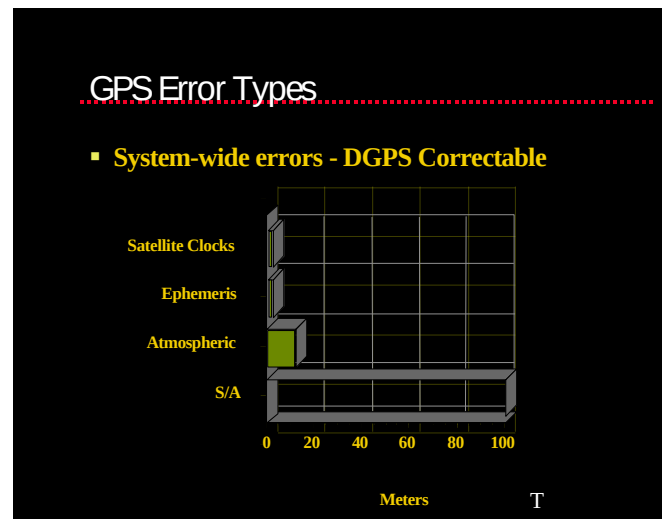
PDOP - The key to using the GPS system for accurate positioning relates to the relative position of the satellites you are using for your position. The ideal orientation of four or more satellites would be to have them equally spaced all around the receiver, including one above and one below. Because we're taking our position from only one side of the Earth, that's really not possible since that part of space is blocked by the planet itself. The best orientation is to have one satellite directly above and three evenly

spaced around the receiver and elevated to about 25 to 30 degrees (to help minimize atmospheric refraction). This would result in a very good DOP value (Dilution of Precision). A low numeric Dilution of Precision value represents a good satellite configuration, whereas a higher value represents a poor satellite configuration. The DOP at any given

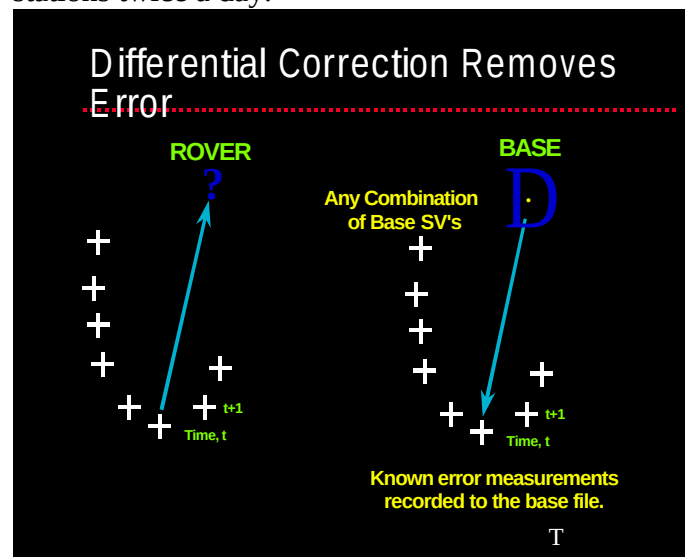


moment will change with time as the satellites move along their orbits. The mapping grade GPS receivers monitor the DOP values and provide changeable mask settings that prevent the GPS operator from collecting poor positional data due to high DOP values.

Selective Availability was an intentional degradation of the GPS signal imposed by the U.S. Department of Defense (DoD). S/A was turned on in May 2000 because the DoD felt that we have enough radio jamming technology to be able to protect our country from unfriendly nations who would use the GPS system for navigational purposes of an attack nature. Keep in mind the DoD retains the power to turn it back on should the need arise. Without S/A the accuracy of GPS position is about 15 meters with great improvement also in the Z values.



Other errors still inherent in the GPS signal relate to atmospheric error (distortion as the signal passes through our atmosphere), clock error (differences between atomic clock on the satellite and clocks in the receiver), and ephemeris errors (minor disturbances of satellite orbit caused by the sun and moon; gravitational pulls and the pressure of solar radiation). The five monitoring stations run by the DoD regularly transmit correctional data to the satellites as they pass overhead, each one of the stations twice a day.



Differential GPS – The more sophisticated receivers can correct atmospheric and multipath errors, and can therefore be accurate—when the GPS data is differentially corrected—anywhere from 5-meter to sub-meter range. Differential correction requires two receivers. Place one receiver at a known location—an accurately

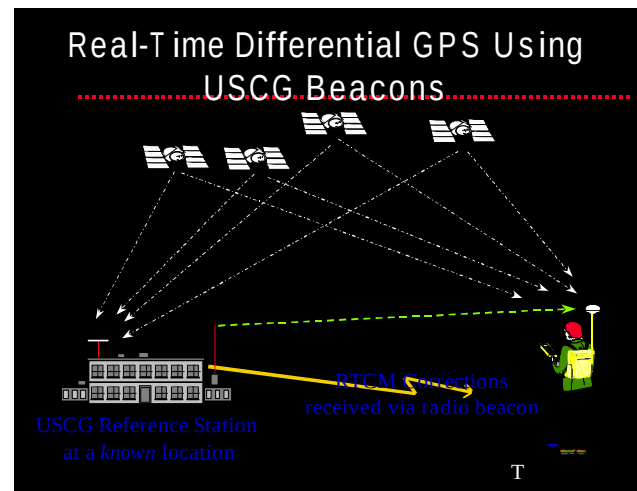
surveyed point. This is the base station. The other receiver, the rover, you carry around with you, logging latitude/longitude coordinates. The base station receiver compares where the satellite the signals say it is with where it knows it is. The difference is the amount of error. The satellites are so far away that if the two receivers are close to each other—say within 300 miles—they will be subject to the same amount of error, having traveled through more or less the same corridor or atmosphere.

Generally, if the rover is within a hundred miles of a base station, the resulting positions will be accurate to within the specifications of the receiver. The farther away you are, the less accurate the positions will be. If the rover is 100 to 200 miles from the base, accuracy will be approximately two times worse than receiver specs; if the rover is 200 to 300 miles away, accuracy will be two-and-a-half to three times poorer than spec. Recent advances in technology have made it possible to process over distances greater than 300 miles, but decreased accuracy is still a factor. There are many, many public base stations providing their files for free over the Internet. Some provide the files in Trimble .ssf format and others provide the files in a generic format called RINEX.

Real-time versus postprocessing – First, a word of caution: it's not a good idea to rely on uncorrected GPS data, even with S/A turned off. S/A's absence benefits mainly people using GPS for real-time navigation or autonomous positioning (Automatic Vehicle Location, for example), as well as recreational users: hikers, campers, anglers. Even though data collected without interference from S/A may be off by only 10 to 15 meters, the data can still be shifted from its actual position, and lines or polygons can appear spiky instead of straight. Also, keep in mind that the DoD can scramble the GPS signal anytime it needs to. If you want the accuracy your receiver is built to deliver, you have to differentially correct your data.

Real-time processing is generally less accurate than post processing because of the distance from the base station and latency in the

time the signal is received, as well as, the rate the signal is sent.



Several real-time differential correction radio signals are available. The US Coast Guard has beacon transmitters being placed strategically throughout the United States for eventual full coverage. These signals operate at 200-300 MHz and are ground following from the radio transmitter. You need a separate radio receiver to receive beacon signals. Some receivers have the beacon radio receiver built in, others require a separate receiving radio. Omnistar and Landstar provide real-time differential via a geostationary satellite for a fee of approximately \$900 per year in the U.S. Again, you need the radio receiving device to get that signal – some receivers have it built in, others require a separate radio receiving device. WAAS signals are satellite differential provided by the FAA for accurate navigation of aircraft. WAAS is still in the testing phase. WAAS satellites use the same frequency as the GPS satellites; therefore, use one of your GPS channels. They broadcast from an East coast and West coast located satellite and are fairly low on the horizon for use in the middle U.S.

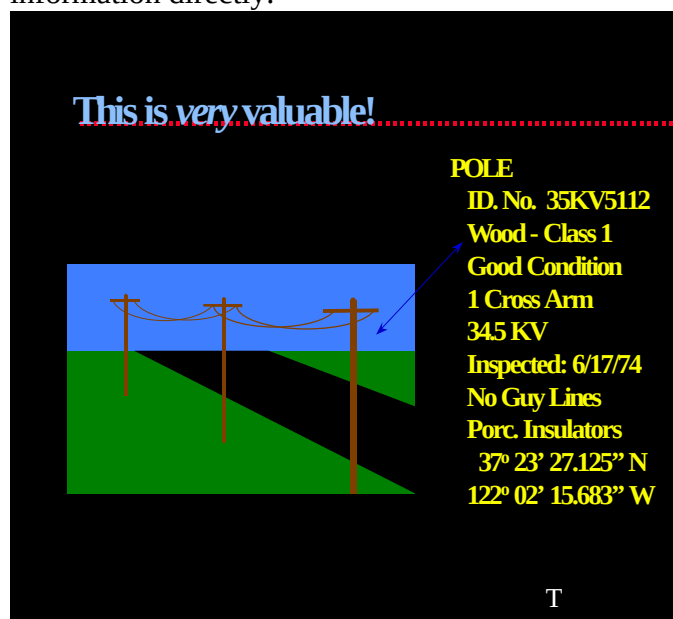
For best accuracy post-process differential from a base station within 100 miles will yield the best result.

Geographic Information systems (GIS) – In a sense, GIS is simply a method of organizing and presenting virtually any kind of information about “stuff” in the world around us. What “stuff?” “Stuff” can be anything from fluvial systems (rivers), topography (shape of the

surface), land use (cities or fields), and “ordinary” road maps, to city sewer lines, telephone poles, fire hydrants and more. Basically, if it’s out there it occupies space. If it occupies space then it has spatial characteristics such as *where* it’s at, and individual characteristics like “big” or “small” or an individual serial number. This is all useful information to those who, in some form or another, plan, administer and manage such “stuff”.

GPS fit hand-in-glove with the requirements of GIS. All of the information about “stuff” that’s required for a computerized GIS can easily and accurately be acquired with GPS technology. The beauty of GPS for GIS applications is the simplicity and directness of data acquisition. For all intents and purposes, a GPS receiver can collect the necessary information and feed it directly into a computerized GIS with little effort expended in between.

The way GPS is used to provide GIS data can be categorized in two broad areas. The first is simply applying a controlling reference to some other source of data from which the GIS can collect the information that it needs. The other is to use the GPS to acquire the GIS information directly.



Using the GPS to acquire the GIS information directly requires the creation of a

data dictionary that will travel with you into the field to define information about the features you are collecting. To create a data dictionary, you will need to think of every feature you want to inventory as either a point, line, or area. For instance, trees, poles, and fire hydrants are points; fences, pipelines, and roads are lines; and land parcels or parking lots are areas. GPS positions are simply latitude/longitude coordinates, with no attribute—i.e., descriptive—data. GPS positions plotted as lines or areas are simply positions joined together, in the chronological order you collected them—a “connect-the-dots” puzzle. You need to think not only of features to be inventoried and how to define them, but also the questions about those features that need to be answered when you are in the field. In a GIS, this type of information is referred to as attribute data. For example, you might want to know a tree’s species and height. In your data dictionary, the tree is the feature; the attributes, or questions, are species and height; and the answers to those questions are the values, which will be filled in by the user in the field.

Attribute types can be defined in a data dictionary as a menu choice, as text, or as a numeric, date, or time field. Using menu choices is often the best way to structure the attribute value because it insures that the spelling and structure of a word will always come into the GIS in the same way no matter who collects the feature in the field.

Mapping and high-resolution GPS systems have a wide range of application and they’re much more accurate, principally because they are differential-capable. In addition, mapping grade receivers have some form of Feature/Attribute/Value recording capability for GIS applications. If you’re concerned about the nearly instantaneous obsolescence that seems to plague consumers as computer technologies grow and change, keep this in mind: the foundation of a good GPS unit is the capability to both post process data and correct it in real time. Whatever else changes, your unit will remain viable and valuable for many years if it can perform these tasks.

No one really knows where GPS is going in the future. Ten years ago, no one had a clue that GPS would take off as it has. One thing for sure, it has become such a widely used technology in so many different areas, it is not going to go away. Advancements in the technology will include size, accuracy, power, battery technology and application specific software and more.

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Understanding the GPS by Gregory T. French

**ABANDONED AND INACTIVE MINE (AIM) LANDS INVENTORY FOR THE
USDA – FOREST SERVICE, REGION 9
MONONGAHELA AND WAYNE NATIONAL FORESTS**

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ABSTRACT

According to the Abandoned Mine Land Inventory System assembled by the Office of Surface Mining (OSM), there are over 575,000 acres of abandoned mine land in the eastern United States, some of these abandoned mines are encountered within National Forests. As a result of the need to better manage public land, the Forest Service was tasked with identifying features associated with abandoned mines. The inventories developed would enable the Forest Service to better understand and improve watersheds impacted by acid mine drainage. In addition, inventories would be a useful component for various resource applications. Region 9 of the Forest Service and the United States Army Corps of Engineers (USACE)-Huntington District joined efforts and developed a format and methodology to perform abandoned mine inventories at the Monongahela Forest and Wayne National Forest (WNF). Corps personnel implemented the methodology and completed the abandoned and inactive mine (AIM) land inventory for the Monongahela Forest, the Iron-ton District of the WNF, and for three additional watersheds within the Athens District of the WNF. Fuller, Mossbarger, Scott, and May Engineers, Inc. (FMSM) performed inventory work in the Athens District through the Corps of Engineers' indefinite delivery contract. Successful partnering between the Forest Service, the Corps of Engineers, and FMSM has culminated in the completion of a highly versatile inventory with application and value for many environmental stewardship agencies and organizations throughout the region. This highly successful collaborative effort is expected to continue as the Forest Service plans to extend the inventory into additional basins as funding becomes available.

INTRODUCTION

The Monongahela and Wayne National Forests are part of the Eastern Region of the Forest Service, also known as Region 9. Both National Forests are situated within the Appalachian Coal Region, which extends from northern Pennsylvania to northwestern Alabama. The Monongahela National Forest (MNF) is comprised of 909,000 acres in ten counties along eastern West Virginia (see Figure 1). The Wayne National Forest (WNF) is divided into three Districts — Athens, Marietta and Ironton — which extend over 232,900 acres in southeastern Ohio (see Figure 2).



Figure 1. Monongahela National Forest Boundary

As a result of the abundance of thick seam coal deposits, large areas of each park have been subjected to extensive surface and underground coal mining since the 1800's. Exploitation of these resources created numerous adverse impacts associated with coal mines operating prior to the enactment of the Surface Mining

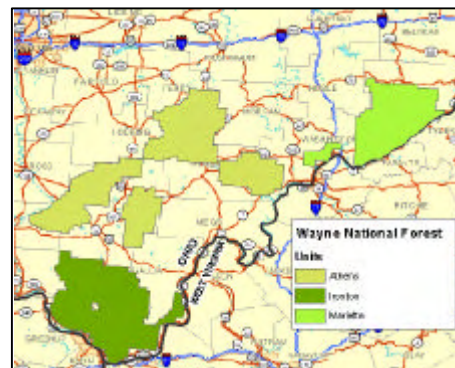


Figure 2. Wayne National Forest Boundary

Control and Reclamation Act of 1977 (SMCRA). Modern signatures of these earlier impacts include subsidence failure of the overburden, mine entrances left open, abandoned unstable highwalls, piles of toxic gob spoil material, and the release of acid mine drainage (AMD) that contaminates the surface streams. Although most of the disturbed land is now covered with relatively mature vegetation, remnants of the mining such as voids created near the surface by ground subsidence, unstable highwalls, open portals and acid mine drainage pose hazards to public safety and environmental health.

PARTNERSHIPS AND RECLAMATION MEASURES

For several years personnel from both parks have developed and implemented projects to reclaim the land disturbed by previous mining work. Some of these projects are funded and/or implemented in partnership with other state and federal agencies, and private entities. For example, in the case of the WNF, the Monday Creek Restoration Project is a reclamation effort involving American Electric Power, Hocking College, the Office of Surface Mining, Ohio EPA (OEPA), Ohio Department of Natural Resources (ODNR), Ohio University, West Virginia University, Rural Action, the Forest Service, and the U.S. Army Corps of Engineers. OSM and EPA have recognized this effort as a model of partnering for improvement of the environment.

The measures to reclaim abandoned mine lands include treating acid mine drainage, restoring drainage channels, filling in subsidence depressions and surface voids, grading, soil

capping and re-vegetating gob piles, and installing bat gates at mine openings or closing them. A description of current individual projects performed at each park can be reviewed at their respective web sites, www.fs.fed.us/r9/mnf/ and www.fs.fed.us/r9/wayne/.

INVENTORY WORK

The significant extent of the disturbance caused by prior coal mining resulting in thousands of hazardous abandoned mine land (AML) features scattered throughout both Forests prompted Region 9 of the Forest Service to develop an inventory of the associated impacts. Initial inventory methods implemented in Region 3 of the Forest Service were first used as a basis to plan inventory work at the Monongahela National Forest. The MNF represented by Linda Tracy and the United States Army Corps of Engineers (USACE), Huntington District represented by Steve Brewster and Steve Spagna, all co-authors of this paper, teamed up and developed an inventory method, which included developing a data dictionary to organize and facilitate the fieldwork. A Global Positioning System (GPS) was used in the field to record the exact location of each AML feature. In addition to selected laboratory testing, water quality field parameters were obtained for streams, seeps and ponds using portable equipment. This initial inventory effort in Region 9 of the Forest Service was completed in 1998.

The USACE-Huntington District partnered again with the WNF to inventory abandoned mine lands in the Ironton District of the WNF. The results of this work are reported in the Ironton District Abandoned Mine Lands Inventory, dated June 2000, which can be viewed on the Ironton District web site at www.fs.fed.us/r9/wayne/.

In 2000, the WNF prepared a Statement of Work for Athens Ranger District Abandoned and Inactive Mines (AIM) Inventory, which the USACE-Huntington District then used as a basis to contract Fuller, Mossbarger, Scott and May Engineers (FMSM) to inventory AIM land in the WNF Athens District. Phase 1 of the work consisted of inventorying 4,000 acres within the boundaries of the Athens District, in the general vicinity of Nelsonville, Ohio. This initial inventory was focused within the Monday Creek watershed. The USACE-Huntington District provided mapping which delineated Forest Service property and boundaries for the 35 search areas, a data dictionary depicting data collection requirements for each search area, and assisted in the initial fieldwork to train the teams deployed by FMSM. The Forest Service prioritized areas for inventory, based on ODNR-Division of Mineral Resources underground mine maps and known underground mine locations (see Figure 3).

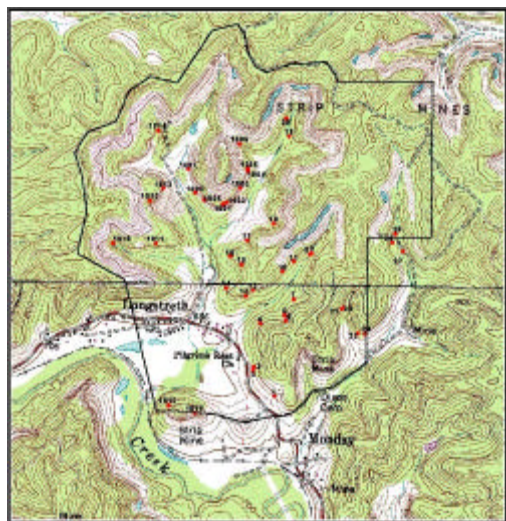


Figure 3. Portion of USGS Topographic Quadrangle Showing Location of Mine Portals Encountered Within the Big Four Search Area

The work order for Phase 1 was issued November 2000 and required that FMSM provide four two-person teams, each led by an experienced geologist, to perform discovery and field inventory work by walking up drains (hollows) and along hillside elevation contours of known coal seams and benches in specified areas. When a mine feature was found, its exact location was

recorded using a GPS Unit. Because GPS reception is limited by topography and forest cover, field data was collected during the fall and winter months when GPS signal interference from tree canopies is reduced. Where GPS reception was limited, locations of mine features were carefully placed onto US Geological Survey quadrangle maps. UTM coordinates were scaled off the maps in these situations. GPS-obtained location information was differentially corrected by downloading base station data from an Internet web site.

Additional information about each mine feature was then recorded in the data logger of the GPS unit. The data logger was programmed in advance of the fieldwork using the data dictionary provided by the USACE-Huntington District. The data dictionary defined nine (9) types of AIM features to be inventoried, such as portals, ponds, subsidence features, etc. The dictionary also included several descriptive parameters for each type of feature. For example, when a portal was encountered within a search area, the dictionary dictated that pertinent information such as coordinate locations, dimensions, distance from nearest improvement, evidence of visitation, water discharge, water quality testing and dangers to public be recorded.

LINE ID	COL NAME	TYPE	AGE (YEARS)	SIZE (SQ FT)	TIME	DIR	IMPROVEMENT	DEP	COLO	WATER	DISCHARGE	PHOTO	Latitude	Longitude
2082	004	Sp	1	6.27	2.23	1.28	0	225	No	No	0	0042	38.386258	-82.281822
2083	1	Dep	0.08	6.97	69.2	0.77	170	3.7	112	No	0	0042	38.386258	-82.281822
2084	2	Dep	3.8	7.88	124.8	-8.02	1.81	533	166	No	0	0042	38.386258	-82.281822
2085	3	Sp	1.1	8.11	80.5	0.46	4.98	1.8	178	No	0	0042	38.386258	-82.281822
2086	4	Sp	8.82	4.28	784.0	1.09	1.92	248.5	18	No	0	0042	38.386258	-82.281822
2087	5	Sp	8.1	2.48	89.3	0.83	1.32	105.5	229	No	0	0042	38.386258	-82.281822
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2089	7	Sp	3.2	2.34	287.8	3.85	8.44	83.0	72	No	0	0042	38.386258	-82.281822
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2094	12	Sp	3.82	6.32	224.2	-0.07	5.75	0	0	No	0	0042	38.386258	-82.281822
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2112	30	Dep	6.08	6.2	87.7	3.87	0	0	0	No	0	0042	38.386258	-82.281822
2113	31	Dep	6.08	6.08	378.8	8.39	0	0	0	No	0	0042	38.386258	-82.281822
2114	32	Dep	6.08	6.57	30.1	2.71	0	0	0	No	0	0042	38.386258	-82.281822
2115	33	Dep	6.08	8.02	124.8	1.8	0	0	0	No	0	0042	38.386258	-82.281822
2116	34	Dep	8.82	8.11	75.7	4.82	0	0	0	No	0	0042	38.386258	-82.281822
2117	35	Dep	8.1	5.88	142.4	0.74	0	0	0	No	0	0042	38.386258	-82.281822
2118	36	Sp	6.08	8.11	85.0	2.23	10.24	8.88	784	No	0	0042	38.386258	-82.281822
2119	37	Dep	6.08	8.27	95.1	3.78	6.34	14.2	583	No	0	0042	38.386258	-82.281822

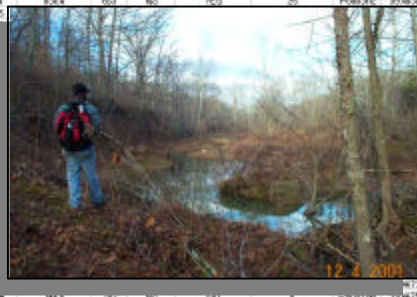


Figure 4. Example of Field Data Collected of Ponds Identified Within One Search Area and a Digital Photograph of One of the Ponds

feature was taken and exported into the respective data file.

At the end of each day, the field teams transferred the information stored in the GPS data collector to a laptop computer, where it was stored in a spreadsheet (see Figure 4). Having all the information in a spreadsheet allowed the teams to perform quality control reviews and check for errors. Back in the office, the spreadsheet information was assembled in ArcView export format to create topographic map plots of the different search areas. Symbols and identification numbers were used to show each feature on the map plots (see Figure 3). The basic delivery to the USACE-Huntington District and the Forest Service included hard and electronic copies of the spreadsheets containing the field data and the search area plots.

Phase 2 of the work added 28,400 acres of federal land to the scope of work. Subsequent modifications to Phase 2 added to the inventory work 3,300 acres of private property within the Monday Creek watershed, and 2,800 acres located in the Ironton District. The statement of work

also required that a database be created with the entire inventory data, and merging it with an existing database of the Ironton District. Phases 1 and 2 of the work were completed in April 2001.

In the 2001-2002 winter season, the USACE-Huntington District issued another work order to perform Phase 3 of the inventory, which consisted of searching 24,000 acres of Forest. These search areas extended over two new watersheds, Sunday Creek and Raccoon Creek, located within the Athens District.

DATA PROCESSING AND APPLICATION DEVELOPMENT

The Forest Service's immediate objective was to identify abandoned and inactive coal mine sites and their associated features, collect required field data, then prepare a database and merge it with the existing Abandoned Mine Land database. Once all the data is compiled, the Forest Service will work with partners including the U.S. Army Corps of Engineers, Ohio Division of Mineral Resources, EPA and OSM, etc., to identify, prioritize, propose, and fund reclamation projects, which can improve aquatic ecosystems and protect human health and safety.

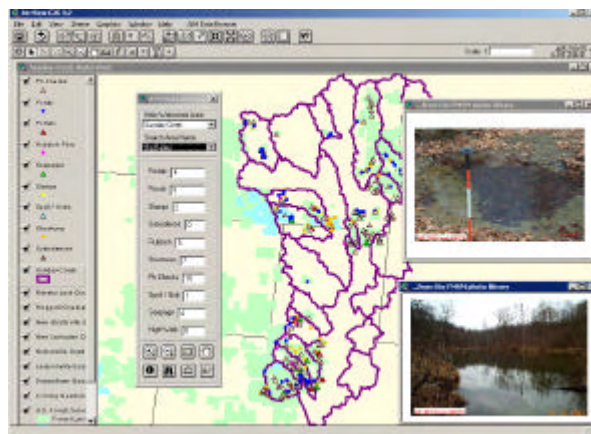
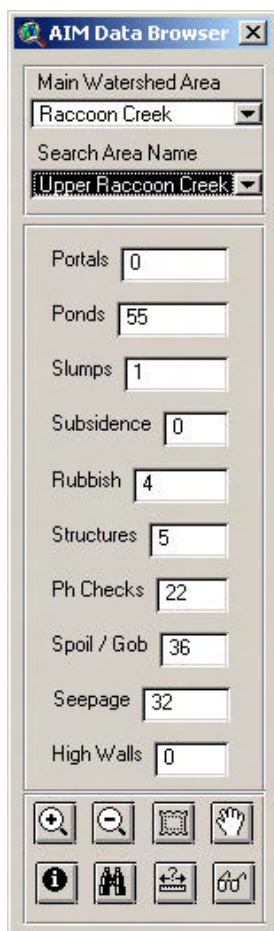


Figure 5: GIS Data Browser Application



For example, the Forest Service may need to query the database to identify certain or all open mine entries suitable for bats access, while other personnel can prioritize mine openings for closure based on their proximity to buildings, trails, or recreation areas. Or the Forest Service may decide to evaluate some or all the mine seeps, calculating chemical loadings, and making determinations of the impact each seep has to the overall water quality of the watershed. These queries may allow for the prioritization of treatment options.

Because the AIM data collected included thousands of features, with each feature characterized using several parameters, it is critical for the Forest Service to access, manage and share the voluminous database in an effective manner. Typically, the products for these inventory efforts require that contractors, such as FMSM, deliver all electronic inventory information in a standardized format and stored on CD-ROMS, which makes the management of such large database cumbersome and costly.

In order to allow the Forest Service to manage the data effectively, FMSM designed a GIS-based application specialized for user-friendly access to inventory data and maps. The Abandoned and Inactive

Mineland (AIM) Data Browser was developed as a tailored ArcView 3.x application. The application consisted of an ArcView project containing a wealth of spatial data, including: Forest Service land, locations of AIM features as identified through the inventory effort, USGS 24K topography maps, and watershed and county boundaries.

The AIM Data Browser enables non-technical users to access digital pictures, feature information, inventory statistics, and create standard map outputs using specialized templates.

Customized routines provide users flexibility for identifying AIM inventory features within sub-watersheds, querying and searching inventory attributes, viewing related digital photographs and accessing relevant statistical information.

THE CHARACTERIZATION OF THE KEMPTON MINE COMPLEX, MARYLAND AND WEST VIRGINIA, USING GIS TECHNOLOGY

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ABSTRACT

Acid mine drainage (AMD), a legacy left by pre-law coal mining (prior to the 1977 Surface Mine Control and Reclamation Act), affects miles of western Maryland waterways, including the headwaters of the Potomac River. Prior to degradation, the North Branch of the Potomac River (North Branch) supported one of the largest trout and bass fisheries in the eastern United States. The Kempton Deep Mine Complex (Kempton) is the main source of AMD impairment in the North Branch. Kempton covers more than 12 square miles, or 7,680 acres, and discharges an average of five million gallons a day of acidic water into Laurel Run, a tributary that enters the Potomac River. Since 1994, the State of Maryland has maintained six lime dosers to neutralize AMD along more than 32 miles of the mainstem of the North Branch. Trout are stocked annually and populations of native fish and macro-invertebrates have returned to the river. In 1998, the Maryland Bureau of Mines began investigating whether a more permanent technology than in-stream dosing could solve the AMD problems of Kempton. A comprehensive, in-depth investigation of the Kempton Mine and surrounding area was conducted and developed into an accurate, detailed geologic/topographic map and technical database. Geographic Information System (GIS) technology was determined to be the best approach to store, view, and evaluate the large quantities of data and information. The Kempton GIS mapping and database includes numerous features that affect and impact the Kempton discharges in Maryland. The Kempton GIS has proven to be an invaluable tool to evaluate alternative AMD remediation technologies and was developed using ESRI Arcview and its extensions, Spatial Analyst and 3D. The GIS includes all data and maps collected in the study in an easily viewed format.

KEMPTON MINE COMPLEX OVERVIEW

The Kempton Mine Complex (KMC) is an underground deep mine located in the southernmost tip of western Garrett County, Maryland and extending southwest into West Virginia (Figure 1). Henry Gassaway Davis founded this mine complex. It operated as the Davis Coal and Coke Company from 1886 until 1950 and grew to encompass 12 square miles of interconnected underground workings in the Upper Freeport coal seam. The development of this mine complex began as nine smaller mines scattered amongst six small mining towns, one of which was

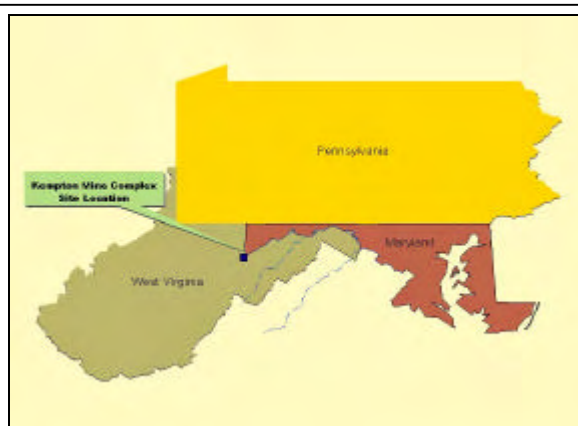


FIGURE 1 - GENERAL LOCATION OF THE KEMPTON MINE COMPLEX

Kempton, Maryland (Kempton). Between the years 1914 and 1950, approximately 650 people resided in Kempton using the mine as their primary means of support.

The Kempton portion of the mine began operations in 1914. Access to the coal was obtained through two deep mine shafts that extended 420 feet into the earth. These shafts, known collectively as Mine #42, entered the Upper Freeport at one of the lowest points of a plunging syncline. Gravity carried the water to the lowest point of the complex and pumps were then used to remove it. As the entire mine complex slowly grew, engineers were forced to deal with more water problems.

In 1950, operations ceased throughout the entire complex, as did the pumping of the water. Water built up within the void spaces of the mine and began discharging acid mine drainage (AMD). Nine AMD discharges were located in Coketon, West Virginia and drained into the North Fork of the Blackwater River, and two discharges appeared north of Kempton. By 1952, AMD north of Kempton became a major polluter to the North Branch of the Potomac River (North Branch). The North Branch is a branch of the Potomac River, a designated American Heritage River, and a major tributary to the Chesapeake Bay. The Maryland discharges from an abandoned Airshaft and Power Borehole which were used when the mine was active (Figure 2) and flows directly into Laurel Run, a tributary of the North Branch. Flows range from a minimum of one million to a maximum of six million gallons a day (mgd). In 1988, the State of Maryland began to investigate the abandoned mine complexes' impacts to the river as well as to develop a strategy that could remediate and/or abate these problems.

PROJECT OBJECTIVES

Maryland Department of Environment, Bureau of Mines (Bureau) and Maryland Department of Natural Resources, Power Plant Research Program (PPRP) launched the KMC Project in cooperation with the State of West Virginia and private industry in 1998. The overall objective was to restore the quality of the North Branch by reducing the impact of AMD discharging from the Airshaft and Borehole locations to the North Branch by “1) improving the quality and/or reducing the quantity of recharge to the deep mine and/or 2) improving the quality of the discharge from the mine pool” (Maryland Department of Environment, Water Management Administration, Bureau of Mines Environmental Protection Agency 104(b)(3) Grant #X983070-01-0). A Geographic Information System (GIS) would be developed to aid scientists in understanding the mine structure and the hydrogeology. “The visualization and computational capabilities of GIS enhance our ability to conceptualize the geometry and hydrology of the deep mine complex” (Hayes, Meiser, Lyons, pg. 1). In 1998 the Bureau was awarded \$225,000 from the United States Environmental Protection Agency (EPA) for Clean Water Act Section 104 (b)(3) monies to develop the *North Branch Potomac River Watershed Restoration Project: Investigation and Definition of the Geologic/Topographic Structure and Hydrology of the KMC*. The funding of this project allowed Bureau personnel and supporting organizations “to conduct a comprehensive, in-depth investigation of Kempton and

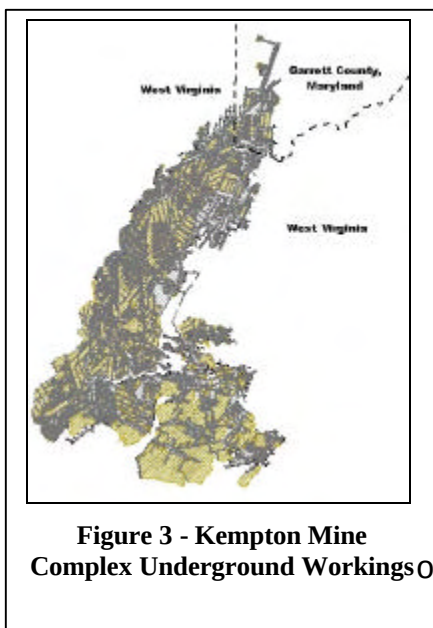


FIGURE 2 - KEMPTON, MARYLAND AMD INTO LAUREL RUN

the surrounding area” by compiling “an accurate, detailed geologic/topographic map of the entire deep mine complex and surrounding area of features that may have the potential to affect and impact the Kempton discharges, a detailed hydrogeologic report and a GIS that includes all data, maps, and relevant information tied in the course of the study, and an investigative report that evaluates and interprets the data and offers preliminary findings towards meeting the goal of reducing the acid load from the Kempton Mine” (Maryland Department of Environment, Water Management Administration, Bureau of Mines Environmental Protection Agency, Region 3, 104(b)(3) Grant #X983070-01-0).

GIS DEVELOPMENT

A crucial component in building a GIS is data collection. Detailed digital mapping (Figure 3) of the entire underground complex was provided to the Bureau by Western Pocahontas Properties, Inc. After geo-referencing this coverage to digital topographic maps, field technicians went out to the area to conduct a thorough investigation of the complex as a whole. Elements of this investigation consisted of the following:



- Baseline monitoring that included identifying and monitoring mine seeps, areas of water infiltration, and precipitation data;
- Mapping the topography, geology, and mine workings in and around the KMC including abandoned mine features such as high-walls and subsidence;
- Compiling the KMC history concentrating on areas such as water problems, drainage patterns, areas of weak mine roof, and ventilation schemes;
- Characterizing the stratigraphy and geologic structures for lineaments and fractures natural and resulting from mining;
- Defining the hydrogeology of deep mines, surface mines and surrounding areas;
- Identifying the relationship between the Upper Freeport and any overlying coal seams;

Investigating the mine and overburden geochemistry and identifying sources of alkalinity and acidity that could be contributing to the mine pool’s chemistry.

To accomplish these goals, technicians began compiling a vast amount of information. Weirs were installed at all eleven discharges (2 in Maryland, 9 in West Virginia) for regular baseline monitoring. Data from National Oceanic and Atmospheric Administration (NOAA) regional precipitation stations were obtained for comparison to the discharge levels to monitor recharge patterns. Flows were taken at all streams located throughout the KMC. Any stream that exhibited a loss was monitored on a regular basis to help identify potential surface water infiltration to the mine complex. Regional core log and coal seam data was obtained from West Virginia Geological and Economic Survey (WVGES) and many historic mine maps and records were obtained through The New Historic Society of Thomas, West Virginia. The West Virginia Department of Environmental Protection provided the Bureau with access to all recent and past problems associated with mining in the area of interest. PPRP funded the flying of low-altitude orthophotography during spring 1999, the development of topographic coverages, and the

production of hyperspectral imagery throughout the KMC. All information was incorporated into a stand-alone GIS for analysis and review. The GIS development effort was initiated in FY1998 with the final version projected for completion and submittal to the EPA by December 2002.

GIS UTILIZATION

The GIS proved to be a valuable tool in the analysis of the KMC. Spatial relationships and trends can be more easily identified using the modeling tool with various data. “Three-dimensional stratigraphic [models] and isopach maps help identify hydrogeologic features such as stratigraphic pinch outs, changes in dip, and mine pool barriers” (Hayes, Meiser, Lyons, pg. 2). Organized databases can be integrated into a GIS so that coverages in the forms of points, lines and polygons can be developed. The organization chose to use ArcView® Version 3.2 in conjunction with the Spatial Analyst and 3D Analyst extensions for the GIS platform.

The first phase in the development of the GIS was to characterize the geology of the mine complex in orientation to overlying and surface features. Specific areas of interest were the “regional geologic structure of the coal seam; [the] precise locations of underground mine workings; [the] degree of coal extractions; [the] locations of coal outcrops; and [the] proximity to overlying coal seams that have been mined” (Hayes, Meiser, Lyons, pg. 3). Using the geo-referenced digital mine layer and the detailed structure contours for the Upper Freeport coal provided by WVGES, it was possible for GIS technicians to create a 3-dimensional model of the workings to depict their true orientation and to help identify any remaining coal barriers that still exist within the KMC and the coal elevation to which it extends (Figure 4). This digital 3-dimensional model also helped guide scientists in predicting flow patterns and paths throughout the mine workings. The Bakerstown coal seam lies approximately 180-200 feet above the Upper Freeport coal seam and was also extensively mined. Structure contours and mine extents for the overlying Bakerstown coal were draped on this model and coal outcrop lines for both seams were digitized and plotted.

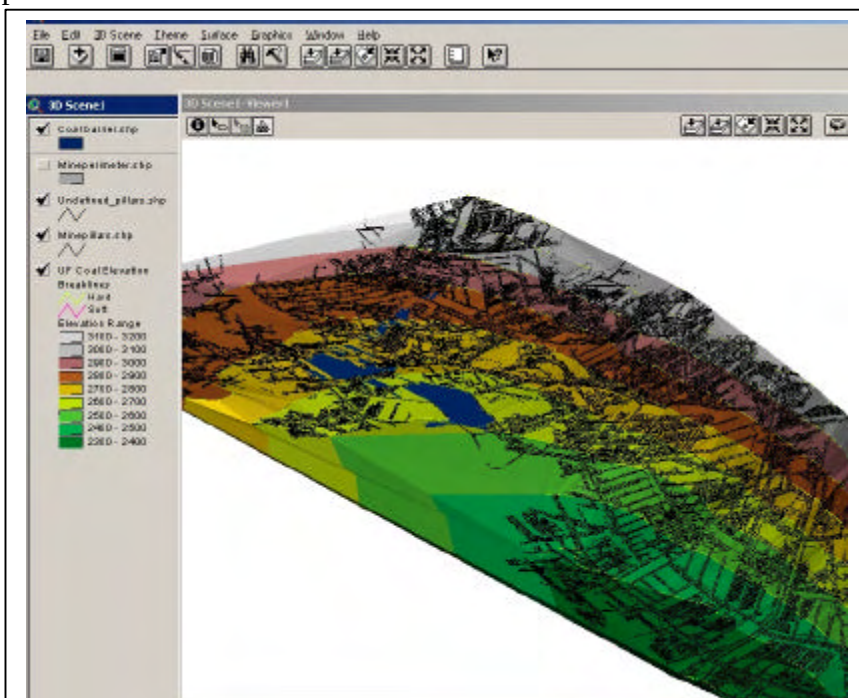


Figure 4 - 3-Dimensional Model

After the geologic visualization of the KMC complex was completed, the ability to look for hydrologic relationships between the underground mine and its overburden was enhanced. Using GPS positions of all the AMD discharges from the complex, elevations were established for the discharges at both ends of the complex. These elevations are representative of the pool

elevations in the underground complex. Once the elevations of the discharges were known, they were compared to the elevation of which the coal barrier extended and it was determined that two separate mine pools must exist within this underground complex. Plotting these points onto the KMC model allowed a GIS technician to extrapolate the pool coverage as it would exist in the mine (Figure 5) and calculate the total area of flooding in each pool (Table 1).

Table 1: Characteristics of the portion of the Kempton Mine Complex Underground Pool Flowing to Maryland and Impacting the North Branch of the Potomac River

Pool Name	Discharge Elevation	Total Area of Recharge (acres)	Portion of Area Flooded (acres)	Percentage of Flooding	Average Flow
Kempton Pool	2652	5100	1890	35%	2700 GPM

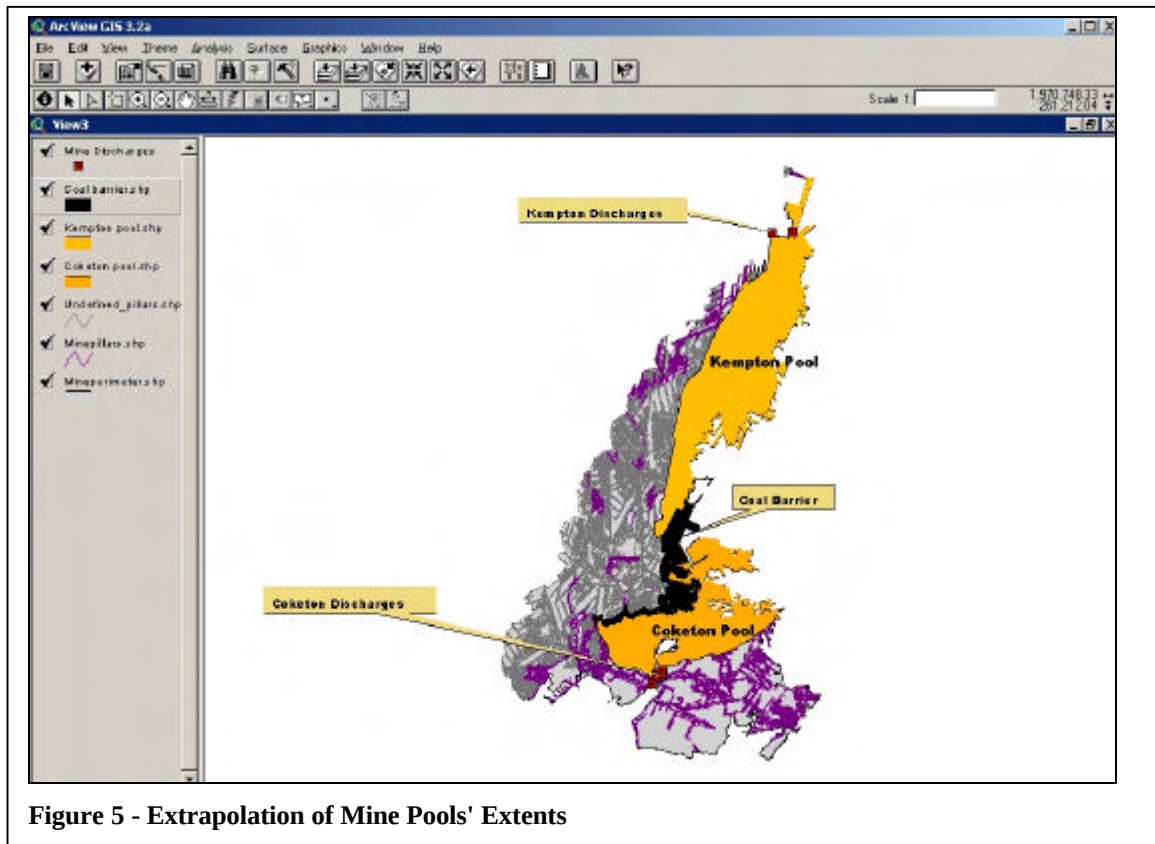


Figure 5 - Extrapolation of Mine Pools' Extents

Flows that were taken at the weirs were plotted against daily precipitation data collected from surrounding NOAA monitoring stations. These plots appeared to show a direct correlation of increases in discharges to rainfall events. Using a GIS buffering function, a buffer zone of 50 feet was calculated around both the coal outcrop and the streams (Figure 6). The intersection of these calculated 50-foot buffers were highlighted and used to determine specific areas of concentration for field personnel. Streams that exhibited losses at these targeted zones were part of a routine sampling plan. Flows were taken above and below the outcrop/stream intersection zones at three streams that show signs of loss on a regular basis.

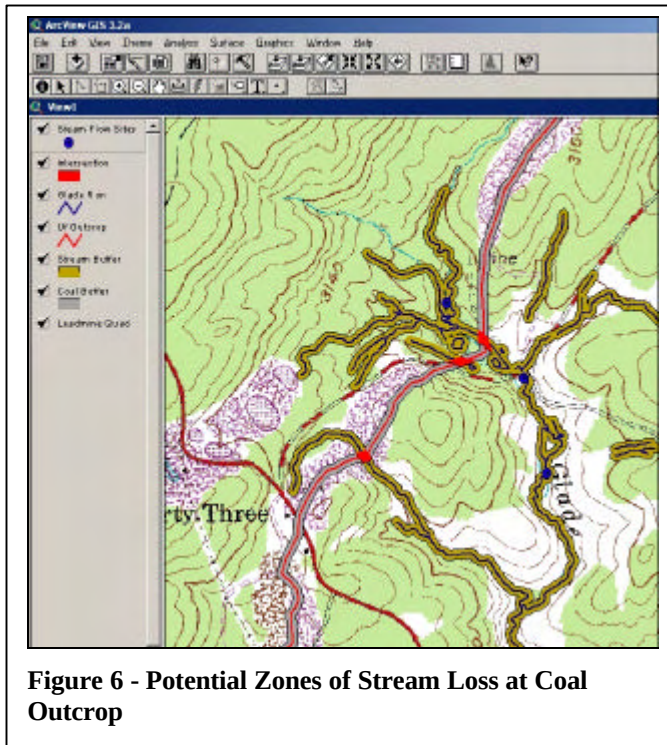


Figure 6 - Potential Zones of Stream Loss at Coal Outcrop

Another topic of interest pursued when examining the interconnectivity between the mining complex and the surface water was in areas that show evidence of subsidence on the ground surface. Using the GIS Spatial Analyst extension, technicians used ground elevation and coal elevation contour shape files to produce grids of the spatial coverage. Grids are raster-based data that store a numeric data value for each cell useable during analysis and calculations. These grid-projected elevations were subtracted from one another to produce a depth-to-coal layer. This layer helped technicians identify areas of shallow overburden throughout the KMC that could be affected by subsidence. Thickness maps were produced and taken to the field for reconnaissance of the

suspected areas. Large plots of area that exhibited the classic signs of subsidence (terrain features uncommon to the area, out-of-place depressions, odd vegetative disturbances) were GPS'd and plotted onto the thickness layer for review (Figure 7). All of the areas plotted fell within the tolerance range to be considered possible subsidence of the overburden into the KMC.

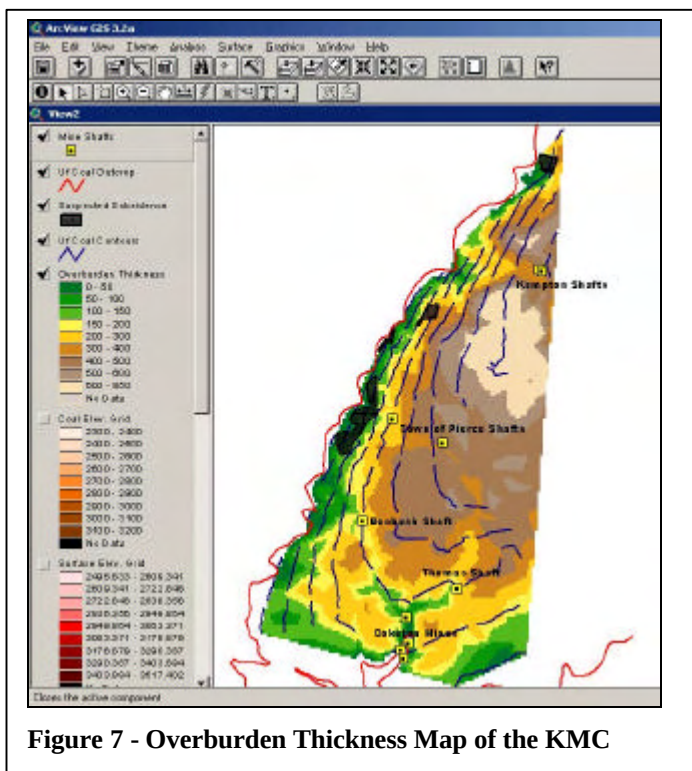


Figure 7 - Overburden Thickness Map of the KMC

COMPLEXITY OF DEVELOPMENT

The complexity of the development of this GIS involved many steps and many organizations. The Bureau worked with the EPA, PPRP, and WPP to investigate this problem. Bureau and PPRP employees worked with individuals at Frostburg State University, Geospatial Research Group (GRG) on a regular basis to conduct field studies and collect all possible field data needed to launch this project. Meiser and Earl, Inc. and Dr. Benjamin Hayes from Bucknell University provided the Bureau with the initial development of the GIS technology using ArcView® 3.2 and the extensions 3D and Spatial Analyst. GRG employees used the basic GIS and built it into a working system as described in the EPA work plan.



Figure 9 - Kempton Mine Tipple

forms of data are historic mine photos (Figure 8), old and GIS generated maps, digital aerial photography (Figure 9), and water quality data collected at the weirs and in the streams.

The Bureau refined the GIS produced by GRG and worked with Meiser and Earl, Inc. and Hughes-Martin Ink to finalize the product into an organized, powerful tool for the visualization and the analysis of the KMC. The structure of the GIS was built in a logical system of nine files that contained numerous folders: Base Map Features and Images (37 folders), Drill Logs (4 folders), Geology (30 folders), Hydrology (53 folders), Layout Boundary (1 folder), Mining (52 folders), Project Images (0 folder), Project Posters (0 folder), and Water Quality Tables (4 folders). This filing system was used to break up the information into general topics and then break down those

The GIS was built to provide users with the capabilities to analyze and model using “real” field collect information. Examples of the many



Figure 8 - Kempton Complex Aerial Photography

topics into reasonable folders of similar information. Not only is the information organized, but also a user has the capability to navigate throughout the GIS in a logical and systematic way.

Throughout this project, the GIS proved to be an extremely powerful tool in both the visualization and the analysis of the KMC. Without all the cooperating parties it is unlikely that this project would have come together as well as it did. As expected in a project this size, problems did arise bringing the information together. However, with the commitment of all participating individuals to complete the work, the project has been a remarkable success.

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TECHNICAL PAPER SESSION 8
EDUCATION AND SAFETY

Title: [Abandoned Mine Safety and Reclamation Education Materials Development Projects](#)

Authors: [Edward A. Dalton](#)*, Ed.D., President and CEO, National Energy Foundation

ABANDONED MINE SAFETY AND MINING RECLAMATION EDUCATION MATERIALS DEVELOPMENT PROJECTS

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ABSTRACT

The National Energy Foundation (NEF), as an outgrowth of the Utah Mineral Resources and Mining Education program identified a need for additional supplementary educational resources that could be used by teachers and students to enhance and enrich classroom instruction. As a consequence, NEF initiated and is carrying out the development of two instructional posters and primers dealing with Abandoned Mine Safety and Mining Reclamation. NEF has conducted research, prepared the materials in phases, and is currently distributing the materials in teacher training workshops and directly to teachers in a variety of ways. The reclamation phase was completed first, the abandoned mine safety component is presently under development and will be completed prior to the NAAMLPS Conference.

The project has been extremely well received by the education community and directly relates to the work of the National Association of Abandoned Mine Land. NEF proposes to describe the materials development process including design and methods. We will explain and distribute items that have been made and show how they are used and explain additional implementation and distribution opportunities. We also intend to share other findings and experiences that have occurred as a result of this project.

This project is one of the family of *Out of the Rock* Education Program activities. *Out of the Rock* is the nation's premiere Mineral Resources and Mining Education program.

INTRODUCTION: ABOUT THE NATIONAL ENERGY FOUNDATION

The National Energy Foundation is a unique 501 (c) 3 non-profit educational organization dedicated to the development, dissemination, and implementation of supplementary educational materials, programs, and courses. These resources for education relate primarily to energy, water, natural resources, science and math, technology, conservation, and the environment and all enrich and enhance teaching and learning. They recognize the importance and contribution of natural resources to our economy, national security, the environment, and our quality of life.

NEF is devoted to the implementation of a variety of innovative teacher training and student programs. The NEF Academy offers several university graduate credit independent study courses developed for K - 12 school teachers. The Foundation, supported by the education community, businesses, government agencies, and associations, has more than two decades of expertise in carrying out educational partnerships.

NEF has become a national leader in forming "partnerships" on behalf of teachers, students, and the education community with a wide variety of businesses, associations, educational institutions, and government agencies.

Energy and natural resources directly impact our environment, our nation, and the world. It is important that the population, especially teachers and students, be educated about the social, economical, political, technological and scientific implications of energy, natural resources, and

environmental choices. NEF strives to achieve this in a responsible, balanced, and objective manner.

NEF's MISSION

The mission of the National Energy Foundation is to provide teaching and learning opportunities, which promote a better understanding of energy, other natural resources, and the environment.

In order to achieve this end, NEF will...

- Provide opportunities for businesses, associations, government agencies, and the education community to participate in the improvement and enhancement of education.
- Develop, produce, and provide cost-effective and affordable supplementary instructional materials about natural resources to aid educators in the teaching process.
- Conduct a wide variety of motivational teacher, employee, and student training programs.
- Provide teachers and students with incentives to participate more intensely in the teaching and learning process.
- Provide support and consultation to sponsors.
- Grow the Foundation in a manner such that it will prosper sufficiently to achieve its mission.
- Carry out an on-going strategic planning process with accompanying financial information, which will be used to prudently manage and administer the Foundation.

NEF SPONSORS AND PARTNERS

Over the years, NEF has provided services and materials to a diverse, numerous variety of satisfied customers. More than 300 public and private electric and water utility companies and over 250 natural gas utility companies have purchased NEF programs, materials, courses, and services as do many, many more schools and individual teachers. Many NEF sponsors also include state energy offices as well as public and private schools, universities and school systems.

PROGRAMS AND SERVICES

NEF believes that education empowers people to achieve at higher levels. This is done through understanding and the application of knowledge, skills, and experience. NEF empowers teachers and learners to take positive action regarding valuable resources.

Custom Programs

Instructional materials are extremely important in teaching and learning, but it is training that intensifies the amount, intensity, and level of implementation. That's why NEF provides a variety of customized teacher training programs. These workshops, conferences, and institutes or "families" of them, are developed and carried out in particular geographic regions. Custom programs include a coordinator, facilitators and implementation committees, instructional materials, evaluation, reporting, etc. Each "program" lasts approximately one year and is usually extended over longer periods of time. Custom programs have been one of NEF's dominant strengths for more than two decades.

Custom Workshops

NEF develops and conducts teacher workshops on a variety of specific natural resource topics or for participating groups of educators. Workshops may be anywhere from a few hours to several days in length depending on the need. Workshops include instructors, materials, field experiences and usually carry graduate credit.

NEF also conducts a variety of other programs such as debates, field trips, student expositions, and competitions and other motivating and inspiring teacher and student programs.

NEF Academy

The Academy is a department within the Foundation that provides a variety of diverse services. Independent study courses are carefully developed to comply with the rigorous academic requirements of accredited universities. Once certified, Academy courses are made available to teachers directly or with corporate scholarship support. Teachers can earn either one or two semester hours of graduate (600 level) credit by satisfactorily completing the approved course.

Custom Services

NEF also provides a variety of custom services including instructional materials development services to meet exacting needs and specifications. NEF custom prints select instructional materials and conducts its unique fulfillment and distribution process in specific geographic regions. The Foundation also provides consultation and assistance services based on our experienced and competent personnel. NEF also develops, maintains, and conducts educational programs for sponsors using the World Wide Web.

Resource Action Programs

Resource Action Programs provide not only instructional materials but also actual technologies to put learning into practice. NEF's RAPs frequently include school-to-home and school-to-work learning experiences. They are also rich in service learning opportunities. Several specific resource action programs are presently available. These include:

Resource Action Pack (Energy Action Patrols or Teams, Living Wise, graduate credit, and the Energy Action Challenge bundled nicely as a school-wide and school-to-home resource action program); Living Wise, NEF's newest and most sought after program, Learning to Be Water Wise , the finest technology based water conservation program available; Energy Action Patrols - one of NEF's most popular programs; Energy Action Teams, and NEF's new and fun Energy Action Challenge.

The action-oriented focus of these amazing programs helps relate behavioral change (learning) to science and technology learning activities, enabling students to actually see and measure how their habits and knowledge can affect the world around them.

These educator-developed programs are built on 26 years of proven development practices, strategies, and materials. They have been extensively field-tested and are widely used.

NEF ACCOMPLISHMENTS

During the past two decades NEF has...

- Distributed well over of a half million instructional posters through journals of the National Science Teachers Association (NSTA).
- Conducted teacher training sessions for over 50,000 teachers.
- Provided more than 4,000 university graduate credit courses through the "NEF Academy."
- Established a nation-wide materials distribution (fulfillment) program now reaching more than 8,000 teachers each year in 46 states.
- Conducted classroom educational programs for nearly a half million students annually, including such popular NEF activities as debates, field trips, competitions and expositions.
- Collaborated in major materials development, distribution, and implementation project alliances with several hundred sponsors from government, industry, associations, and the education community.
- Created and implemented the Igniting Creative Energy Challenge throughout the United States and Canada.

NEF RECOGNITION

NEF has received numerous national energy and environmental education awards from organizations such as the US Department of Energy, The US Bureau of Reclamation's Water Conservation Award, Texas Governor's Clean Texas 2000 Award, and Learning Magazine's Teacher's Choice Awards. NEF has twice been awarded the National Energy Resources Organization's Public Education Award. In 2002, NEF was awarded the "Spirit of the Land" environmental education award by the 2002 Salt Lake Olympic Committee for NEF's outstanding efforts in energy, water, and mineral resources education.

INSTRUCTIONAL MATERIALS

NEF's supplementary materials for teachers, students, and the education community are among the finest in the nation. NEF has developed an extensive collection of unique, educator-developed, classroom-tested instructional materials. These include a multitude of:

- integrated learning activities for grades K - 12
- instructional posters (44 presently available)
- frameworks, glossaries and guides
- kits, videos, CDs, totes, and shirts

NEF is the nation's premier, full-service provider of natural resources-related materials, courses, programs, and services.

OUT OF THE ROCK PROGRAM AND FAMILY OF MATERIALS

During the past few years, the Out of the Rock program has become the premiere mineral resources and mining education program in the nation. It includes a wide variety of educator developed, classroom tested instructional materials. These include the Out of the Rock Teacher's Guide, which includes several sections such as the introduction, from the ground up, supplemental resources, mineral resources glossary, and the unique conceptual framework.

It also includes more than one hundred integrated learning activities designed by grade level. Instructional videos, computer software, T-Shirts / Tote Bags.

Instructional Posters include Mountains to Metals, Mountains to Metals – Spanish version, Rocks and Minerals, Rocks and Minerals – Spanish version, From The Mine To My Home, Aggregates: Nature's Building Blocks, Coal Technology: The Future is Now, Petroleum Technology, Construction Materials and now the Mining Reclamation and Active and Abandoned Mine Safety posters.

Primers include Minerals and the Mining Industry, Coal, Oil, Natural Gas, Water, and Mining Reclamation, and Active and Abandoned Mine Safety.

Training Programs

NEF also conducts a variety of professional development courses and training programs to complement and extend the use of these materials. It has been found that excellent materials coupled with teacher training results in more implementation and implementation over a longer period of time.

RESPONDING TO NEEDS AND FILLING THE GAPS

The Out of the Rock program resulted in the development of a wide range of Mineral Resources and Mining Education materials. They have been embraced and extensively used in select communities, particularly in the West and Mid-west. Through teacher training and additional educator and industry input, it was determined that some additional materials development and distribution was needed. Particularly, on the topic of mining reclamation and active and abandoned mine safety.

It was also felt that instructional materials that would provide instruction about these topics through music should be developed. NEF proceeded to create the "Rock Music" CD and instructional materials to meet this need.

MINING RECLAMATION AND ACTIVE AND ABANDONED MINE SAFETY EDUCATION

After extensive development and implementation of the Out of the Rock program, it was determined that a couple of significant topics needed further development and concentration. These topics included Mining Reclamation and Active and Abandoned Mine Safety.

Plans and strategies were developed, support sought and the projects initiated in phases. The first phase included the development of an instructional poster and primer dealing with Mining Reclamation, the second phase the development of instructional posters and primers dealing with mine safety. Mine safety would also include the production of the instructional poster in Spanish as well and English.

NEF proposed to create beautiful full-color 23" X 35" posters specifically illustrating important mining reclamation and active and abandoned mine safety concepts and practices. The posters were to be similar to several other posters created by NEF. NEF has developed more than forty instructional posters dealing with numerous mineral resources, water, and energy topics. The poster was also to be printed on the backside with additional information and activities for educators.

PURPOSE OF THE PROJECT

There are several important reasons that such a project was needed. Most importantly, teachers, students, and the general public need to know more and understand the importance of mining reclamation and abandoned mine safety. The importance of informing and educating young people and their families is essential. People need to know what is being done to return mined land to beneficial uses. It important they understand that staying out of active and abandoned mine areas could mean staying alive. There are serious problems every year and this message needs to be broadcast loudly in a variety of ways. It was anticipated that these instructional posters would penetrate deeply into schools throughout the nation. Good education in this regard is good business.

UTILILIZATION OF EDUCATIONAL RESOURCES

The posters would have many uses but they were primarily being created for teachers, students, and the general public. They could also be used for home schools, lapidary clubs, recreationists like snowmobilers and 4-wheeler riders, etc. Posters are also being used in libraries and community buildings, at visitor centers, with tourists, and in a variety of public and community relations ways. The posters were intended to be helpful to every state mining reclamation and abandoned mines safety program. They can be used in teacher workshops. They can be given to visitors who inquire about mining reclamation and active and abandoned mine safety state programs when visiting visitor centers or in other ways.

ROLES OF SPONSORS

Project sponsors are important in several ways. The posters need guidance and direction from a technical standpoint. Sponsors also help promote the project with other interested organizations.

PROJECT BENEFITS

It was anticipated that organizations would obtain many benefits by sponsoring and collaborating with this educational project. These would include recognition on the back side of all posters, acknowledgement in magazines, recognition by other organizations, agencies, and businesses who may obtain the posters for distribution in other parts of the country, low prices for posters in the future, and well developed instructional materials devoted specifically to communicating the importance of mining reclamation and active and abandoned mine safety.

FINDINGS AND RECOMMENDATIONS

Sponsor support and participation has been commendable. It has been difficult to obtain, but sufficient to carry out the projects. The projects have been and are being completed on time and within budgets. The support of the National Science Teachers Association has been outstanding. The first magazine insert was extremely well received. The mine safety poster is now scheduled for distribution in the April issue of *Science Scope* magazine.

It is recommended that the project be continued and shared with other interested individuals and organizations. These materials can be of great help to many organizations.

THE FUTURE

Completion of this phase of Out of the Rock will result in welcome and highly usable new instructional materials. The challenge is not so much in making materials, but in seeing that they get into the hands of teachers, students, and the public who can use them.

We urge you to consider ways you can extend the reach of this great program. How can you use these materials within your circle of influence? Join us in reaching out to educators everywhere and help this project reach it's full potential.

**TECHNICAL PAPER SESSION 9
GEOGRAPHIC INFORMATION SYSTEMS - PART 2**

Title: [GIS-based Statewide Inventory for Wyoming](#)

Author: [Chris Arneson](#)*, GIS Hydrologist, TriHydro Corp.

Title: [GIS as a Prioritization and Planning Tool in Abandoned Mine Reclamation](#)

Authors: **Megan Southwick**, Reclamation Specialist, **Daniel Smith***, GIS Programmer;
and [Chris Rohrer](#), Senior Reclamation Specialist, Utah Division of Oil, Gas & Mining

Title: [Use of Integrated GPS and GIS Systems in Mine Reclamation](#)

Author: [Oliver P. Wesley](#)*, P.E. and **Alan G. Steckelberg**, Managing
Partners, Opal Group, L.L.C.

Title: [Developing Abandoned Mine Lands](#)

Author: [John Husted](#)*, Ohio AML Program Director

GIS-BASED STATEWIDE INVENTORY FOR WYOMING

Chris Arneson, TriHydro Corporation, Laramie, WY 82070, carneson@trihydro.com
Evan Green, Wyoming Dept. of Environmental Quality, Abandoned Mine Lands Division,
Cheyenne, WY 82001

Jack Bedessem, TriHydro Corporation, Laramie, WY 82070

ABSTRACT

The Wyoming Department of Environmental Quality Abandoned Mine Lands Division (WDEQ/AML) required a comprehensively updated statewide database and an efficient method of accessing, querying, and utilizing this information for project management, budgeting, and decision-making purposes. A customized Geographic Information System (GIS) application was envisioned and developed to serve as a user interface to WDEQ/AML's MS Access database, which was subject to updating through an ongoing inventory project. This application was built in an ArcView GIS software environment, which provides users with an up-to-date status of AML sites, a user-friendly query system, a single interface for digital site data, relevant site background information (hazards, ownership, mineral, costs, etc.), and a structure for future data.

Spatial coordinates for sites were created from newly acquired GPS coordinates and supplemented with historic legal descriptions. These spatial coordinates were used to generate GIS layers, which can change daily "on the fly" from the current database. Using custom forms and SQL queries, a menuing system was created that allows querying of sites based on a variety of information.

Additional GIS layers including digital USGS quadrangles (DRGs), roads, elevation, and aerial photography are scale-dependent and added to the project automatically as a user zooms in. Custom programming has also been added to the project to allow the "linking" of other types of non-GIS data to the individual sites, including GPS files, photos, scanned field notes, CAD construction drawings, and other digital files.

WDEQ/AML personnel are able to add new files (photos, GPS, etc.) to the specific site directory and immediately have that information accessible within the GIS. Future plans for the project call for integrating additional types of data (site characterization data, reclamation design drawings, construction as-builts, etc.) as it becomes available. The addition of this supplemental site information creates a true electronic archive and library tool for project management.

INTRODUCTION

The Wyoming Department of Environmental Quality Abandoned Mine Lands Division (WDEQ/AML) required a comprehensively updated statewide database and efficient method to store, retrieve, access, and query pertinent AML site data. To accomplish this task, the existing WDEQ/AML database was updated and redesigned to meet 3 major requirements:

1. Store data generated by ongoing inventory activities and incorporate this information and site data from previously inventoried sites into the WDEQ/AML data base;
2. Use a Geographic Information System (GIS) to create a user-friendly interface, supply query-friendly, real-time location and site-specific information; and
3. Export data to the Office of Surface Mining's (OSM) Abandoned Mine Land Inventory

System (AMLIS) and the Bureau of Land Management's (BLM) abandoned mine database in order to streamline management and funding for reclamation projects.

The project was envisioned to provide WDEQ/AML project managers with an easy to use tool that would enable them to access information about abandoned mine sites quickly. In a state where the ratio of abandoned mine sites to project managers is approximately 500:1, it is critical to properly organize and maintain any existing information about these sites. After researching progress in other states, WDEQ/AML and its database contractors determined that a well-designed database/GIS could ensure that information about individual sites is properly archived and that projects can be more efficiently managed. Also, new agency employees experience a shorter learning curve developing familiarity with the complexities of AML work in Wyoming.

Between 2000 and 2001, AML project teams conducted site visits at priority-abandoned mines throughout the State. As a part of this effort, Lidstone and Associates of Fort Collins, Colorado, the prime inventory contractor, visited and documented approximately 1,013 sites in Wyoming. Field forms, Global Positioning System (GPS) receivers, and digital photographs were used to document current conditions as well as to estimate reclamation costs. WDEQ/AML estimates that an additional 1,500 sites will be inventoried and incorporated into the database in future years. Lidstone and Associates subcontracted with TriHydro Corporation of Laramie, Wyoming to design and program an updated database and create the GIS application.

DATABASE STRUCTURE

A database structure was designed to include information from past surveys and site visits, meet current departmental organizational and query needs, and contain all necessary information for both the BLM and OSM databases. The MS-Access database was revised to consist of a series of linked tables, input forms, and custom reports. The database included information about location of the site, background information, hazards, land ownership, recommended remediation needs, and a reclamation priority assessment. Legal descriptions (township, range, and section locations) were used in a GIS routine to derive latitudinal and longitudinal coordinates for 3,300 existing AML inventoried sites. Using these coordinates, additional database fields were populated from publicly available GIS layers including County, Hydrologic Unit Codes, USGS 1:24,000 quadrangle sheet names, planning unit names, and land ownership. Export tools were created in Access using Visual Basic for Applications (VBA) to create output tables designed to mesh with AMLIS and BLM's database when updates to those databases are necessary.

GIS STRUCTURE

The custom GIS application was developed in ArcView GIS Version 3.2 and was designed to directly link to the MS-Access database (Figure 1). By leaving WDEQ/AML's Access database intact and simply linking to it with the GIS, several goals were achieved. First, a complex database structure using linked tables, defined ranges within fields, field aliases, validation rules, and custom import forms was possible. Secondly, data can be input, updated, and viewed by users without GIS software available. Finally, site data was maintained in only one location reducing the possibility of software version problems. The GIS application provides users with an "always up-to-date" status of AML sites, a user-friendly query system, a single interface for digital data applicable to a given site, relevant site background information (hazards, ownership, minerals, costs, etc.), and a structure for pertinent future AML site-specific data.

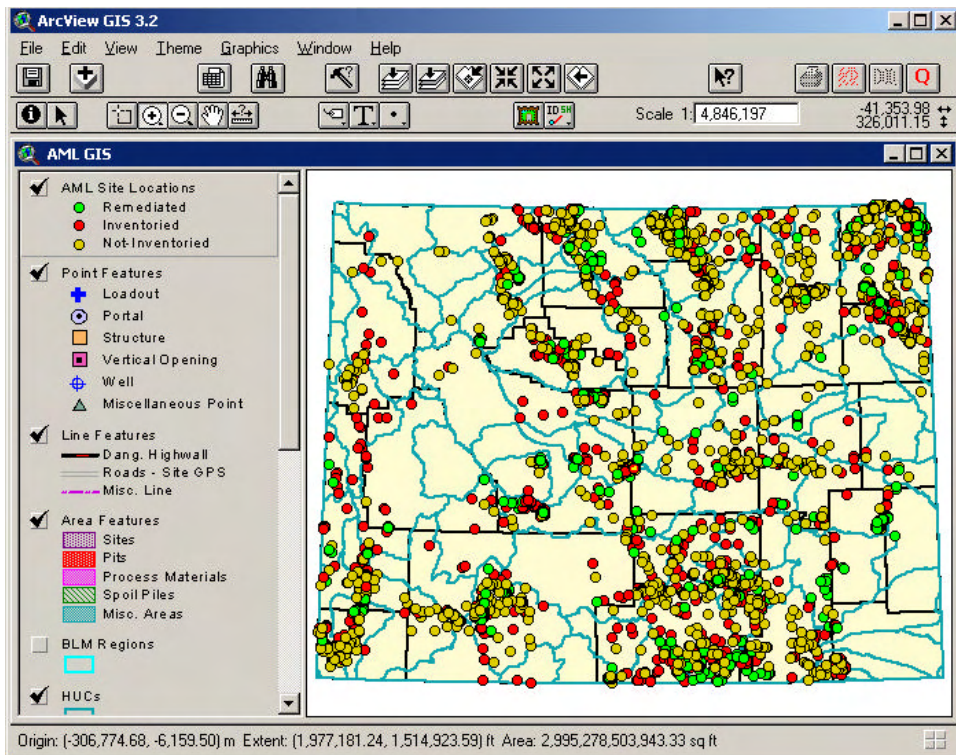


Figure 1: AML GIS Interface

The GIS interface has several key features including a broad suite of publicly available statewide data such as scanned USGS quadrangles at 3 scales (DRGs), aerial photos (DOQQs), streams, roads, watersheds, land ownership, township/range/sections, and counties. Custom programming allows the application to change map projections seamlessly throughout the State. The GIS layers have been designed to be scale-dependent so that the user views only appropriate data for the current view scale. As the user identifies an AML site of interest and zooms to a more local scale, additional GIS layers including digital USGS quadrangles (DRGs), detailed roads, elevation layers, and aerial photography are added to the view automatically.

Finally, the GIS creates an “up-to-minute” layer of AML sites by querying the database each time the GIS is opened. This technique provides users with an “always up-to-date” status of AML sites on which a user-friendly query system can be driven. Using custom forms and SQL queries, a menu system was created which uses custom forms and SQL queries to allow for the querying of mine sites based on a variety of information (Figure 2).

Each site in the State has its own directory, so custom programming will allow the “linking” of other types of non-GIS data to the individual sites such as GPS files, photographs, scanned field notes, CAD construction drawings, and other digital files (site characterization data). In each situation the GIS executes an external piece of software to open the data (e.g. MS-Word or Acrobat to open a report) therefore adding simplicity to the program. WDEQ/AML personnel are able to add new files (photos, GPS, CAD, etc.) to the specific site directory and immediately have that information accessible within the GIS. The addition of this supplemental site information provides a true electronic archive and library tool for project management.

Figure 2: Custom Query Window

CONCLUSIONS

Ultimately the database/GIS combination produced in this project will continue to revolutionize the way work is conducted at WDEQ/AML. The application has already been used to prioritize project sites, based on criteria such as hazards, mineral type, proximity to population areas, and locale. All WDEQ/AML project managers have expressed an eagerness to embrace the product particularly for establishing future budgets, setting up monitoring programs, and tracking reclamation progress.

Work continues to integrate site-specific reclamation/remediation plans into the statewide structure and incorporate improvements. The physical locations and structure of the GIS/database are currently being refined through policy. Separate copies of the GIS application, GIS data, and AML database currently exist at each WDEQ/AML field office. While this structure has advantages in that no network connection is required, it also limits the department's ability to real-time edit the database. Currently quarterly updates are conducted on-site at each field office. Efficiencies may be realized by employing a more network-reliant structure.

FUTURE PLANS

As reclamation/remediation design and site characterization data becomes available it will be added to the GIS application. TriHydro Corporation is currently conducting a pilot effort to create a GIS-based final reclamation/remediation design report for the Sunset Pit in central Wyoming. While functionality currently exists in the project to link and view CAD engineering drawings with a shareware CAD viewer, future goals call for embedding engineering plans within the GIS so that project managers can see proposed topography related to current conditions and analytical sampling data.

Additionally, plans for the project call for the GIS application to be ported to the ArcView 8.3 or 9.0 environment using VBA as its core development tool. Current versions of the ArcView 8.x technology lack the core functionality that was used to develop the project in the 3.x environment. Finally, Wide Area Network (WAN) functionality may be employed in future releases so that a single version of the WDEQ/AML database will reside at a central State-operated server with the field office GIS applications querying remotely. Static GIS layers such as aerial photos, USGS quads, and base layers, may still reside locally in the field office to reduce bandwidth transfers.

GIS AS A PRIORITIZATION AND PLANNING TOOL IN ABANDONED MINE RECLAMATION

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ABSTRACT

The Utah Abandoned Mine Reclamation Program has developed a new GIS model for selecting reclamation project areas. The selection process utilizes three main factors that would influence the potential hazard for mining areas. These factors include known mining activity or mineral resource occurrence areas, the population density in proximity to the mining areas and the potential access to the mining areas.

Mine closure priorities should be ranked according to the degree to which the public is exposed to the dangers associated with abandoned mines. The first step in ranking mines for reclamation is to know where they are or where they are likely to be based on potential mineral resource locations. Known mines and the density of those mines received a higher ranking in the model than potential mining areas or mineral resources. The data sets used in the mining component include Computerized Resource Inventory Base (CRIB), gilsonite veins, phosphate deposit areas, locatable mineral occurrences, historic mining district and un-patented mining claims.

The second ranking criteria we use to prioritize abandoned mine closures is the mine's proximity to population centers and the density of the population area. We assumed that mines located near densely populated areas receive greater visitation than mines located far from population centers. The population component of the model uses the census data from 2000.

The third major component of the ranking model is access to the mining areas. The easier a mine is to get to, the more likely people are to visit it. Thus a mine's proximity to a high density of roads significantly contributes to its hazard potential. A roads data set was used to determine the potential access to a mining area. The mining activity, population, and access components were combined to determine which abandoned mines pose the greatest potential risk to the public. The model is then used to generate a map of all areas above a certain hazard-rating threshold. The composite score for each of these areas determines its rank. Thus using GIS, the Utah's AMRP is able to focus abandoned mine reclamation efforts in those areas which pose the greatest threat to public safety.

WHY WE CREATED THE GIS MODEL

In order for the Utah Abandoned Mine Reclamation Program (UAMRP) to achieve primacy under Surface Mining Control and Reclamation Act (SMCRA) it had to have an approved plan outlining its policies and procedures for implementing the act. One significant requirement of the plan was a section detailing how abandoned mine sites would be ranked and selected for reclamation.

The approach the UAMRP took in 1982 looked at the “badness” of a mine site (and its priority for reclamation) as a function of the number and type of problems at the site and the likelihood that people would encounter them. This in turn was a function of the population near the site and the accessibility of the mine to that population (as inferred from the distance, degree and type of road development). Mines would be scored numerical values based on their site features, proximity to people, and accessibility, and ranked by their scores.

When the plan was written in 1982, the UAMRP fully expected the process to be automated. The approach anticipated a GIS, but the available GIS software at the time was rudimentary and cumbersome. GIS-type operations, such as scoring the population within a specified radius of a site, were done manually (by placing a template over a map and consulting census tables). Besides being crude and slow, this necessitated breaking data types into coarse categories or ranges. Nuances in the data were lost and the scoring became a “point in time” snapshot that was not easily updated as conditions changed.

The UAMRP ranking system depended on field inventory data for its scoring. It was originally conceived as working from a data pool with complete or nearly complete statewide field inventory data. In actual practice, the UAMRP could not complete a statewide inventory in a meaningful timeframe (the working estimate is that there are 20,000 abandoned mine openings in the state). The UAMRP proceeded with reclamation as it continued its field inventory effort. Construction projects were selected from the pool of available field data, but since the field inventory generally advanced only a year or two ahead of the construction, the choice of areas to inventory was becoming the *de facto* selection of construction projects.

By the late 1990s it became increasingly clear that the UAMRP project ranking and selection process needed refinement. The underlying philosophical assumptions of risk being a function of features, population, and accessibility were still considered sound, but there needed to be a more systematic application of the ranking and selection principles to the selection of field inventory areas. This required a suitable body of data from non-field sources to work with. Fortunately, advancements in GIS over the years had made such data available and had provided an automated system in which to analyze them conveniently.

By the mid to late 1990s, most of the coal work had been completed and more and more non-coal projects were being targeted. The basic nature of non-coal is that it is more appropriate to rank aggregations—treat groups of mines or regions as ranking unit rather than individual mine openings

THE CONCEPTUAL FORMULATION OF THE GIS MODEL

How the model developed. What we thought we’d want in the model. What we ended up with in terms of available data.

We began formulating a conceptual GIS model to rank and prioritize abandoned mine site areas for reclamation by creating a list of all the spatial datasets we could envision that would give us an indication as to where abandoned mines exist and which of those mines pose the greatest threat to public safety. The following are examples of what we came up with:

Where mines exist:

- CRIB/UMOS
- Mining claim locations
- Mining district locations
- USGS map adit and shaft symbols
- Geologic map (favorable host rock/veins/alteration zones)

Factors increasing public safety hazard of mine site:

- Accessibility (Roads, ATV trails, Hiking trails, etc.)
- Proximity to population centers
- Proximity to recreation areas (State Parks, National Parks, National Monuments and National Recreation Areas, etc)
- Hunting/Sportsman visitation
- Proximity to Tourist destinations
- Use by OHV recreationalists

The next step was to determine what if any data existed as statewide digital data sets. In Utah we have a state agency Automated Geographic Reference Center (AGRC) that is dedicated to storing and maintaining a vast array of statewide data sets. They were our most valuable resource. But by contacting numerous other state and federal agencies we were able to collect some potentially useful data sets as well as to get a feel for what datasets may be coming available over the next few years. The biggest limiting factor in determining which data was useful was whether the data set was available statewide. For example the USFS has digitized all adit and shaft symbols for USGS 7.5 min quad maps containing Forest Service Lands. If available statewide it would likely be some of the most useful data we have as to the locations of abandoned mines, however because the data does not exist for the entire state we were unable to incorporate it into the GIS ranking model.

Once we determined what datasets were available we looked at the data's attributes and began to determine which attribute would provide information for our model. For example the roads dataset contains attribute information detailing the road surface type as well as number of lanes. These attributes give us a clearer picture of the functional mobility they provide beyond just whether a road is or is not present.

CONCEPTUAL GIS MODEL EXPLAINED

The modeling and ranking process looks at three main factors that would influence the potential hazard for mining areas. These factors include known mining activity or mineral resource occurrence areas, the population density in proximity to the mining areas and the potential access to the mining areas.

Mine closure priorities should be ranked in a way that reflects how much exposure to the danger the public is getting. The first step in ranking mines for reclamation is to know where they are or where they are likely to be based on potential mineral resource locations. Known mines and the density of those mines received a higher ranking in the model than potential mining areas or mineral resources. The data sets used in the mining component include Computerized Resource Inventory Base

(CRIB), gilsonite veins, phosphate deposit areas, locatable mineral occurrences, historic mining district and un-patented mining claims.

The second ranking criteria we use to prioritize abandoned mine closures is the mine's proximity to population centers and the density of the population area. We assumed that mines located near densely populated areas receive more visitations than mines located far from population centers. The population component of the model uses the census data from 2000.

The third major component of the ranking model is access to the mining areas. The easier a mine is to get to, the more likely people are to visit it. Thus a mine's proximity to a high density of roads significantly contributes to its hazard potential. A roads data set was used to determine the potential access to a mining area.

The mining activity, population, and access components were combined to determine which abandoned mines pose the greatest potential risk to the public. The model is then used to generate a map of all areas above a certain hazard-rating threshold. The composite score for each of these areas determines its rank. Thus using GIS, the Utah AMRP is able to focus abandoned mine reclamation efforts in those areas which pose the greatest threat to public safety.

TECHNICAL IMPLEMENTATION OF THE CONCEPTUAL GIS MODEL

The geographic datasets were processed using Environmental System Research Institute's (ESRI) Arc/Info software including the Grid extension. The processing of each dataset was programmed in ESRI's Arc Macro Language (AML). By using AML's to process the datasets, attribute values could be easily changed to see how the output datasets varied with different attribute values.

Three main groups of data were used for the model, the access component, which used two roads coverages, the people component consisting of the 2000 census data, and the mines component consisting of a variety of mining datasets. All datasets were converted to grids with a quarter mile grid cell size. Weighted values were assigned to the various attribute components and in the case of the roads and census data, densities were calculated using focalsum calculations. The grids were then merged to form a final composite coverage. Within the final dataset, areas were ranked to define critical areas for AML mitigation.

ADAPTABILITY OF THE GIS RANKING PROCESS

Future

GIS is helping us to concentrate our efforts and resources in those areas where they can do the most good. The datasets produced can be used to represent the portion of the state in which abandoned mine reclamation has been completed. The model also indicates the portion of the state that we have left to investigate on the ground. GIS will help us maximize our limited funding by streamlining the process of prioritizing and planning our future work in these areas.

USE OF INTEGRATED GPS AND GIS SYSTEMS IN MINE RECLAMATION

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ABSTRACT

Development of Global Positioning Systems (GPS) and Geographic Information Systems (GIS) has progressed to a point at which their sophistication and cost allow them to be effectively integrated in reclamation programs. This paper describes how these tools are being economically employed to inventory, prepare closure designs and reclaim former mine sites.

From the initial inventory of abandoned mine features through the closure of mines and mills, integrated GPS and GIS systems are playing an increasing role in abandoned mine land reclamation. The GPS system can provide state agencies nearly real-time data regarding the types and locations of abandoned mine sites through uploading of GPS data files onto an agency-accessible web site. The GPS data can subsequently be overlaid onto GIS maps to provide precise routes to, and locations of, those features.

The GPS surveying and GIS mapping allows rapid sizing and plotting of mine openings, waste piles and cultural features for accurate drawing and quantity computations during office design of the closures. Tied to state coordinate systems, the maps are accurate with respect to orientation and provide precise information for the preparation of construction documents. The GIS database provides streamlined storage of all pertinent information regarding the mine features including location, access routes, photographs and tabular summaries of dimensions, land ownership and notes regarding each location. Three-dimensional views generated by the GIS system can be used to illustrate the pre- and post-reclamation design features.

In the final construction phase of reclamation, the integrated GPS and GIS systems can similarly be used to locate the site, monitor closure during construction and provide as-built dimensions and documentation of closure within the database. It is the authors' intent to describe these capabilities and provide examples of their use in recent reclamation activities associated with the Star District mine reclamation project in Utah.

INTRODUCTION

Throughout the United States there are many thousands of abandoned mine sites posing potential hazards to the population. In the state of Utah approximately 4,000 coal and non-coal abandoned mines have been safeguarded to date¹. Yet, in this state alone, there remain an estimated 17,000 abandoned non-coal mine openings to be identified and potentially closed.

The cost of identifying, locating and compiling a database of these numerous sites has been greatly reduced by the integration of Global Positioning Systems (GPS) with Geographic Information Systems (GIS). The routes to, locations of, and dimensional data associated with, each mine site can be easily collected; the information can be electronically uploaded to a File Transfer Protocol (FTP) site while in the field, providing

office engineering and regulatory agency personnel nearly real-time access to view and evaluate the field inventory data and progress.

In addition to reducing site inventory costs and providing timely access of data to interested parties, the integrated use of these systems facilitates the negotiation of access agreements with landowners. The landowner can view the precise location of the hazardous mine on maps and, if needed, guide the landowner directly to the site using the GPS to view the hazard.

The easily accessible electronic GPS/GIS files continue providing efficiency during reclamation design and construction. During the design of the mine's closure, further savings are realized by the immediate availability of mine feature dimensions, orientation and photographs in the office. This information can continue to be shared with all interested parties via the dedicated FTP site. During the reclamation construction phase, the easy relocation of the site and documentation of as-built closure conditions further streamline the closure process.

This paper discusses an example of the use of the integrated systems during the state of Utah's recent abandoned mine inventory project in the Star Mining District, located in southwestern Utah.

ABANDONED MINE AREA

The Star Mining District is located approximately six miles west of Milford in Beaver County, Utah. Extensive hard rock mining has occurred in the mountainous Star Range from the late 1800's to today's presently limited mining activities. Minerals sought included copper, lead, zinc, turquoise, silver and gold. Hazardous features, including deep vertical shafts, horizontal openings (adits), trenches and highwalls frequent the area.



Figure 1 – Typical Vertical Shaft

The mined area is characterized by a semi-arid environment and fairly rugged topography, ranging in elevation from approximately 5,200 feet to more than 6,800 feet. Vegetation in the area is limited to cold desert shrubs (sagebrush) at the lower elevations to pinyon and juniper communities in the higher areas. The accessibility of many of the mine sites and historic features by established trails attract a variety of hikers, spelunkers, and off-road vehicles, necessitating the inventory of the sites for closure purposes.

USE OF THE INTEGRATED GPS AND GIS SYSTEMS

Sixteen land Sections, approximately 16 square miles, were investigated to identify the presence or absence of hazardous mine openings in the Star Mining District. A total of 198 mine features were inventoried over a period of 18 days. The inventory included locating, tagging, photographing and measuring each mine feature. Various inventory forms and engineering sketches were completed at each mine feature location.

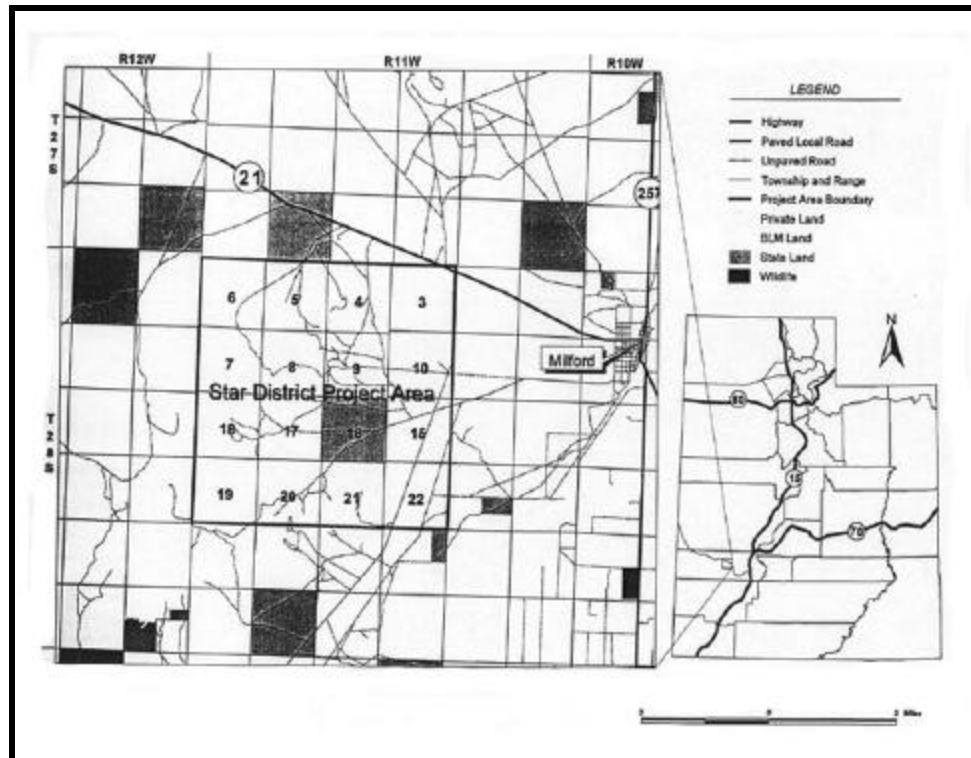


Figure 2 - Star Project Site Vicinity Map

The success of the inventory was dependent upon a methodical approach of inspecting this relatively large area. The similarity of the terrain throughout the area and anticipated large number of hazardous mine features made sole reliance on existing topographic mapping impractical and costly. Suitable means of conducting accurate field location surveys and storing collected data were necessary to:

- Identify locations of land Section lines,
- Find probable mine sites noted from the review of conventional topographic mapping and aerial photography of the area,

- Document areas that had been previously inspected and inventoried,
- Precisely locate previously unknown mine locations that were discovered in the field for tagging, photographing and measuring purposes,
- Electronically store, correlate and transfer collected data obtained from each mine site,
- Identify areas that remained to be inventoried, and
- Allow the inventory of mine sites to resume in the future where the previous inventory terminated.

To accomplish these objectives, compatible Global Positioning Systems (GPS) and Geographic Information Systems (GIS) were selected and employed. A Trimble Pathfinder® real-time differential GPS receiver (XRS) and a GPS receiver with post processing differential correction (GeoExplorer 3) were used to log the roads/paths to, and positions of, the mine sites. The inventory was thoroughly conducted using a combination of four-wheel drive vehicles, all-terrain vehicles and extensive walking routes.



Figure 3 - Trimble GeoExplorer3 (left) and Pathfinder (right)

A pre-defined inventory data dictionary was loaded into the GPS instruments prior to field use. The dictionary had three levels of information for field logging purposes, in a format consistent with ESRI's ArcView® 3.2a GIS software that was selected as the project's information database.

The data dictionary was first divided into the four basic features of "mine sites," "miscellaneous points", "miscellaneous polygons" and "roads." These were further subdivided into attributes, examples of which include vertical openings (VO's), horizontal openings (HO's) and prospects (PR's) for "mine sites" and four-wheel drive access, two-wheel drive access and walking routes for "roads." Data collected for the attributes would include information such as the directional bearings and dimensions of the mine openings.

Information obtained from the office review of U.S. Geological Survey (U.S.G.S.) topographic mapping, aerial photography and mine ownership records was also loaded into the instruments prior to conducting field inventory so that suspect mine opening

locations could be readily found and mapped, in addition to those previously unknown sites identified while in the field.

The actual field inventory was performed by a methodical inspection of each land Section typically progressing from the northwest to the southeast. Those Sections with the highest elevations and most severe topographic relief were mapped first due to access concerns during the winter season and the possibility of snowfall covering mine features. The GPS surveying of routes and mine locations was performed using four-wheel drive trucks, four-wheel drive all-terrain vehicles (ATV's) and extensive walking routes over steep terrain.

Each instrument's horizontal survey accuracy was checked between the two GPS receivers and with a permanent U.S. Coast & Geodetic Survey Benchmark in the field on a daily basis. All routes shown on existing U.S.G.S. mapping as well as newer roads and trails were surveyed within each land Section. Routes to each mine feature, as well as the precise location of the feature itself were recorded. Approximately eight to twelve mine features were located and inventoried each day, typically employing a three-person crew.

At the end of each day of field data collection, GPS rover files were processed for differential correction. This processing was accomplished using the U.S. Geological Service South Dixie Forest base station located approximately 50 miles south of the project.

Field personnel electronically uploaded corrected and uncorrected GPS files nightly to a File Transfer Protocol (FTP) computer server; the FTP site was remotely accessible by others. Files were uploaded in both uncorrected and differentially corrected, post-processed formats for access, review and comment by other home-office engineering and state of Utah AMR personnel. This process provided easy data access by all parties to review the field progress and comment on a near real-time basis. Data gaps and questionable field data resulting from the review could be addressed the following day in the field. The FTP site was structured, and data transferred, using Cute Pro 2.0 utility software.

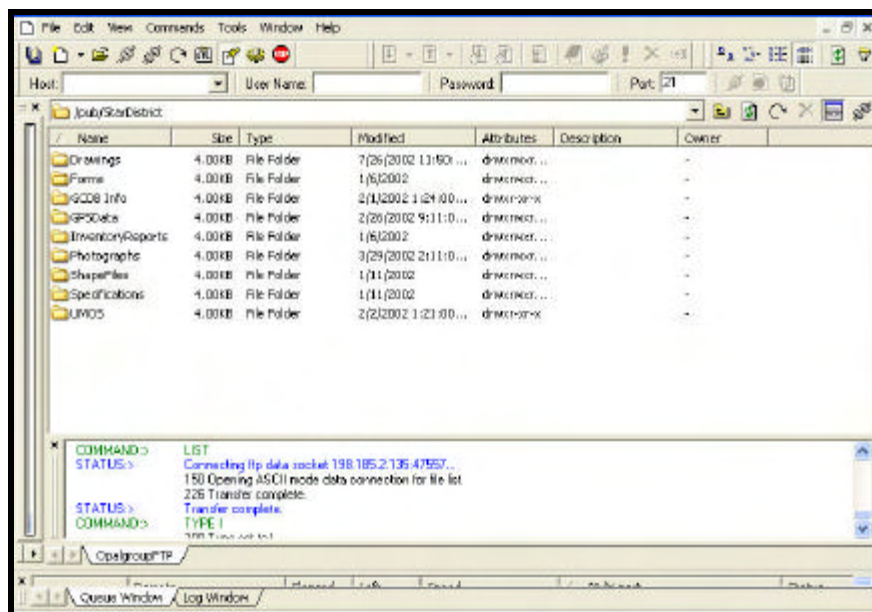


Figure 4 - Sample File Transfer Protocol (FTP) Site Structure

During the field inventory the daily GPS routes, mine locations and related field survey data were exported from the Trimble Pathfinder Office software and electronically converted to the form of a shape file (*filename.shp*). This file was subsequently imported into the ArcView® 3.2a GIS software as a GIS “theme” and superimposed on a Digital Raster Graphics (DRG) file of the area’s topography, using a common location coordinate datum.

Similar uploading of the ArcView® 3.2a GIS files to the FTP site was performed concurrently with the daily uploading of the GPS data files. The combined files were viewed in the home office as well as in the field to ensure the consistency of field data and plan the field inventory activities for the following day. The routes and sites plotted directly on the topography enabled the field personnel to plan their inspection routes on a daily basis and confirm that all areas of the site had been inspected.

Once the field inventory was complete, office design activities were similarly streamlined. Back-up files of all field data already existed by virtue of the daily transfer of data through the FTP site. The electronic data was employed during design by exporting the information into various engineering software packages, such as materials handling volumetric determination programs. For example, using a triangulation method program such as Trimble’s “Site Works” or AutoCAD’s “Civil Soft,” the materials handling quantities for available backfill from mine waste dumps were readily determined and viewed in three dimensions, if necessary.

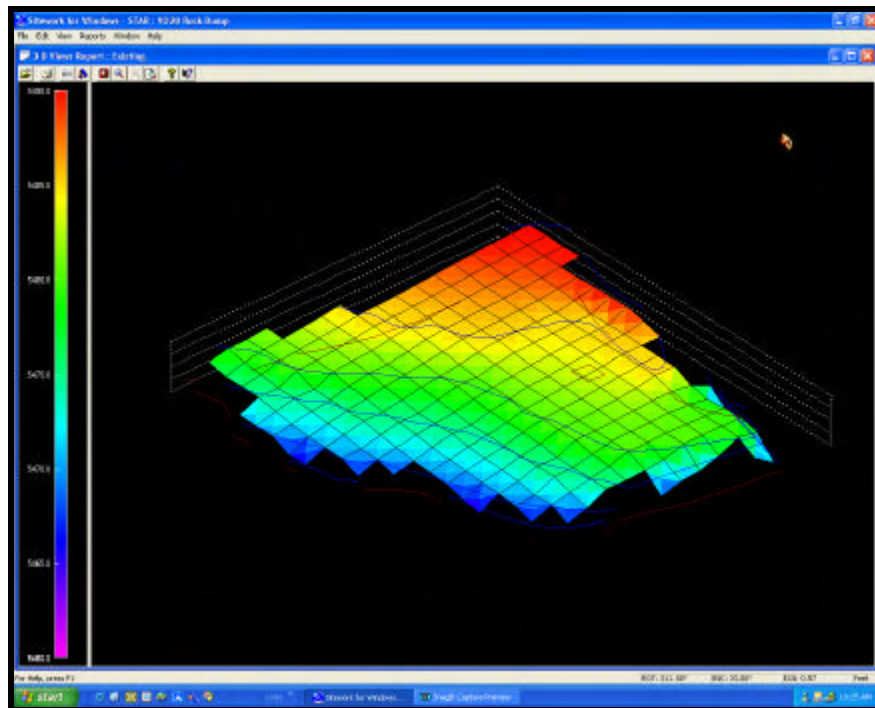


Figure 5 - Volumetric Determination Mine Waste Dump

Finally, the downloaded files easily form the basis for the reclamation construction document site location maps. The GPS/GIS data, when superimposed on the DRG topographic mapping files (as previously used in the field to confirm inventory

coverage), provides precise illustration of the location of, and route to, each mine site requiring closure. This information satisfies needs of the reclamation contractor to identify access to the site as well as the nature of the surrounding terrain for pricing purposes, since the contractor may not currently have the technical capabilities of electronically importing and viewing the GPS/GIS data.

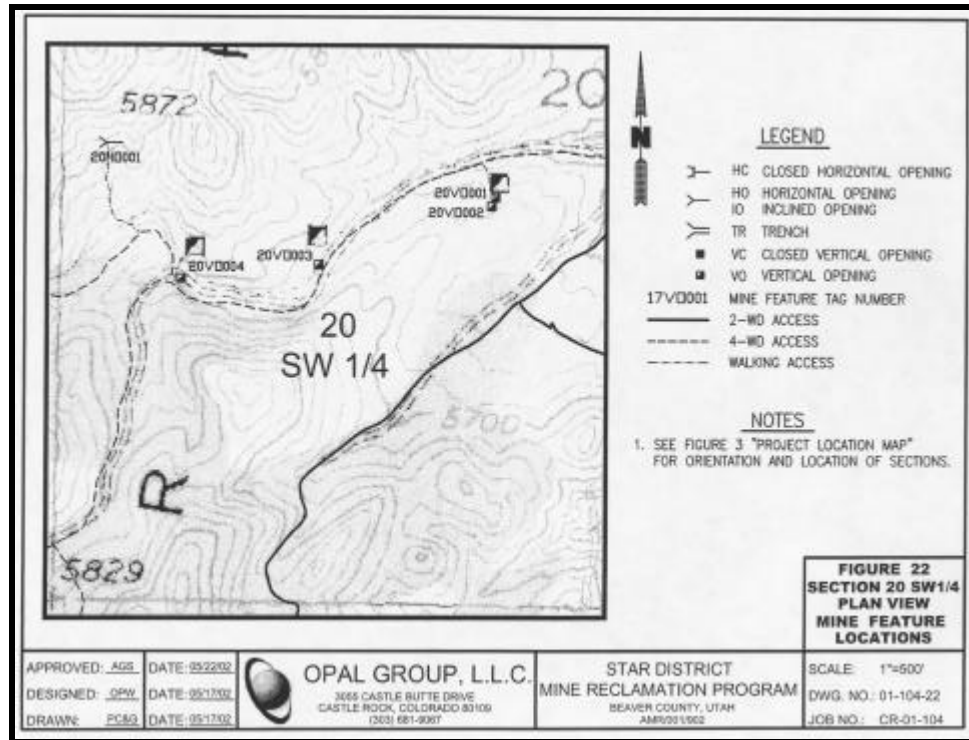


Figure 6 – Typical Construction Drawing Showing Mine Locations and Routes

SUMMARY AND CONCLUSIONS

The integrated use of GPS and GIS data provides significant savings of time and engineering costs during the inventory and closure design for abandoned mine sites. It is projected that the time required locating and logging inventory data associated with each mine feature has been reduced to one third or less of that required by more traditional and conventional means. The thoroughness and accuracy of the inventory provided by the combined technologies provides a significantly higher-quality engineering product. The transfer of data via an FTP site from the field to the office further provides a compression of project schedule along with an increased degree of accuracy provided by near real-time independent review of data collected in the field. The massive numbers of hazardous abandoned mine locations remaining to be inventoried and closed make the combined technologies a mandatory part of the abandoned mine reclamation program.

ACKNOWLEDGEMENTS

We wish to thank the State of Utah Division of Oil, Gas and Mining Abandoned Mine Reclamation for information and use of materials associated with the abandoned mine reclamation inventory in the Star Mining District. In addition we appreciate the time dedicated by ESRI personnel in assisting us to streamline the data collection, transfer and storage process.

REFERENCES

Annual Summary Evaluation Report of the Colorado-Utah Abandoned Mine Land
Review Team for the Utah Abandoned Mine Reclamation Program for Evaluation
Year 2001

ABANDONED MINE LAND DEVELOPMENT GUIDE



ASK

BEFORE YOU BUILD

**A guide for landowners,
developers and local officials
to better assess abandoned mine lands
before building**



WHAT'S THE NEED?

Landowners in Ohio are experiencing site development problems associated with building on abandoned mine lands (AML). These problems can lead to expensive repairs when settling occurs, landslides develop or mine gases are encountered. As rural areas are developed for residential and or recreational purposes abandoned mine lands are becoming more attractive to purchase. The AML program does not fund reclamation or stabilization projects if the landowner fails to address the AML problems prior to development.

WHAT'S THE PURPOSE OF THE GUIDE?

The AML Program has created the “**Ask Before You Build Guide**” as an educational outreach resource for the public and local officials to assist in evaluating past mining sites for house, road or other development. The guide includes descriptions and illustrations of AML land development problems along with program eligibility guidelines for funding. Also included are the names of other ODNR Divisions and Federal, State and local agencies that can assist with providing information during the development phase of building on abandoned mine lands.

WHAT IS AML?

AML (Abandoned Mine Lands) are areas that have been mined prior to 1977 in which the mine operator has no continuing reclamation responsibility. AML problem types from surface and underground mining operations include: dangerous highwalls and impoundments, landslides, mine spoil, mine subsidence, mine openings, flooding, mine drainage, mine gas and other mining related hazards.

WHAT ABOUT ACTIVE MINING SITES?

Active mining sites are defined as areas permitted by the State Regulatory Authority that have been mined after 1977 and fall under the Federal Surface Mining Control and Reclamation Act (SMCRA) regulations. These more recently reclaimed mining sites can have unique qualities that call for special design and construction techniques to address the settling of mine spoil, prevention of hillside slippage and overly-compacted soil layers. Before building on these areas, **always consult a trained professional**, who can provide design advice to avoid problems that can occur as a result of site development on reclaimed post-1977 land.

WHO SHOULD READ THESE GUIDELINES?

√ Prospective buyers	√ Construction-design firms
√ Landowners	√ Zoning board members
√ Homeowners	√ Developers
√ Local officials	√ Engineers
√ Realtors	√ State and Federal Agencies
√ Community planners	√ Township & County Agencies

STAY OUT-STAY ALIVE CAMPAIGN

Ohio along with other States participate in the Federal “Stay Out-Stay Alive” national public awareness campaign to warn children and adults about the dangers of exploring and playing on active and abandoned mine sites. For more information go to <http://www.msha.gov/PLACES/PLACESHP.HTM> or call 614-265-6910.

DISCLAIMER

The Division of Mineral Resources Management always recommends that the landowner or developer **contact an experienced, qualified engineering firm to assist in site evaluation of AML when being considered for development**. Some AML sites are not suitable for development or are not suitable without the properly-engineered site development work prior to construction. **This analysis is deemed necessary as site stabilization or building repairs on developed AML areas are not eligible for reclamation funding under the AML program.**

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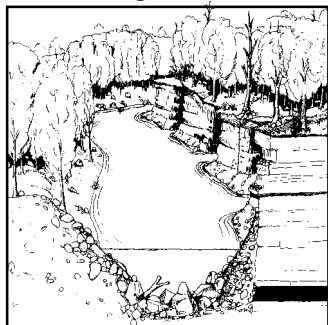
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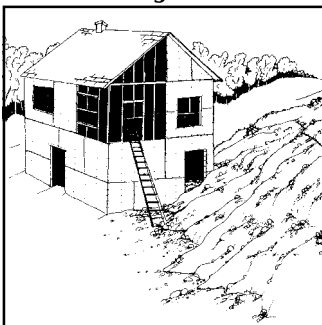
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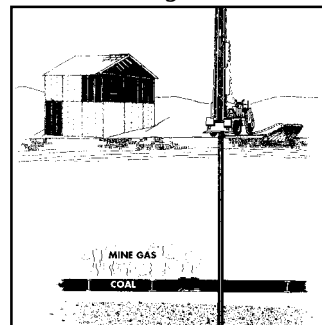
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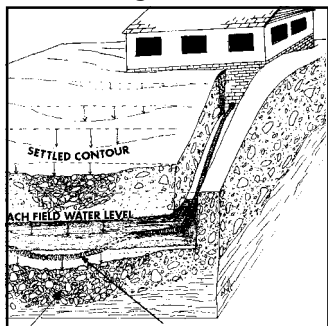
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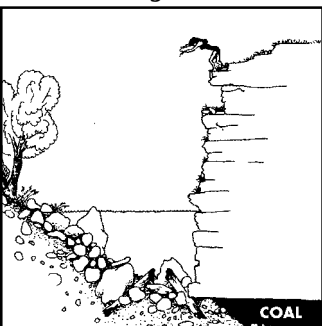
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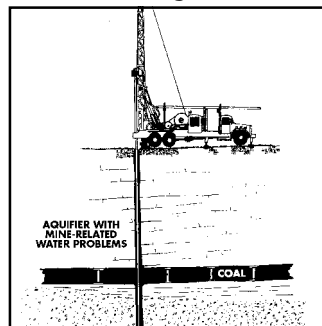
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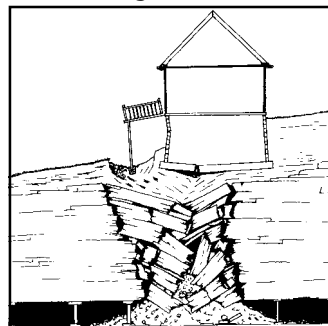
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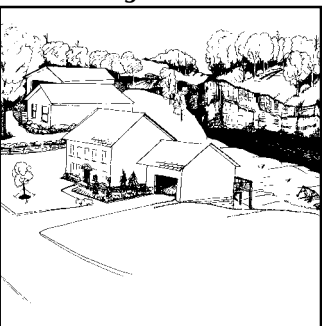
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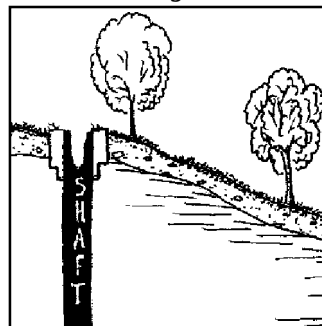
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Dear Customers!

The “Ask Before You Build Guide” has been created to assist the public and local officials in identifying development and building problems associated with abandoned mine lands (AML). The guide should be used as an informational resource before you build. Have you heard the old saying “It is difficult to make wise decisions without all the information”? The goal of this educational outreach effort is to inform the public, our customers, about building and development problems associated with AML *before* construction begins, so AML concerns can be accommodated as part of the planning.

Ohio has a long mining history, which began around 1800. Underground and surface mining were the two primary methods for coal and industrial minerals mining in the Ohio. Mining legislation was first enacted in Ohio in 1947 and gradually increased until the passage of the 1972 Ohio Strip Mining Law. This law required regrading to approximate premining contour of the land, replacement of topsoil and the establishment of a successful vegetation cover by the mine operator prior to the State’s release of reclamation bond. On August 3, 1977, the United States Congress passed the Surface Mining Control and Reclamation Act (SMCRA). This Act established stringent national standards for coal mining and reclamation.

With the creation of SMCRA came the Federal Abandoned Mine Lands (AML) Program. Since 1977 a federal tax has been imposed on each ton of coal mined and that tax is used to administer the programs that regulate coal mining and the reclamation of AML. The Division of Mineral Resources Management maintains an inventory of over \$200 million dollars worth of AML areas. The State receives only \$5–6 million dollars a year to reclaim the inventory therefore only the highest priority AML sites get reclaimed.

This AML “Ask Before You Build Guide” is another tool for the AML program to serve the public and protect them from the hazards created by past mining. Ohio’s rural areas are being developed and many past mining areas look attractive because of their locations, aesthetic qualities and price. Landowners and developers who build on these AML areas find that significant problems can develop as a result of subsurface conditions created by past mining. The following problems can be found on AML: underground mine subsidence, landslides, flooding, dangerous highwalls and impoundments, polluted water and other mining related conditions. The AML program is unable to assist individuals who build over these areas when they failed to address these site conditions in the design of their home, road, well or other structures. As referenced earlier, the goal of this educational outreach effort is to inform the public about these mining hazards *prior to* building and developing these AML sites, so abandoned mine conditions can be taken into account to avoid future, more costly problems.

You can help us to assess the usefulness of the AML development guide by completing and submitting the survey form found in the back of the booklet. The Division plans to conduct public meetings and make these guides available to the County Soil & Water Conservation Districts, local government agencies and other interested organizations and individuals. The distribution will primarily take place in the coal-bearing region of Southeast Ohio. The AML Educational Information will also be available on the web at <http://www.ohiodnr.com/mineral>. Your input on this important subject is greatly appreciated.

Sincerely,



Mike Sponsler, Chief
Division of Mineral Resources Management

Abandoned Mine Land Program Eligibility Guidelines

BACKGROUND

The Division of Mineral Resources Management's Abandoned Mine Land Program is responsible for abating the highest priority public health and safety and environmental problems associated with abandoned mines. These problems include, but are not limited to, subsidence, mine gases, mine drainage, landslides, dangerous highwalls and pit impoundments, flooding, open mine portals and shafts, and domestic water supplies impacted by acid mine drainage.

AML SITE DEVELOPMENT PROBLEMS

Buildings are prohibited from being repaired and/or replaced under the AML program. Site stabilization and water replacement on developed AML areas are also not eligible for reclamation funding. Consult a trained professional prior to site development who can provide design advice to avoid problems that can occur as a result of site development on AML areas.

FUNDING

State and federal funds provide resources for the Division's Abandoned Mine Land Program to investigate environmental, public health and safety problems to design and construct projects to address the problems related to abandoned mines. The Division maintains an inventory of abandoned mine problems and has valued the cost of their remediation at more than \$200,000,000. With annual funding ranging between \$5,000,000 and \$6,000,000, only the highest priority public health and safety and environmental problems are selected.

GENERAL PROBLEM ELIGIBILITY AND PROJECT SELECTION CRITERIA

Problem eligibility and project selection considerations include the following criteria:

- **The date of mining and abandonment.** For *state* funds, mining must have occurred prior to April 10, 1972. To be eligible for *federal* funds, the surface mining responsible for a specific problem must have been abandoned prior to August 3, 1977. In order to address a problem related to a deep mine, the deep mine must have been abandoned prior to September 1, 1982.
- **The availability of cooperative funding and in-kind services.** Due to limited in-house funds, the availability of funds and in-kind services from other agencies, private sources and non-profit organizations can elevate the status of a problem for project consideration.
- **The probability of successfully abating the problem.** The abandoned mine land problems that have the highest probability of successful completion with minimal or no maintenance will be given higher consideration.
- **Determination of the existence of a party responsible for the presence of an abandoned mine land problem.** Mining companies are not held responsible for the existence of the vast majority of abandoned mine problems, as the reclamation requirements in existence at the time of mining and abandonment were minimal. Even if deemed responsible, however, most of the companies in existence prior to the dates of effective reclamation laws no longer exist. Current land-owners, however, can be deemed responsible for creating public health and safety problems primarily as a result of poor development decisions.
- **Priority Designations.** Each problem site is field reviewed and evaluated based upon site characteristics. Depending on site severity, a site is classified as either an Emergency or a Priority 1, 2 or 3. All problems deemed an Emergency are granted immediate funding. Those identified as Priority 1 public health and safety problems are placed in the next available annual grant. Only the most serious Priority 2 public health and safety concerns and Priority 3 environmental problems receive funding annually. Additional eligibility discussion may be noted in the following pages for specific abandoned mine problems.



AML Problem Type: Highwall

BACKGROUND

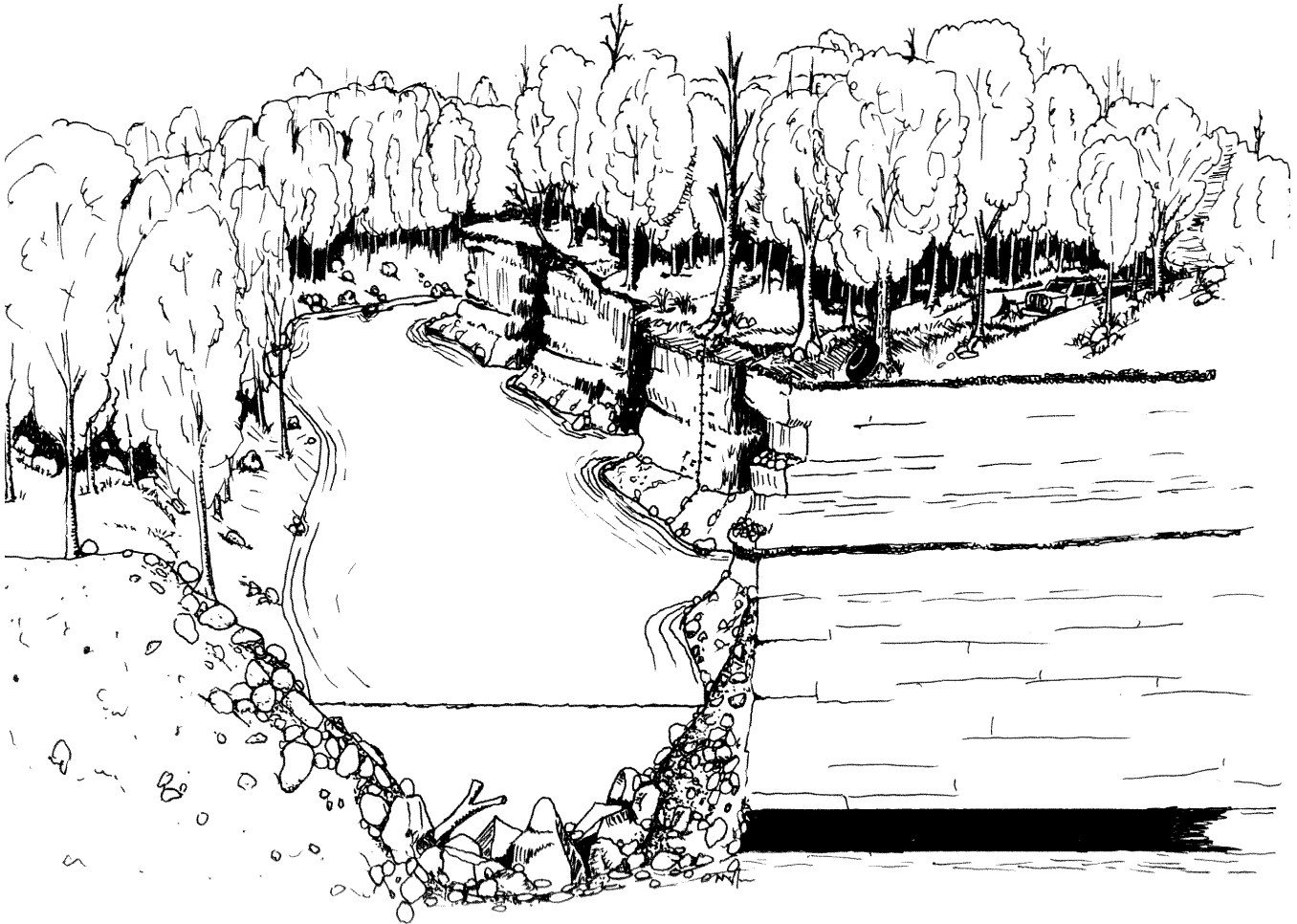
Prior to the requirement of returning mine land to approximate original contour, vertical rock faces, called highwalls, were left as the last cut of the strip mining operations. Some highwalls exceed 100 feet in height. Depending on the rock strata composition, highwalls can be unstable. As a result, highwalls can present a significant danger when in close proximity to occupied structures, public roads and frequently visited sites.

HIGHWALL SITE DEVELOPMENT PROBLEMS

- Structures built above or below highwalls may be damaged by falling rock. Highwalls are inherently unstable because blasting and heavy mining equipment were used to create these vertical rock faces.
- Building near a highwall can also increase safety concerns. Injuries can result from pedestrians walking above or below highwalls and rock faces giving way causing physical harm.



Home built on mine spoil next to dangerous highwalls.



Dangerous highwall created by mining operation.

FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to safeguard against dangerous highwalls. Eligibility and selection of sites are evaluated on a site by site basis and are subject to funding availability. The primary criteria for establishing eligibility for funding abatement of dangerous highwalls includes the following:

1. The highwall height must exceed six feet. Its slope must be greater than 50° from the horizontal or the slope must exceed 35° if loose material exists on the face.
2. The highwall is composed of unstable material and occupied structures, roadways and improved property are located below the highwall and endangered as a result of falling material.
3. There is an improved road within 40 feet of the highwall or an unimproved road within 15 feet of the highwall.
4. There is an occupied structure within 500 feet of the top of the highwall or frequent visitation to the top of the highwall is evident.
5. There is a public recreation area within 500 feet of the highwall with evidence of intensive public visitation.
6. There is a mine-related water body (pit impoundment) adjacent to the highwall used for recreation and the public is exposed to danger traversing the highwall to access the water or uses the highwall as a diving platform or the area above the highwall as a parking area or rest area.
7. **A dangerous highwall will not be considered eligible for funding if:**
 - Structures have been placed within a 500-foot distance above a pre-existing highwall.
 - Roads, structures, and other improved property can be threatened if placed near an unstable, pre-existing highwall.

AML Problem Type: Mine Spoil

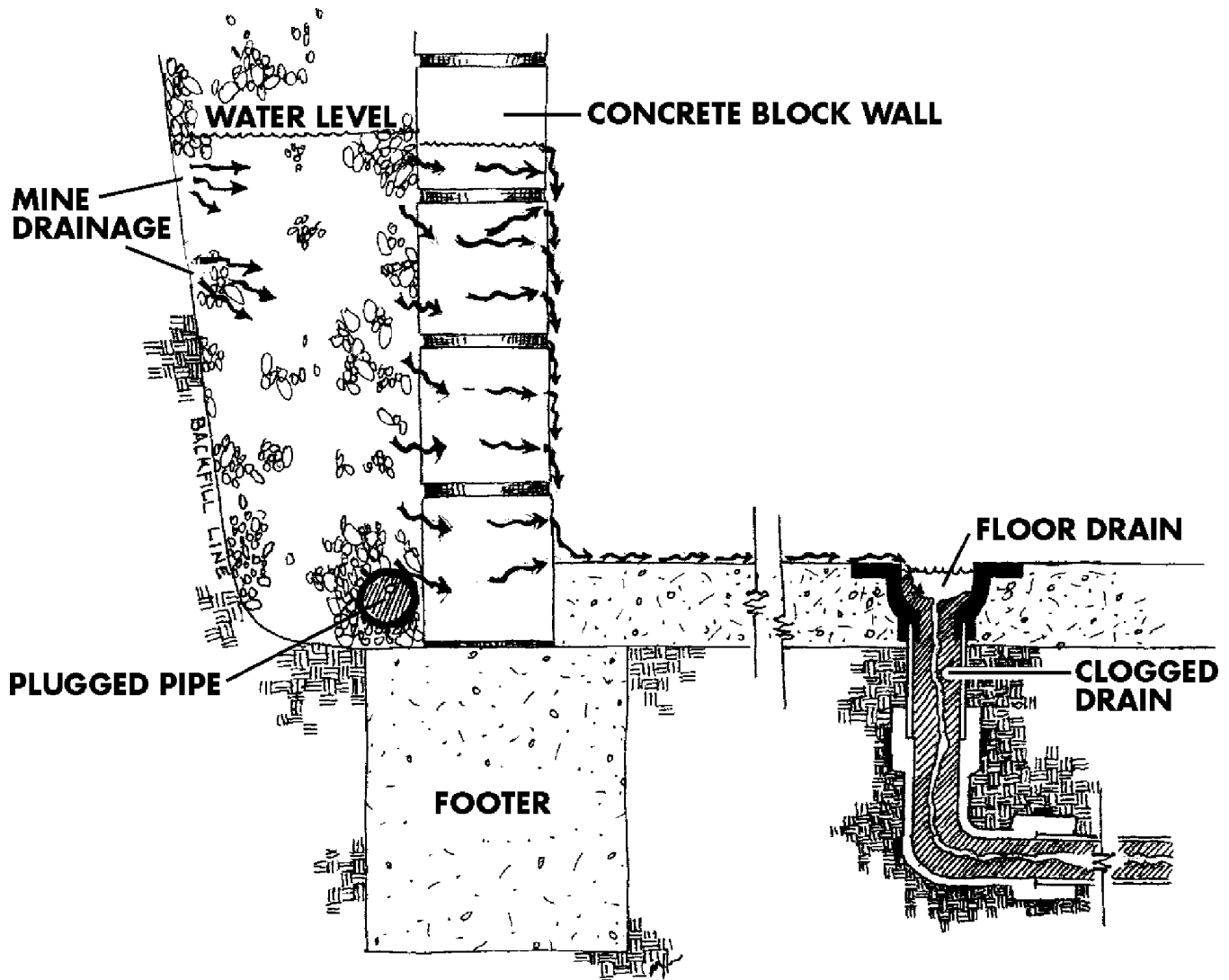
BACKGROUND

Mine spoil is intermixed unconsolidated rock, rock fragments and soil that result from a surface mining operation. Coal refuse is waste coal, with some crushed rock impurities, left as a result of coal processing. In its post-mining state, mine spoil and coal refuse, if unvegetated, can be highly erosive, and can be a source of significant sediment and acid mine drainage to streams. If the flow capacity of a stream is significantly reduced due to sediment accumulation, the stream will flood more frequently, possibly damaging structures and overflowing roadways. Mine spoil and coal refuse, even if reclaimed, are prone to settlement and are subject to movement by freeze-thaw cycles.

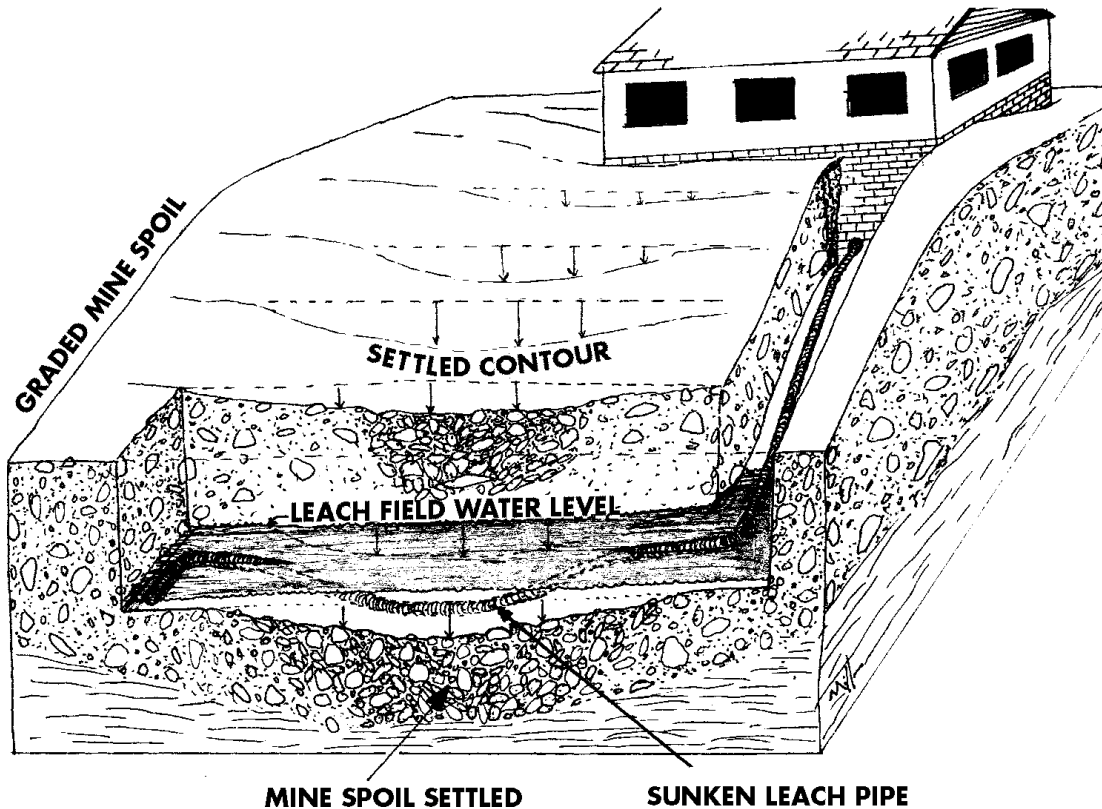
MINE SPOIL SITE DEVELOPMENT PROBLEMS

Buildings, septic systems and other such features located on mine spoil may settle, move or have leachate problems.

1. Buildings can be damaged as a result of mine spoil settling under the foundation.
2. A building's footer drains can stop functioning as a result of mineral leachate clogging the drainage system. Coal refuse and certain types of mine spoils have high amounts of minerals, which are susceptible to leaching when introduced to air and water.
3. Septic systems can be damaged as mine spoil settles. The leach field of the septic system settles and no longer functions as designed.



Mine water clogging foundation drainage system.



Home with settlement problem built on mine spoil.

The following problems can occur to houses, garages, septic systems and other types of structures from spoils settling or to footer drains not operating properly: Interior or exterior wall cracking, bowed basement walls, cracks in walls, water leaks or non-functioning leach fields.

FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to reclaim mine spoil and coal refuse. Eligibility and selection of sites are evaluated on a site by site basis and are subject to funding availability.

The primary criteria for establishing eligibility for funding the reclamation of mine spoil and coal refuse includes the following:

1. There is a previous record of frequent flooding or a high probability of an occurrence of flooding of a stream laden primarily with sediment from an abandoned strip mine or refuse pile.
2. Occupied structures, improved property, roads or public facilities are located in the flooding limits and would be subject to destruction or water damage as a result of increased flood frequency and levels resulting from reduced channel capacity. **New development in flood-prone areas, however, will not provide sufficient justification to establish a higher priority.**

3. There is a deteriorated water retention structure or pit impoundment on the abandoned mine site that is currently impounding a large quantity of water and sediment that, if suddenly discharged, could result in immediate flooding and sediment deposition downstream.
4. As mentioned previously, mine spoil or coal refuse, even if reclaimed, is subject to settlement and to the freeze-thaw cycle. Further, acid mine drainage may be generated in the spoil material or coal refuse as surface water infiltrates into and through the spoil. Structures constructed on mine spoil, without proper consideration of the unstable nature of the spoil material or the caustic nature of acid mine drainage, could be damaged. **It is the Division of Mineral Resources Management's policy that a landowner is responsible for determining the presence of mine spoil or coal refuse when considering a site for development. Further, a landowner will be solely responsible for adopting construction methods that will insure stability and intercept and divert acid mine drainage should an abandoned site, either in a reclaimed or unreclaimed state, be developed.**

Consult a trained professional prior to site development, who can provide design and construction techniques for mine spoil related problems that can occur as a result of site development. This may include but are not limited to compaction of mine spoil to prevent settling or selecting certain soil types for sanitary leach fields.

AML Problem Type: Mine Subsidence

BACKGROUND

The room and pillar method of extracting coal from deep mines can result in mine subsidence when the pillars of coal and the roof supports that were left in the mine can no longer support the bedrock above the mine. This loss of support is transferred to the ground surface which also drops, creating structural problems for houses, roads or utilities in the subsidence area as well as public safety concerns on other improved property. When buildings are damaged as a result of mine subsidence most insurance policies do not automatically cover the damage to your home. The Ohio legislature enacted a law in October, 1987, that established the **Ohio Mine Subsidence Insurance Fund**. It allows individuals residing in certain counties to purchase insurance for protection from losses due to mine subsidence. For more information, see the Resources section.

MINE SUBSIDENCE SITE DEVELOPMENT PROBLEMS

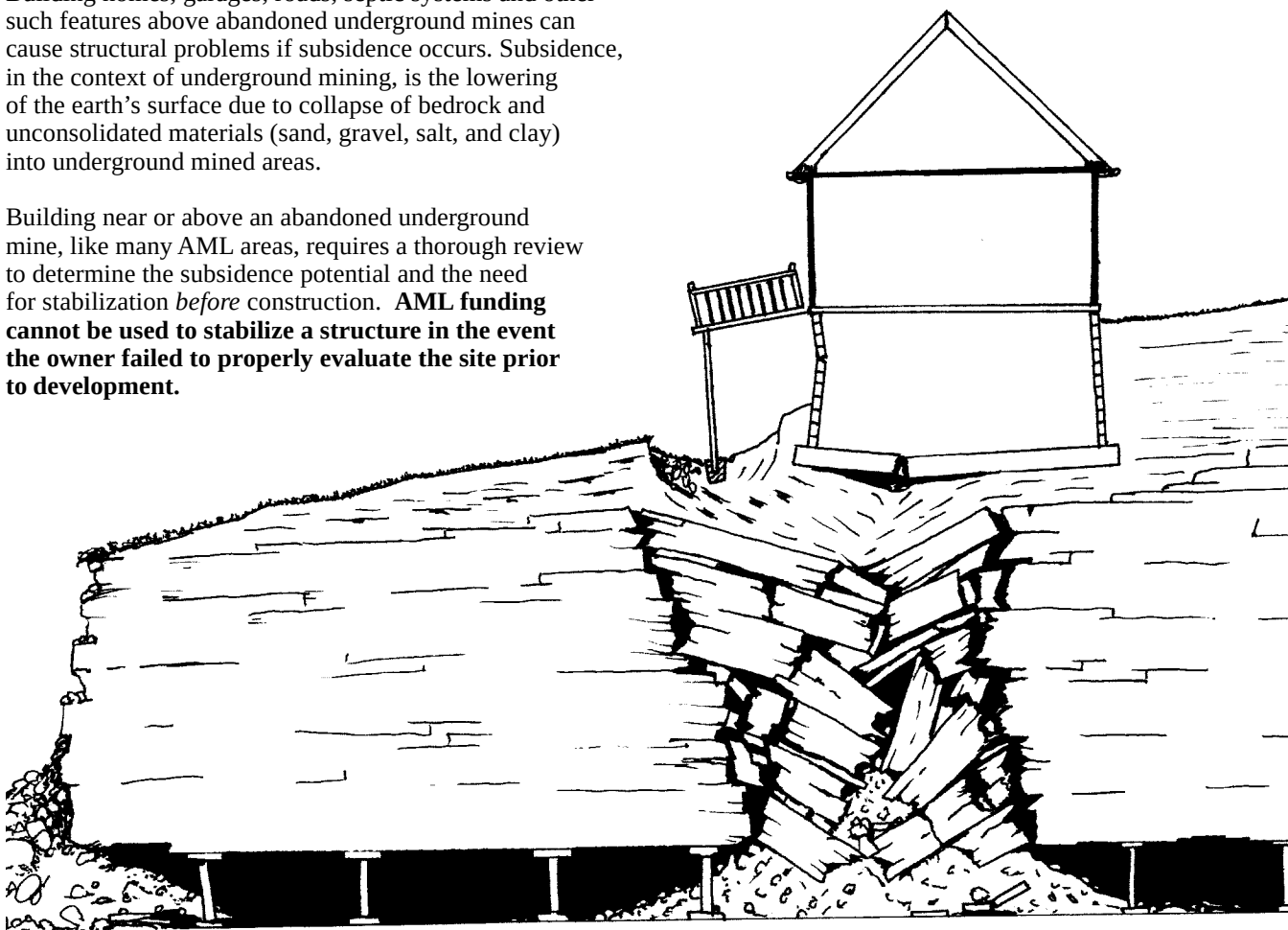
Building homes, garages, roads, septic systems and other such features above abandoned underground mines can cause structural problems if subsidence occurs. Subsidence, in the context of underground mining, is the lowering of the earth's surface due to collapse of bedrock and unconsolidated materials (sand, gravel, salt, and clay) into underground mined areas.

Building near or above an abandoned underground mine, like many AML areas, requires a thorough review to determine the subsidence potential and the need for stabilization *before* construction. **AML funding cannot be used to stabilize a structure in the event the owner failed to properly evaluate the site prior to development.**

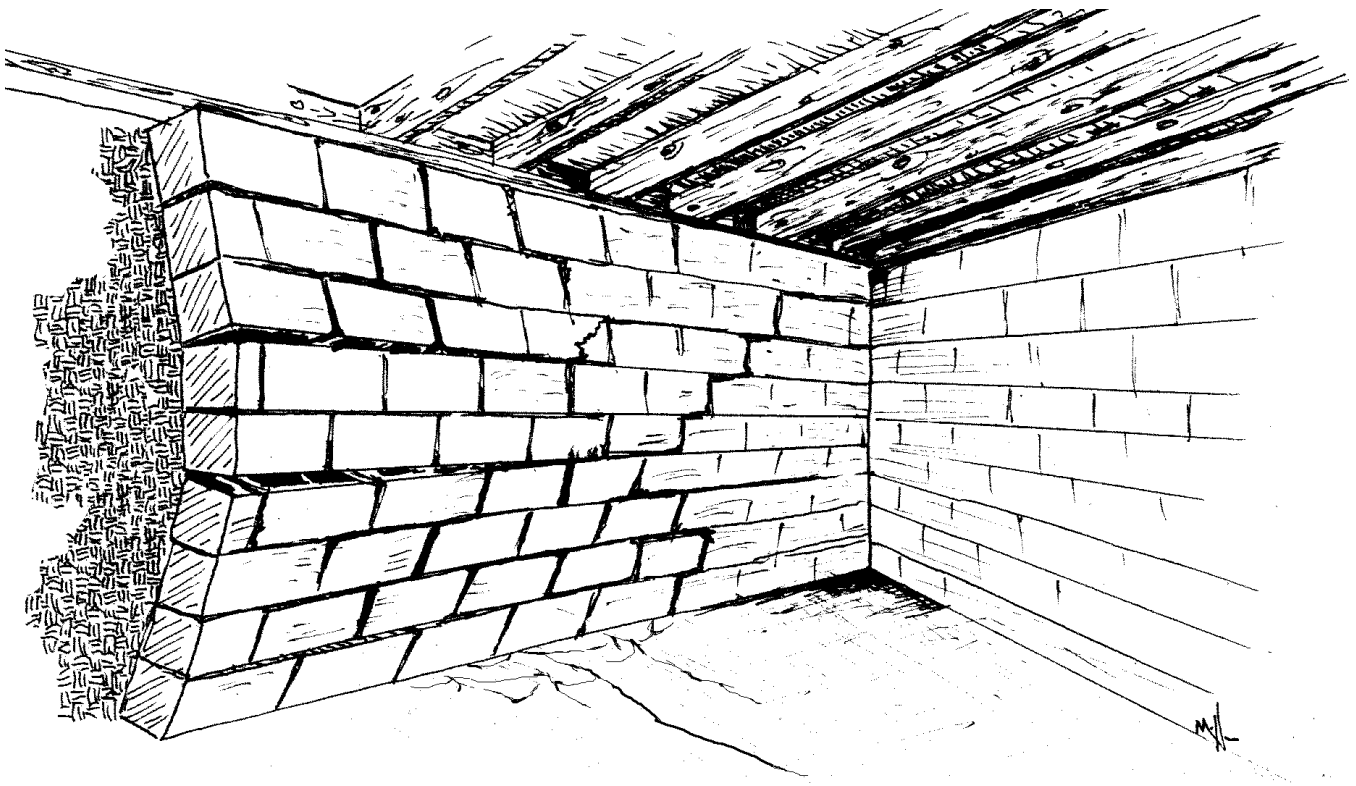
FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to stabilize mine subsidence. Eligibility and selection of sites are evaluated on a site-by-site basis and are subject to funding availability. The primary criteria for establishing eligibility for funding includes the following:

1. The actual or potential subsidence must be related to an underground coal mine abandoned prior to September 1, 1982, or an underground industrial mineral mine abandoned prior to August 3, 1977.
2. An actual subsidence has occurred beneath or immediately adjacent to an inhabited structure, roadway, public facility or public utility.
3. The potential exists for near-term subsidence beneath or immediately adjacent to an inhabited structure, roadway or public facility that could result in serious injury or excessive economic loss. To be considered for funding,



House impacted by mine subsidence.



Interior basement wall impacted by mine subsidence.

an area of potential subsidence must have had at least one actual prior subsidence event either addressed or substantiated by the Division. Further, investigative drilling by the Division must establish a significant potential for near-term subsidence that could result in serious injury or economic loss.

4. An evaluation must be completed by the Division to determine if the landowner, public agency or public utility is responsible for actual or potential mine subsidence damage. **If it is determined by the Division that, under reasonable circumstances, a landowner, public agency or public utility should have known about the presence of an abandoned mine and the potential for mine subsidence prior to constructing an inhabited structure, roadway or public facility over an abandoned underground mine, the actual or potential subsidence problem will not be eligible for program assistance.** If, under reasonable circumstances, the potential for mine subsidence should be known, the local political entity, if applicable, shall require a landowner, public agency or public utility to evaluate the potential for mine subsidence and to adopt, where appropriate, preventative measures under or within the angle of draw of the structure, roadway or utility. The angle of draw is used to define the limits of the area of potential surface effect for subsidence. It is based on the

type of geology, depth of the mineral and seam height. The angle of draw can affect areas up to 35 degrees away from the mineral extraction area. If there is no political entity responsible for issuing development permits, a landowner, public agency or public utility must perform subsidence evaluation in conjunction with other site development considerations. **Consult a trained professional prior to site development, who can provide design and construction techniques for the stabilization of underground mining areas to avoid mine subsidence problems. This may include, but is not limited to, drilling and injecting grout and/or concrete into the mine void.**

Reasonable circumstances include, but are not limited to:

1. The presence of past mine subsidence in the general vicinity of the site in question;
2. The media coverage of past subsidence event(s) in the general vicinity of the site in question;
3. The completion of educational outreach programs by the Division regarding the Abandoned Mine Land Program;
4. The availability of technical information for pre-development evaluation purposes;
5. The date of specific development or construction relative to items 1 through 4 above.

AML Problem Type: Mine-Related Landslides

BACKGROUND

The indiscriminate placement of steeply sloped unconsolidated mine spoil, prevalent on abandoned surface mines, can result in landslides that impact existing roads, structures and streams. Drainage from deep mines and strip mine impoundments can also saturate native soil units on non-mined slopes and result in the instability of these slopes.

MINE-RELATED LANDSLIDES SITE DEVELOPMENT PROBLEMS

Buildings and roadways if not constructed properly on or near mine spoil can cause hillside slippage also known as a landslide. Grading and/or removing the spoil material on hillsides can cause instability. Mine spoil is the earthen material located above the coal seam that must be excavated to extract or mine the coal. In some cases mine spoil is not a stable material based on type, particle or rock size, subsurface water and mining method.

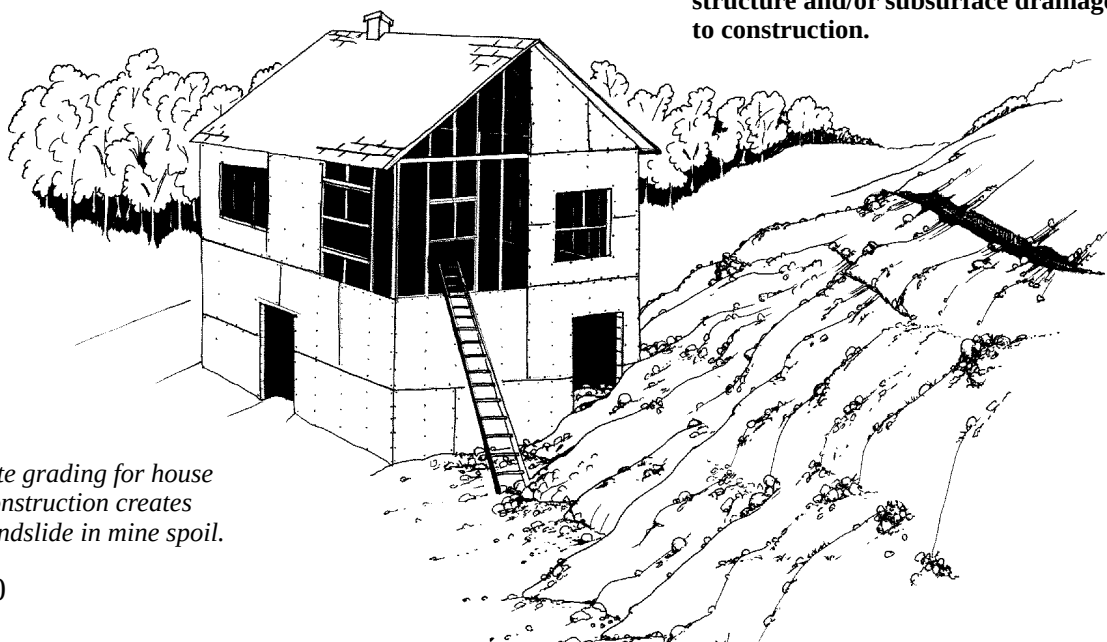
1. Constructing a bench or a level area on a hillside composed of mine spoil for a road, house, trailer or other outbuilding can result in the following problems:
 - Undercutting the spoil material on a hillside may reduce toe or base support for the upper portion of the slope.
 - Excavating spoil material and moving it down slope can overload the hillside. This activity can cause a landslide because the excavated spoil material is adding additional weight, which can make the entire hillside unstable.
2. Subsurface waters or springs can cause mine spoil to become saturated and eventually unstable. Grading mine spoil on a hillside without installing the proper surface and or underdrain system can cause hillside instability.

FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to stabilize a landslide endangering an occupied dwelling, improved property, road or public facility. Eligibility and selection of sites are evaluated on a site by site basis and are subject to funding availability.

The primary criteria for establishing eligibility for funding includes the following:

1. The landslide material is composed of mine-generated spoil or coal refuse. The material could also be composed of native soil that has become saturated and slip-prone as a result of mine drainage from an abandoned deep mine or strip mine.
2. An occupied structure, improved property, public road or public facility is endangered because it is located above or adjacent to the unstable land mass or a potentially unstable land mass.
3. A stream is located at the toe or base of an unstable or potentially unstable landslide and, if blocked by landslide material, would result in flooding that could endanger occupied structures, roadways or public facilities.
4. Landowners can influence the stability of slopes that have been stable since mining by undertaking certain site development activities. By removing material from a hillside to place a road or structure, a hillside's support is lessened at the location of the disturbance. This could result in a landslide or incremental creep, especially on a slope composed of mine spoil or one influenced by mine drainage. **Landowner-induced slope instability will not be considered eligible for program funding. It is the landowner's responsibility to evaluate slope stability prior to affecting a slope or locating below it and to take appropriate stabilization measures (retaining structure and/or subsurface drainage placement) prior to construction.**



Site grading for house construction creates landslide in mine spoil.

AML Problem Type: Dangerous Impoundment

BACKGROUND

Prior to the requirement of returning mine land to approximate original contour, the final cut of a strip mining operation often left a pit between the highwall face and a spoil pile. Depending on the area of surface drainage and the configuration of the spoil material, these pits can impound water. If the water quality is good, these impoundments can be attractive nuisances to recreational enthusiasts. Pit and slurry impoundments can also present a flooding potential if the spoil or dam retaining the water is unstable. These impoundments can retain large quantities of water, sediment and slurry that, if suddenly discharged, could result in immediate flooding and deposition downstream.

DANGEROUS IMPOUNDMENT SITE

DEVELOPMENT PROBLEMS

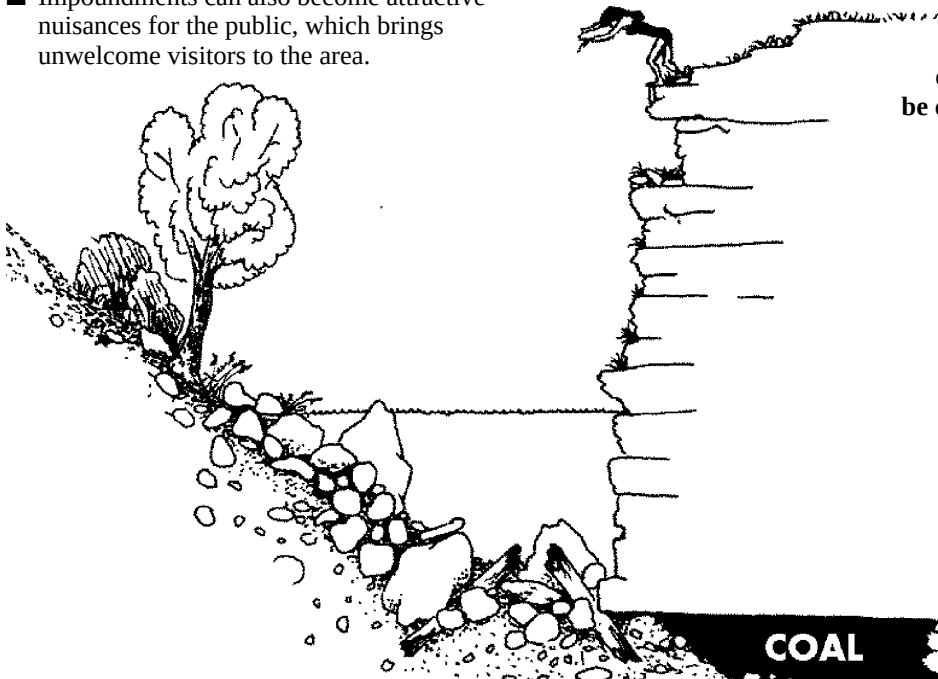
Impoundments left behind by a mining operation can pose many problems for site development, such as:

- Potential flooding problems due to heavy seasonal rains.
- Impoundments can saturate surrounding areas and create seeps, which can cause hillside instability.
- Impoundments can be very dangerous for swimmers due to unstable vertical rock faces, and steep drop-offs or large rocks beneath the water surface.
- Water quality problems can make the impoundment unsuitable for aquatic life or swimming. Impoundments can also be breeding grounds for mosquitoes.
- Impoundments can also become attractive nuisances for the public, which brings unwelcome visitors to the area.

FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to eliminate dangerous impoundments. Eligibility and selection of sites are evaluated on a site by site basis and are subject to funding availability. The primary criteria for establishing eligibility for funding include the following:

1. There is documented evidence of serious injury and/or loss of life attributable to the impoundment.
2. There is an occupied structure, public use facility, improved public road or park or recreational area located within 300 feet of the problem area.
3. There is evidence of either frequent visitation or an easy access capable of carrying vehicles to the impoundment area.
4. There is an occupied structure, improved property, improved road or public facility located within the flood path that would potentially be subjected to destruction or damage in the event that the impoundment retention structure should fail.
5. **If an occupied structure, public use facility, improved public road or park or recreational are placed within 300 feet of pre-existing impoundment that could reasonably be known to exist, the impoundment will not be eligible for program funding to abate present or potential dangers. Further, if similar development occurs downstream of and within the potential flood path of an impoundment with a failing or potentially failing retention structure and its presence could be reasonably known to exist, the problem will be deemed ineligible for funding.**



Underwater dangers of swimming in impoundment created by mining.

AML Problem Type: Flooding and Mine Drainage

BACKGROUND

Surface and subsurface drainage patterns and flow rates may have been altered as a result of land use practices, development and vegetative changes. Past mining is one activity that has impacted these long established drainage patterns and flow rates.

Poorly vegetated mine spoil has significantly higher erosion rates than vegetated spoil or undisturbed land. This situation has resulted in increased sediment in streams, which has reduced channel capacity and increased the frequency of flooding. Even areas reclaimed to grasses prior to 1977 can be responsible for increasing flooding frequency in watersheds that have been heavily mined. This increased flooding frequency is due to higher runoff rates resulting from a change in vegetative cover from trees to grasses.

Mining that occurred prior to existing regulations altered the shape of sub-watersheds from the drainage pattern, to which certain land uses had been accustomed. With reduced channel capacity, higher runoff rates and altered drainage patterns, occupied structures, public roads and farmland can be subject to more frequent dangerous flooding events and mine drainage damage.

Subsurface drainage can also be impacted by abandoned deep and strip mines. A pit impoundment can act as a reservoir for groundwater and increase its quantity and elevation. Deep mines, if located above drainage, can also store and discharge a significant amount of water to both surface and groundwater flow. This increased elevation and flow of groundwater can damage structure foundations, seep into basements and cause additional damage as well as contribute to slope instability.



Homes constructed near mine impoundments.

FLOODING AND MINE DRAINAGE SITE DEVELOPMENT PROBLEMS

Flooding events and mine drainage problems are associated with abandoned surface and underground mines. Abandoned surface mines can change the landform, which can redirect drainage and cause flooding. Impoundments left behind by mining operations can retain and discharge water, which also alters drainage patterns. These changes in landforms present flooding problems for structures, roads and farmland.

Mine drainage from abandoned underground mines or from impoundments can increase the base flow into streams, saturate mine spoils and contaminate groundwater. These problems can cause streams and aquifers to be polluted. Seepage to foundations or basement areas can create structural or nuisance problems. Seepage can also cause hillside instability. **Extreme caution should be exercised when excavating near mine entries or seepage areas near the coal outcrops to avoid intercepting a flooded underground mine. These underground mines can store large volumes of water and if suddenly discharged, could result in immediate physical harm, downstream flooding and water pollution problems.**



FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to address mine-related drainage and flooding that pose public health and safety problems. Eligibility and selection of sites are evaluated on a site-by-site basis and are subject to funding availability. The primary criteria for establishing eligibility for funding includes the following:

1. There is either a potential danger of flooding, a high probability of occurrence or a previous record of flooding in a problem area where a pre-existing occupied structure, improved property, public road or public facility is located within the flood path.
2. The majority of the potential, probable or historical flooding problems must be related to abandoned mine land-related sediment in the stream, increased runoff rates from pre-August 3, 1977, abandoned or reclaimed strip mines and/or altered sub-watershed drainage patterns that are affecting structures, roads and public facilities that pre-dated the mining.
3. An occupied structure, public facility or public road whose foundation stability is impacted by mine-related groundwater must have existed prior to the mining that resulted in the drainage problem. Mine drainage in a basement must result in or have a high probability of causing structural damage, damage to utilities and appliances or health problems related to dampness and mold.
4. Landowner responsibility for flooding and mine drainage problems must also be considered when eligibility determinations are made. These considerations include:
 - Was a structure placed subsequent to the abandonment of the mining feature and alteration of the pre-existing drainage pattern?
 - Was a structure placed subsequent to the mining in the revised flood path limit?
 - Is the landowner contributing to the flooding problem by adopting poor land management practices like allowing cattle in a stream or over grazing?
 - Has the landowner properly sized culverts? Has the public road authority properly sized culverts?
 - Is the landowner maintaining a stream course by removing debris such as logjams?
 - Was the landowner's pre-existing structure placed in a flood plain and subject to flooding prior to mining in the watershed?
 - Is the landowner addressing surface drainage around the structure (presence of gutters, establishing proper surface grades and placement of under-drains to minimize foundation seepage)?

AML Problem Type: Mine Gas

BACKGROUND

Abandoned deep and strip mines can be sources of gases, especially methane and carbon dioxide. Methane, primarily from deep mines, can be an explosive gas in certain concentrations. Carbon dioxide can be liberated from coal seams, be a product of the decomposition of organic matter in mine spoil or result from the dissolution of carbonate rock by acid mine drainage in mine spoil. Carbon dioxide will replace oxygen, especially in low areas such as basements. It can be transmitted through improperly abandoned wells, fissures in rock strata related to mine subsidence and through cracks in basement floors and foundations. If oxygen levels decline sufficiently in occupied unventilated areas, persons exposed can become unconscious and be asphyxiated. Toxic gases can also be discharged from burning coal refuse piles and underground mine fires. These gases can be especially hazardous to those people with respiratory problems.

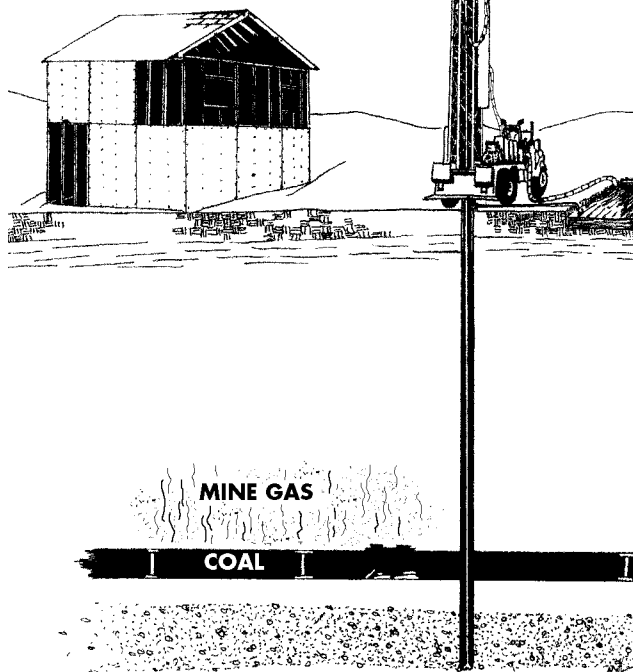
MINE GAS SITE DEVELOPMENT PROBLEMS

Mine gases need to be considered in the site development for occupied buildings. Methane and carbon dioxide are the primary mine gases generated from abandoned underground mines that pose a threat to the public's safety. Burning coal refuse and underground mine fires can generate toxic fumes and present a serious threat. Although not a common problem in Ohio, the decomposition of organic material in certain types of mine spoils can cause low oxygen levels in confined areas such as basements or crawl spaces.

FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to reduce the levels of mine-related gases posing public health and safety concerns. Eligibility and selection of sites are evaluated on a site by site basis and are subject to funding availability. The primary criteria for establishing eligibility for funding includes the following:

- The concentration of gases must indicate the potential for or the presence of a public health and safety problem. This may result from low oxygen levels, explosive levels of methane or smoke and noxious gas from a venting deep mine fire or burning coal refuse pile. The hazardous gas concentrations must be measured within or adjacent to an occupied structure or public facility or at an intensely visited area.
- Landowner responsibility for the presence of mine gases must also be considered when eligibility determinations are made. Landowners will be solely responsible for abating hazardous mine gas concentrations if the following apply:
 - If a landowner constructs a dwelling, or other structure, on program eligible pre-existing mine spoil, the landowner will be responsible for venting hazardous gas concentrations if present.
 - If a landowner burns debris on a coal refuse pile, resulting in ignition of the pile, the landowner will be responsible for its extinguishing.



Site being drilled to monitor for mine gas.

Water Replacement Policy

BACKGROUND

The Division of Mineral Resources Management's Abandoned Mine Land Program is responsible for abating the highest priority public health and safety problems associated with abandoned mines. One of these problems is the impact that abandoned mines have had on the quantity and quality of surface and ground water, especially those sources used for domestic consumption. Mining-related contaminants including sulfates, iron, manganese, and dissolved solids, have rendered potable water supplies unpotable. For the purposes of this program, potable water is defined as water used for human consumption that has concentrations of iron, manganese, dissolved solids and sulfates, as well as pH, within the acceptable limits of the primary and secondary drinking water standards established by the U. S. EPA and the Ohio EPA. Water quality, however, is not the only concern. Deep mine subsidence can also reduce the quantity of water supplied by fracturing aquifers, damaging equipment associated with a private well or collapsing deep mines used as water reservoirs.

FUNDING

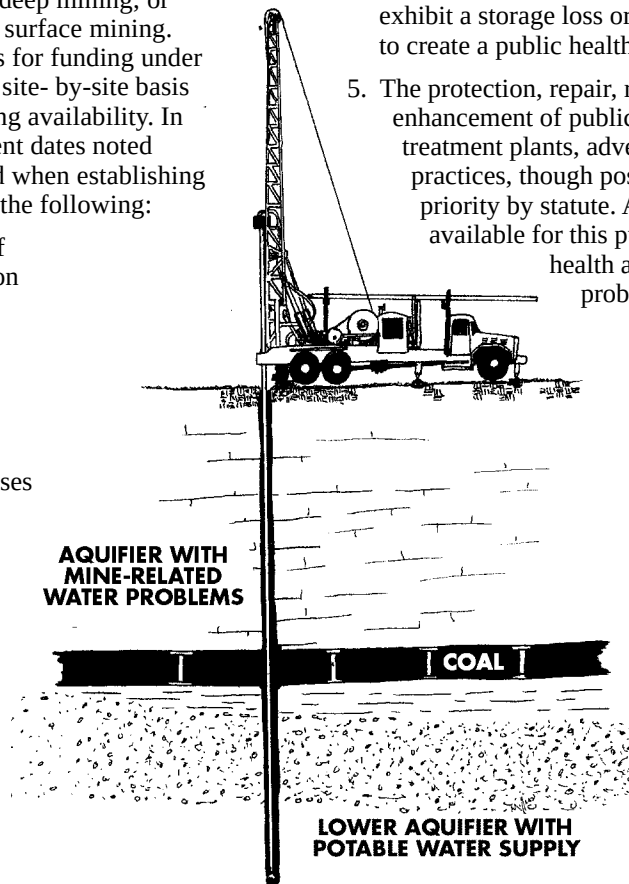
Funding may be available through the Division's Abandoned Mine Land Program to replace water supplies impacted by mining that occurred prior to September 1, 1982, if water quality is impacted by deep mining; or August 3, 1977, if impacted by surface mining. Eligibility and selection of sites for funding under the program are evaluated on a site- by-site basis and are subject to annual funding availability. In addition to the mining affectment dates noted above, the primary criteria used when establishing eligibility for funding includes the following:

1. As part of its investigation of quality problems, the Division will determine the ambient water quality characteristics at the site by analyzing the natural background concentrations of dissolved constituents in the water. A comparison of these analyses

with the analyses of the water supply will be made.

To be eligible for water replacement, a positive correlation between the mining and the dissolved constituents in the water supply sample must be established. The majority of the impact must be associated with past mining.

2. If it is determined that the majority of the water quality impact is associated with abandoned mining, it must be established that the concentration levels create a public health and safety problem. This is established if the primary and secondary drinking water standards, as established by the U.S. EPA and adopted by the Ohio EPA, are exceeded for mine-related constituents in water including, but not limited to, iron, manganese and sulfates, as well as pH and lie beyond the natural background levels (ambient) of the surface or ground water supply.
3. The Division must establish that the existing water supply was used as a principal water supply for a permanent residence prior to its impact. The Division will only replace supplies that were potable and a principal supply prior to impact. The Division must also establish that the water quality has not been impacted as a result of improper well construction or poorly maintained equipment.
4. Water quantity can be impacted by mine subsidence. To be considered for eligibility, a private supply must exhibit a storage loss or loss of yield in sufficient quantity to create a public health and safety problem.
5. The protection, repair, replacement, construction or enhancement of public facilities such as waterline and treatment plants, adversely affected by coal mining practices, though possibly eligible, is considered a low priority by statute. As a result, no funding will be available for this purpose until higher priority public health and safety and environmental problems have been addressed.

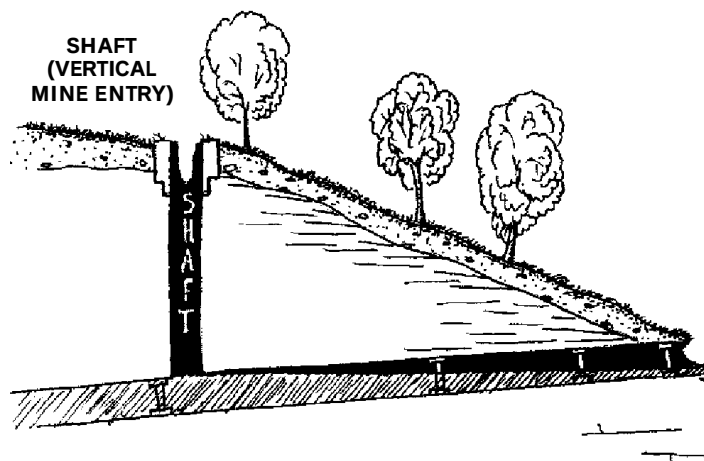


Drill rig establishing a water well below a contaminated aquifer.

AML Problem Type: Portals and Vertical Mine Openings

BACKGROUND

Deep mines are entered through horizontal or sloped entrances (portals) or vertical openings (shafts). Until the 1940's, the sealing of these openings was not statutorily required. Though sealed since the 1940's, many additional portals and shafts have fallen into disrepair. With no provision for continuous maintenance, these previously sealed entrances, as well as unsealed openings, can pose serious public health and safety problems. These problems include the presence of methane gas, especially if at an explosive level, and a low level of oxygen. These gas levels are especially worrisome if access to abandoned underground mines is made. The collapse of mine shafts and tunnels leading away from the portals and slope entrances can also have catastrophic consequences.



PORTALS AND VERTICAL MINE OPENINGS SITE DEVELOPMENT PROBLEMS

Mine openings that are open or improperly sealed are inherently unsafe. These entries can be easy to see or could be concealed by years of vegetative growth or past landscaping practices. Some portals (horizontal entries) are the sources of mine drainage discharge. Problems with developing or building near mine entries include:

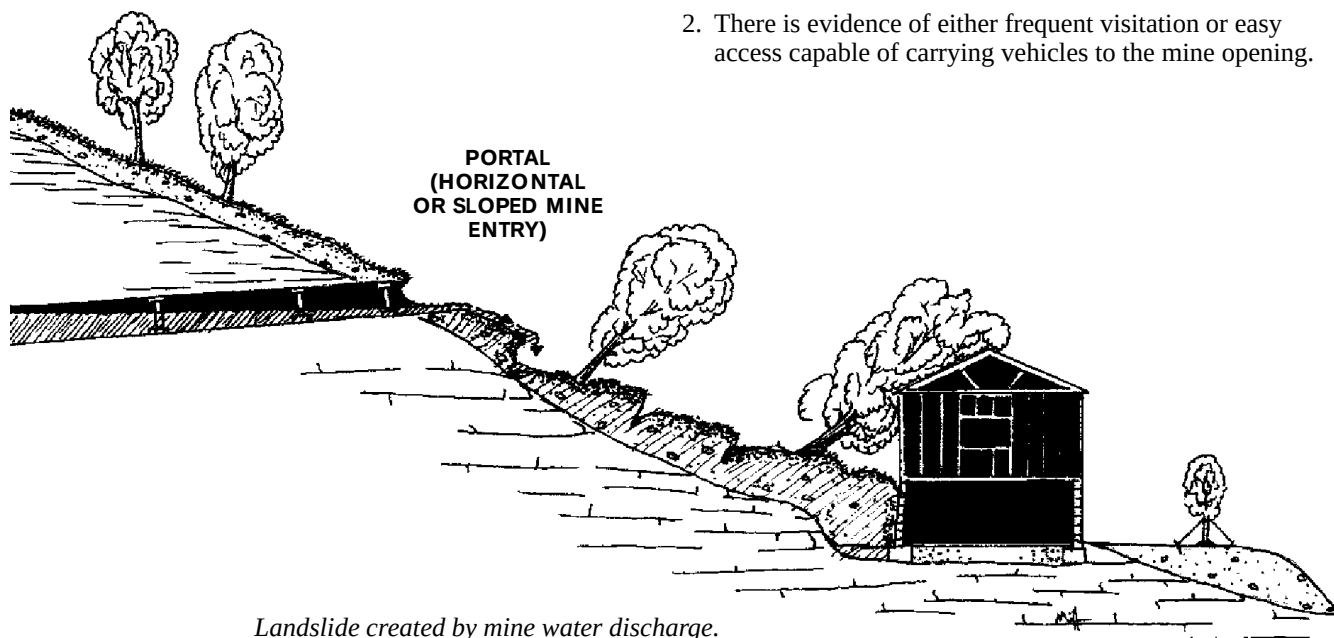
- Foundation problems in the event of a collapse.
- Mine drainage seepage into foundations or basement areas
- Mine drainage seepage can cause hillside instability.
- Mine gas infiltration.

Mine openings are considered dangerous attractive nuisances. Developing near these openings increases public visitation. Portals and vertical mine openings are dangerous to these visitors because of cave-ins, mine gases, and flooded conditions.

FUNDING AND ELIGIBILITY CRITERIA

Funding may be available through the Division's Abandoned Mine Land Program to seal mine openings. Eligibility and selection of sites are evaluated on a site by site basis and are subject to funding availability. The primary criteria for establishing eligibility for funding includes the following:

1. There is an occupied structure, public use facility, improved public road or public park or recreational area located within 300 feet of the mine opening.
2. There is evidence of either frequent visitation or easy access capable of carrying vehicles to the mine opening.



Landslide created by mine water discharge.

“Ask Before You Build” Resources

1. **Consult a qualified experienced geotechnical and/or engineering firm to assist in site development.**
2. **Ohio Department of Natural Resources**
Contact the following divisions through the web
<http://www.ohiodnr.com>
 - a. **Division of Geological Survey** 614-265-6576
 - Staff knowledgeable about Ohio mining history.
 - Topographic maps showing locations of underground mines at a cost of \$4 each.
 - Detailed, individual mine maps with costs ranging from 25¢ to \$6. Some maps show depth to the mine.
 - Drilling records and other geological information for the area.
 - All maps and printed information can be ordered by telephone.
 - b. **Division of Mineral Resources Management** 614-265-7072
 - Information concerning abandoned mine land reclamation programs
 - History of abandoned mine land complaints
 - Drilling records and geotechnical evaluations for some abandoned mines areas.
 - Abandoned Underground Mine Locator Web Site allows anyone with internet access to create a map showing the location of the abandoned underground mines in Ohio.
<http://www.dnr.state.oh.us/mineral/abandoned>
 - c. **Division of Real Estate & Land Management** 614-265-6778
 - GIS maps (scale 1"=1 mile) showing underground mines. Maps cost \$25.
 - Residential land use over underground mines in each county. Maps cost \$50–\$100
 - Electronic files available for GIS use at no charge.
 - d. **Division of Water** 614-265-6750
 - Water well and floodplain management information.
3. **Soil & Water Conservation Districts and the USDA Natural Resources Conservation Service** (see local listing)
Provides technical home site development information to perspective buyers on soils, subdivision, storm water management and erosion control. Also a source for historic site development information.*
4. **County and or City Engineers**
Road maps or aerial mapping, maintenance information on roads, culverts and bridges and historic site development information.* Also a resource for the names of qualified experienced geotechnical and engineering firms to assist in site development.
5. **Regional, County or City Planners**
Site reviews for individual houses or subdivisions, floodplain management and planning services to local governments. Also a resource for the names of qualified experienced geotechnical and engineering firms to assist in site development.
6. **County and City Health Departments**
Issue permits for water wells and residential sewage system designs and historic site development information.*
7. **Township Trustees**
Zoning and historic site development information.*
8. **Ohio Mine Subsidence Insurance Program** 614-839-6446 or 800-282-1772. Contact MSI through the web
<http://www.ohiominessubsidence.com>
 - Information available from the Ohio Mine Subsidence Insurance Underwriting Association on past underground mine subsidence claims.
 - Most insurance policies do not cover structural damage to a home due to mine subsidence. The Mine Subsidence Insurance Fund provides low cost insurance coverage in 37 Ohio counties for homes damaged due to mine subsidence.
 - Report your claim to an agent or the insurance company. The company will notify the Ohio Mine Subsidence Insurance Underwriting Association, who administers and adjusts the claim.
 - Insurance coverage is mandatory in 26 of the 37 counties, with a low annual premium.
 - Available for 1–4 family dwellings having at least 50% of the living area occupied. Mobile homes and farmhouses are also eligible.
 - Coverage is the lesser of \$50,000 or the amount of insurance coverage for the dwelling.
 - Coverage includes costs of excavation, foundations, and underground utilities.
 - Annual premium is \$1 in mandatory counties and \$5 in optional counties.

RECOMMENDATIONS TO LOCAL OFFICIALS FOR ASSISTING THE PUBLIC CONSIDERING THE DEVELOPMENT ON AML:

- Make underground mine maps available at County offices and encourage their use.
- Incorporate underground mine maps into your comprehensive planning process and direct development to areas that are geologically stable.
- Use subdivision regulations to ensure that developers have provided for geologic stability if underground mines are in the area. Specifically cite “underground mines” in your regulations. Areas more susceptible to subsidence can be set aside as open space if mine subsidence stabilization is cost prohibitive.
- Add “underground mines” “ and “surface mines ” to your site review checklists.
- Be aware that not all mines are mapped, particularly old mines dating to pre-1874. Mine maps are only a general planning tool.
- Gather detailed information about subsurface conditions through geotechnical investigations (core borings and analysis). This expense can be borne by the developer in many cases since the developer wants to ensure that stable geologic conditions exist.
- Compile a list of geotechnical firms operating in your region.

* Historic site development information is usually information you will receive from local officials on area land use problems such as flooding, poor soils, landslides, AML etc.



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**The Ohio Department of Natural Resources
Division of Mineral Resources Management**

Bob Taft, Governor
Samuel W. Speck, Director
Michael L. Sponsler, Chief

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TECHNICAL PAPER SESSION 10
ACID MINE DRAINAGE - Part 2

Title: **An Ongoing Evaluation of Bauxsol at the Gilt Edge Mine, South Dakota**

Authors: **Jim Jonas***, Geochemist, CDM Federal Programs Corporation; **Ken Wangerud**; and **David McConchie**

Title: **Rehabilitation of the Old Bevier Passive Treatment Wetland, Macon County, Missouri**

Authors: **Paul T. Behum Jr.***, Hydrologist; **Kwang “Min” Kim**, Hydrologist; **Kevin W. Garnett**, Mining Engineer; **Len Meier**, Physical Scientist, Office of Surface Mining, Mid-Continent Regional Coordinating Center; and **Angela Glascock***, Environmental Specialist, **Brian Hicks**, Hydrologist, **Michael Mueller**, Reclamation Specialist, and **Michael Phillips**, P.E., Civil Engineer, Missouri Department of Natural Resources, Air and Land Protection Division

Title: **Progress of BLM-funded Acid Rock Drainage Research**

Authors: **William White***, Physical Scientist, Bureau of Land Management, Salt Lake Field Office, **Kim A. Lapakko**, Principal Engineer, Minnesota Dept. of Natural Resources, Lands and Minerals Division; and **Edward M. Trujillo**, Associate Professor, University of Utah, Chemical and Fuels Engineering Dept.

REHABILITATION OF THE OLD BEVIER PASSIVE TREATMENT WETLAND, MACON COUNTY, MISSOURI¹

Paul T. Behum, Jr., Kwang “Min” Kim, Kevin W. Garnett, and Len Meier,
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Missouri Department of Natural Resources, Air and Land Protection Division,
Jefferson City, MO.

ABSTRACT

The Old Bevier Aerobic Wetland in Macon County, Missouri, was constructed between 1990 and 1991 by the Missouri Department of Natural Resources, Land Reclamation Program (LRP) for the purpose of treating Acid Mine Drainage (AMD). The principle source of the AMD is from an underground mine that operated during the 1920's through 1950's, which was partially exposed during surface mining in the 1950's. Limestone bedding of an AMD collection system provided alkalinity similar to an Anoxic Limestone Drain (ALD). Because the original aerobic wetland failed when a critical dilution water supply became unavailable, the total acidity of the AMD overwhelmed the limited neutralization ability of the aerobic wetland. The aquatic vegetation deteriorated and treatment became ineffective. The Missouri Land Reclamation Program with the assistance of the Office of Surface Mining, Mid-Continent Regional Coordinating Center rehabilitated the Old Bevier Aerobic Wetland in 2001, incorporating newer technologies to improve the performance. This paper describes the construction of an extended AMD collection pipeline, a 2-stage Vertical Flow Wetland System (VFWS) and associated oxidation cells and aerobic wetlands. The improved system is designed to treat 2.84 liters per second (45 GPM) AMD discharge with high iron (450 mg/L) and total acidity (760 mg/L), but low aluminum content (<2 mg/L). Initial evaluations find that effluent dissolved iron is 4.5 to 56 mg/L, net alkalinity (11 mg/L), and near neutral pH (5.3 to 6.95). Although no specific structures were incorporated in the design for manganese removal, manganese level in the discharge (7.9 mg/L) is significantly lower than the inlet level (10 mg/L). This initial evaluation was conducted during winter months and prior to the establishment of emergent vegetation. Improvements in metal removal are anticipated in the spring of 2002 upon establishment of aquatic vegetation and increased biologic activity.

INTRODUCTION

The Old Bevier II Reclamation Project in Macon County, Missouri, is located 11.2 kilometers southwest of the city of Macon in the watershed of the East Fork of the Little Chariton River (Figure 1). The project area is within the extensively mined Bevier-Ardmore Mining District, historically the most important coal-producing field in Missouri (Hinds, 1912). The extraction of coal began around 1859 in the field with Macon County coal production totaling 39 metric tons (43 million short tons) between 1889 and 1964 (Gentile, 1967). Room-and-pillar mining was extensive in the 1920's through the early 1950's, followed by area-type surface mining. The Bevier-Wheeler coal bed, composed of the upper, thicker Bevier and a lower, thinner Wheeler

coal bed, was the principle target of the mining. At the project site, the overlying 45.7-cm (18-inch) thick Mulky coal was also removed from surface mines (Gentile, 1967). The abandoned underground workings in the Bevier area generate, store, and transmit Acid Mine Drainage (AMD). The surface mining operations often intercepted this AMD and now convey the acid water to a series of seeps along the drainage channels. A number of small coal waste piles (gob) and acid-forming materials exposed by the surface mining generate additional AMD at the Old Bevier site. Several unnamed tributaries of the East Fork of the Little Chariton River are devoid of aquatic life and the river water is degraded by iron, manganese and sulfate from the mine area. Ground water level fluctuations and flushing of AMD from the underground workings during seasonal rainfall events lead to variations in the quality and quantity of water in these streams.

Figure 1. Location Map of the Old Bevier II Project Site.

The original Old Bevier Reclamation Project, designed by Metropolitan Engineering Co. (MECO) of Hannibal, Missouri, was subdivided into three project areas known as the North, South, and East Sites (Hare, 1992; Figure 2). Construction activity began on March 12, 1990, and was completed on April 30, 1991, at a total cost of \$932,089 U.S. The project reclaimed 18.6 hectares (46 acres) of abandoned mine lands, including three acres of gob, 121.9 meters (400 feet) of dangerous highwalls, and one vertical opening. An aerobic wetland, with its associated collection and dilution pipelines, was constructed at the South Site to treat AMD.

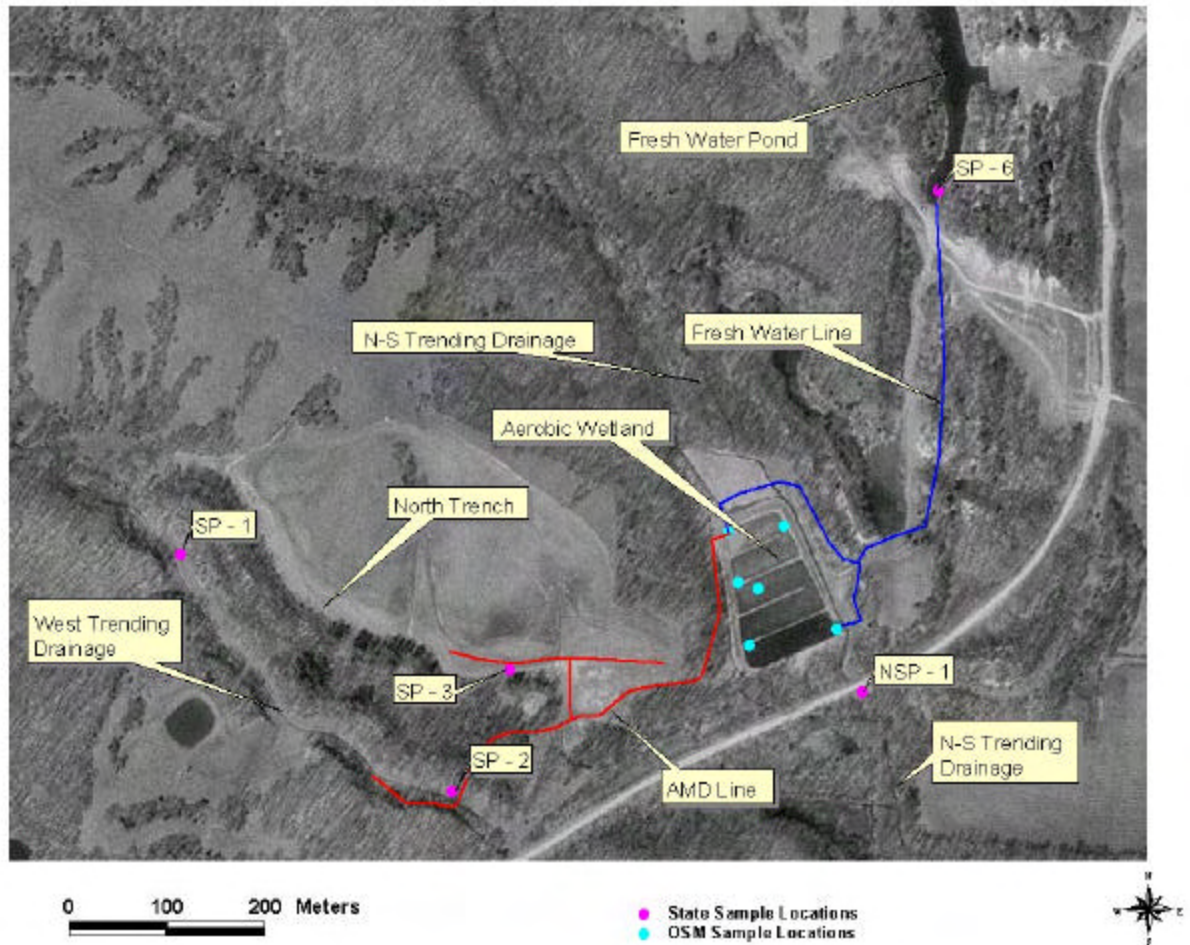


Figure 2. Water Sample Locations.

The South Site AML area is bound by two waterways. The main watercourse (its lower reach is just east of the aerobic wetland) loops around the site to the east and north. A second watercourse (the west trending drainage) flows out of the northwest and drains about 104 hectares (Figure 2). Multiple intermittent seeps, in part fed by underground mine workings, occur along these drainage channels at the base of exposed highwalls, coal outcrops, and spoil ridges. Spoil may be calcareous or acidic. The spoil ridges are often capped by acidic, black carbonaceous shale. Years of erosion deposited a 0.9 to 1.5 meter (3- to 5- foot) thick layer of acid-forming sediment in the watercourses.

The west-trending drainage was mined by contour-type surface methods (Figure 2). Contour mining there progressed along the west-trending drainage until the overburden reached a thickness of 9.1 to 12.1 meters (30 to 40 feet). A series of spoil ridges rose 7.6 to 15.2 meters (25 to 50 feet) above the surface of the watercourses in the former valley. A final cut was at the northern edge of this disturbance. This pit, known as the North Trench in the 1991 project, (Figure 2) was reclaimed to create a swale that parallels the original valley. Reclamation of the valley area consisted of covering the contaminated sediment with a 1.5 to 1.8 meter thick layer of clayey soil and reconstructing a new, elevated stream channel. The raised stream channel was designed to isolate surface drainage from an AMD-impacted zone in the old streambed. The final pit (North Trench in Figure 2) apparently intercepted underground workings and is the

principle source of AMD. Flow from this area was sampled at SP-3 (Figure 2 and Table 1). To the south, AMD flows from an outcrop of the Bevier coal. A pre-reclamation water sample of this AMD (Site SP-2) revealed elevated concentration of iron, manganese, and sulfate (Table 1, Figure 2). A French drain in the North Trench collects seepage and directs the AMD, along with water from a French drain in the west-trending drainage, into the original Old Bevier wetland.

Original Aerobic Wetland

Built as one of the earliest passive AMD treatment systems in the U. S., the Old Bevier Passive Treatment Wetland was initially effective in reducing iron loading, but less effective in reducing discharge acidity (Table 1 and 2; Hare, 1992). The key part of the original design for passive treatment included intake of alkaline fresh water from a nearby lake to increase pH and boost alkalinity. Although the wetland was designed to function as an anaerobic wetland it operated primarily as an aerobic wetland. Designed for a 3.78-liters-per-second [60 gallons-per-minute (GPM)] flow, the wetland was supplied by about 1.89 liters-per-second (30 GPM) of AMD from the two AMD-collection pipelines with the remainder from the fresh water source. A small, limestone-lined chamber at the entrance to the first wetland cell was designed to mix the two water sources (Figure 3).



Figure 3. 1998 Sampling of AMD at the Submerged Outlet of the Collection System (Wetland Inlet).

The original project consultant reported an initial 95% removal of iron, but water samples taken by the LRP in 1991 show higher iron concentrations (Table 1). The reduction of sulfate depended on an adequate supply of dilution water. Due to problems with the dilution source, only a minor reduction in sulfate was recorded in 1991 (Table 1; Hare, 1992). MECO also observed that the wetland behaved aerobically, (dissolved oxygen in the 4 to 5 mg/L range), but anticipated a shift to anaerobic-dominated treatment.

Table 1. Water Quality at the Old Bevier South Site Associated with the 1991 Reclamation¹

Parameter ²	SP-2 AMD from Southern Seeps: 1988	SP-3 AMD from Northern Seeps: 1988	AMD at Wetland Inlet: July 1991	SP-6 Dilution Water: East Site Last Cut Pit Source: 1991	SP-1 West Drainage: 1988 Data (New Dilution Water Source Considered in 2000)	Treated AMD at the Wetland Outlet: July 1991
pH	3.20	2.60	3.20	8.1	7.7	3.3
Total Alkalinity	pH < 4.3	pH < 4.3	pH < 4.3	103	168	pH < 4.3
Total Acidity	1,200	769	625	-57	-96	180
Dissolved Oxygen (DO)	6.3	5.5	NT	8.7	9.2	NT
Total Iron	502	90	299	0.36	1.18	18.10
Total Manganese	13.0	13.7	15.5	0.10	0.99	31.2
Total Aluminum	NT	NT	NT	NT	NT	NT
Sulfate	3,463	3,238	3,060	393	406	3,300
Total Dissolved Solids (TDS)	5,174	4,564	4,620	824	773	4,070

1. Samples collected by the Land Reclamation Program, 1988 through December 1991 and OSM-MCRCC in 1998 thru 2001.

2. All values are in mg/L except pH which is in Standard Units, NT = Not Tested.

Wetland Failure

The AMD treatment by the original aerobic wetland began on June 3, 1991. Emergent vegetation rapidly grew and covered most of the water surface during the first summer. Two consecutive years of drought dropped the pool level of the dilution lake limiting dilution water availability. Later, the fresh-water supply pipeline was damaged. By 1994, the pH in the third wetland cell dropped to about 2.9 because alkaline dilution water was not available to offset acidity released as oxidized dissolved metals (Figure 4). This low pH killed the aquatic vegetation and slowed metals removal. By 1996, the removal rate for iron remained about 92% due primarily to abiotic oxidation (Figure 4). Reductions in acidity, sulfate and manganese were not significant and iron removal deteriorated in latter years (Figure 5). The treatment facility required rehabilitation by 1998 due to failure of the dilution water source, and exhaustion of some of the carbon content of the compost, and accumulation of iron precipitate.

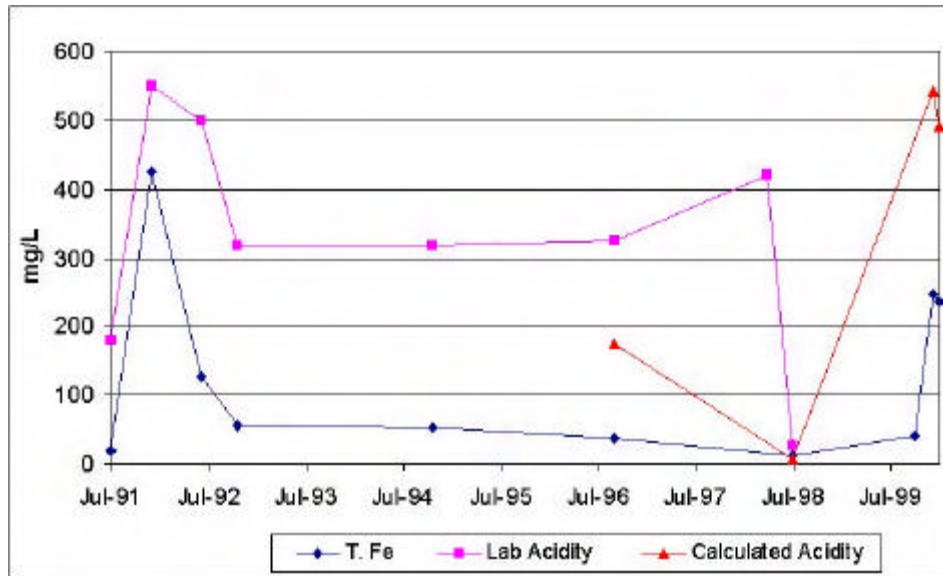


Figure 4. Total Iron and Acidity at the Outlet of the 1991 Old Bevier Wetland.

After completing a systematic hydrologic study in 1999, the LRP and Office of Surface Mining Mid-Continent Region Coordinating Center (OSM-MCRCC) found that the failure of the dilution water supply was the principle problem with the original system. Although the AMD coming into the wetland contained high alkalinity derived from the limestone bedding of the collection pipeline (about 120 to 180 mg/L as equivalent CaCO_3 , Tables 1 and 2), additional alkalinity from the dilution water was needed to offset the acidity (about 620 to 760 mg/L) of the AMD.

HYDROLOGIC INVESTIGATION AND INITIAL CONSTRUCTION ACTIVITY

By early 1998, the LRP/OSM-MCRCC project team decided to conduct a comprehensive hydrologic study at the constructed wetland site to better understand the nature of the AMD. The goal of this study was to gather the scientific and engineering data necessary to transform the Old Bevier Passive Treatment Wetland into an improved passive treatment system. This project was also intended to give the team experience applying recent treatment innovations to the design and construction of AMD abatement facilities. Similar technology might then be employed at other AML sites in Missouri.

Passive treatment is often enhanced when AMD can be collected as anoxic (<1.0 mg/L dissolved oxygen) flow. To best characterize water quality, the AMD should be collected and analyzed in the same chemical state as found in the field. To accomplish this, anoxic water may be sampled from a well, a wet-type mine seal, or an existing AMD collection pipeline as at Old Bevier. The outlet of the drainage collection system at the center of the mixing chamber (Figure 3) was inaccessible because it was submerged and buried in iron floc. A valve-controlled tap in the collection pipe was installed during Phase I construction (Figure 6). From the tap, a 10.2 cm (4-inch) PVC pipe conveys flow for temporary bypass treatment. It provides a means to collect AMD, the characterization of which is critical to the redesign effort, and allows a standpipe connection for water head measurement. The Phase I activity also involved construction of an all-weather access road and facility area near the southwest corner of the original wetland.

Table 2. Pollutant Loading at the Old Bevier South Site applicable to 1991 Reclamation¹

Location/ Constituent	Concentration¹ (mg/L)	x Flow Rate² L/sec (GPM)	x Conversion Factor (86.4)	= Loading (grams/day)
<u>Inlet AMD</u>				
Total Iron	299	1.89 (30)		48,887
Manganese	15.5	1.89 (30)		2,534
Acidity	625	1.89 (30)		102,188
Alkalinity	0	1.89 (30)		0
Sulfate	3,060	1.89 (30)		542,820
<u>East Lake Dilution Source</u>				
Total Iron	0.36	1.89 (30)		59
Manganese	0.1	1.89 (30)		16
Acidity	-57	1.89 (30)		-9,320
Alkalinity	103	1.89 (30)		16,841
Sulfate	393	1.89 (30)		64,256
<u>Pre-Reconstruction Passive Treatment System Outlet</u>				
Total Iron	18.1	1.89 (30) ⁴		2,959
Manganese	31.2	1.89 (30) ⁴		5,101
Acidity	180	1.89 (30) ⁴		29,430
Alkalinity ³	0	1.89 (30) ⁴		0
Sulfate	3,300	1.89 (30) ⁴		539,550

1. The Land Reclamation Program collected samples in 1988 through 1991.
2. Flow values are estimates.
3. Estimated to approximate 0.00 when pH < 4.3.
4. Discharge was 37.9 L/ sec. (60 GPM), dilution source failed.

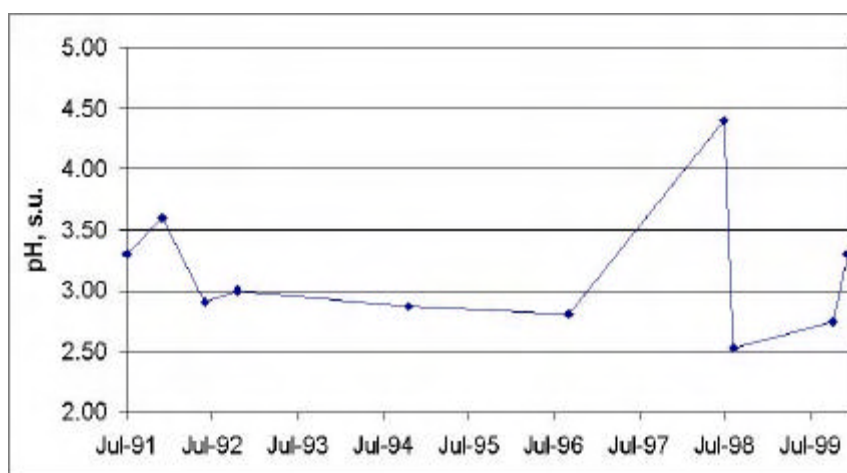


Figure 5. Change in the pH with Time: Outlet of the 1991 Old Bevier Wetland.

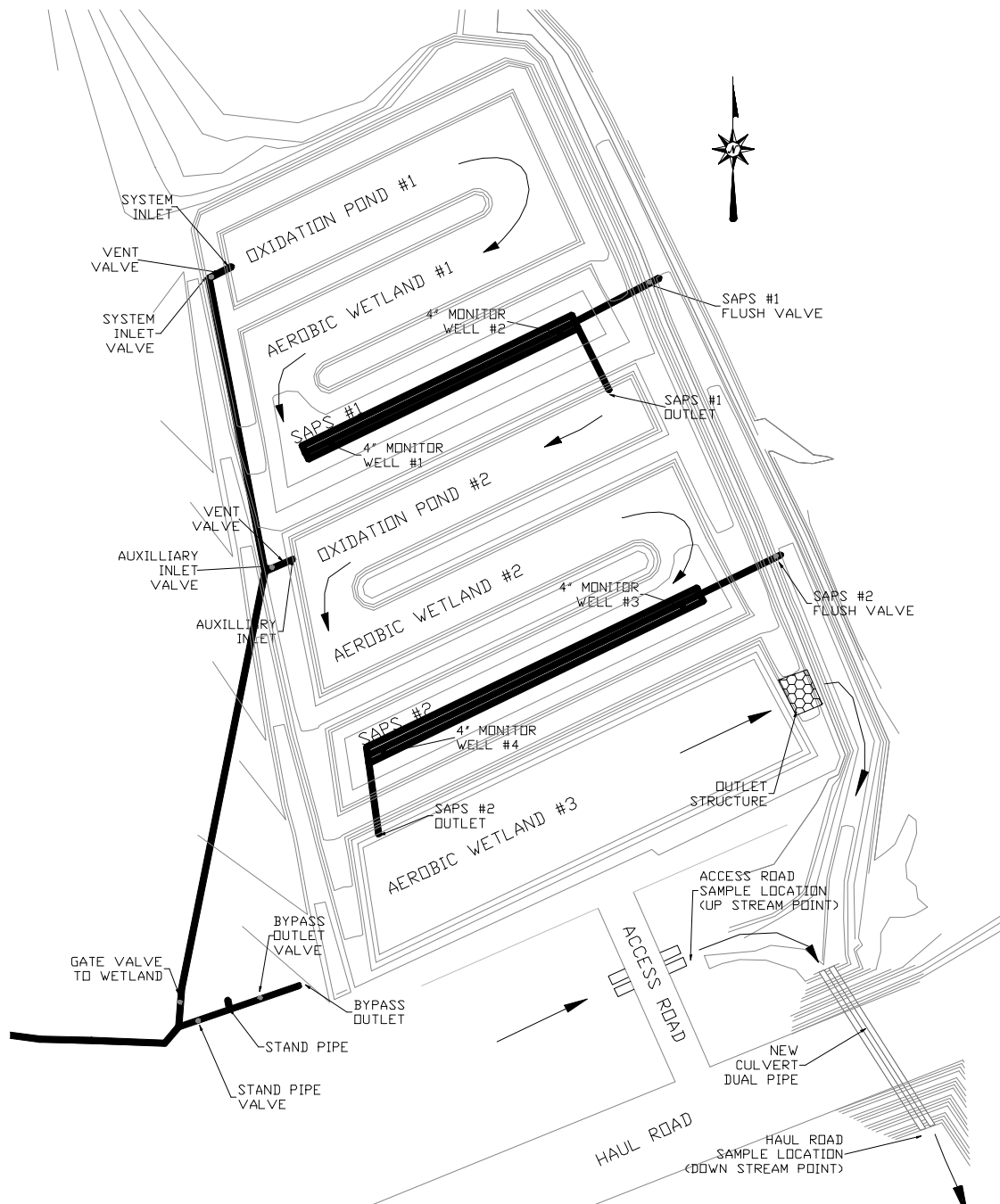


Figure 6. Passive Treatment System of the Old Bevier II Project.

Water Sampling and Analysis

Although some historical AMD water data were available, there was uncertainty about methods employed for field measurements and analyses. Also, there were little or no data on some critical parameters such as aluminum. Systematic water sampling was performed over a two-year period during 1998 and 1999 (Behum et. al., 2001). The parameters selected to characterize the AMD were those suggested by Hyman and Watzlaf (1995) and Wildeman and

others (1997) and include dissolved metals (iron, aluminum, and manganese) and sulfate. The important measurements of both ferric and ferrous iron were also taken during the late 1990s. Total and ferrous dissolved iron concentrations were determined in the field with a portable colorimeter. Dissolved ferric iron values were calculated by subtracting ferrous iron from the total dissolved iron. Similarly, this method was used to estimate total metal values using an unfiltered sample. No attempt was made to directly measure ferric iron in the field as suggested by Wildeman and others (1997). Additional field measurements included temperature, pH, redox potential (Eh), conductivity, salinity, dissolved oxygen (DO), and total alkalinity, using either electrochemical or titration methods. Total acidity was also determined in several rounds of lab tests and supported by calculation methods (Hyman and Watzlaf, 1995). Water samples were collected consistent with standard methods (Eaton and others, 1995).

Jar Test

A Vertical Flow Wetland System (VFWS) was being considered as a possible technology for use in remediation of the wetland. Before this design could be completed, locally derived limestone was evaluated for alkalinity production potential. This task used a modified version of the Jar Test method suggested by Watzlaf and Hedin (1993). A 18.9-liter (5-gallon) plastic carboy was filled with locally quarried limestone. This container was then filled with AMD from the sample site and placed in a cooler with some ice to maintain a temperature similar to the groundwater. Samples were then drawn over the next several days and the total alkalinity was measured (Hach digital titration method). Data were plotted on a chart to show the rate of alkalinity generation (Behum et. al., 2001). Two replicates of the test were run to ensure data consistency. The tests showed that the potential increase in alkalinity using this limestone and AMD combination was 160 to 190 mg/L.

Temporary Chemical Treatment

A popular device commercially known as an *Aquafix* system² (Aquafix Water Treatment Systems, Kingwood, WV) chemically treated diverted AMD while construction progressed on the wetland. The unit was connected to the sampling outlet constructed in Phase 1 and the flow to the wetland was turned off. *Aquafix* treatment of the AMD continued over the course of the construction activity.

PASSIVE TREATMENT

Following the hydrologic investigations, Missouri LRP and OSM-MCRCC developed design options for the improvement of passive treatment at the site.

Design Options

The data suggested consideration of three different design options to rehabilitate the wetland. These options included:

OPTION 1

Dilution Pond Construction and Aerobic Wetland Rehabilitation. An adequate amount of suitable alkaline dilution water could be obtained by constructing a new 7,402 cubic meter (6 acre-foot) impoundment. A rebuilt pipeline from the East Site freshwater impoundment (Figure 2) could deliver the dilution water. Table 3 provides the loading calculations used in this evaluation. As in the original design, this plan has dilution water alkalinity offsetting AMD acidity. An aerobic wetland would provide a favorable environment for the precipitation of metals contained in the AMD/alkaline water mixture. The new dilution water source would be located upstream from the surface mining area and was expected to have relatively high water quality (Tables 1 to 3). Note that both dilution sources have elevated sulfate (>300 mg/L), which would contribute to sulfate loading (Tables 2 and 3).

OPTION 2

Dilution Pond and VFWS Construction with Aerobic Wetland Rehabilitation. This option only uses dilution water from the new, 7,402 cubic meter (6 acre-foot) impoundment as an alkalinity source (Table 3, west dilution source) to partially offset the AMD acidity. However, additional alkalinity is required (compare acidity loading from the inlet to the AMD load of the outlet, Table 3). A Vertical Flow Wetland System (VFWS)-also known as a Vertical Flow Pond- provides the remaining alkalinity. The VFWS is a deepwater pond with piping that drains the AMD/dilution water mixture downward through a layer of compost, through an alkalinity source (a bed of limestone), and out through collection pipes and water level control structure. The critical step is the removal of dissolved oxygen by the deep water and compost. This shift in the redox potential prevents metal precipitation in the limestone bed, which would reduce the life of the system. A downstream aerobic wetland would then provide a favorable environment for precipitation of metals.

OPTION 3

Two-Stage VFWS / Anaerobic Wetland Treatment. Option 3 does not require the use of dilution water to partially offset the acidity. Instead, alkalinity is generated in a two-stage VFWS. Because of the high acidity of the untreated AMD (Tables 1 - 3), additional alkalinity may be required. An aerobic wetland, operating in series with the VFWS, produces this alkalinity from limestone and bacteria-mediated sulfate reduction reactions within its thick compost layer.

PHASE II DESIGN

In assessing design options, the LRP was concerned that, due to site topography, a dilution pond would have to be located remote from the treatment system in a heavily wooded area. This would require a pipeline, a feature that had been employed for the original treatment system, and proved to be troublesome. Also, project costs would have increased from clearing, grubbing, and earthwork associated with dam and impoundment construction in a wooded area.

Based on the above considerations and a review of data collected during the hydrologic evaluation (Tables 1-3), the LRP decided to implement option 3-a two-stage VFWS system with

Constituent	Concentration¹ mg/l	x Flow Rate L/sec(GPM)	x Conversion Factor 86.4	= Loading (g/day)
<u>Inlet AMD</u>				
Total iron	450	1.893 (30)		73599
Manganese	15	1.893 (30)		2453
Acidity	761.7	1.893 (30)		124580
Alkalinity	180	1.893 (30)		29393
Sulfate	3400	1.893 (30)		556088
<u>East Lake Dilution Source</u>				
Total iron	0.36	2.524 (40)		79
Manganese	0.1	2.524 (40)		22
Acidity	-57	2.524 (40)		-12430
Alkalinity	103	2.524 (40)		22462
Sulfate	393	2.524 (40)		85703
<u>West Lake Dilution Source (proposed)</u>				
Total iron1.	18	2.524 (40)		257
Manganese	0.99	2.524 (40)		216
Acidity	-96	2.524 (40)		-20935
Alkalinity	168	2.524 (40)		36636
Sulfate	406	2.524 (40)		88538
<u>Resultant : AMD + East Lake + Proposed West lake</u>				
Total iron	123.3	6.94 (110)		73935
Manganese	4.5	6.94 (110)		2691
Acidity	152.1	6.94 (110)		91184
Alkalinity	147.6	6.94 (110)		88508
Sulfate	1217.8	6.94 (110)		730082
<u>Resultant : AMD + East Lake only</u>				
Total iron	193.1	4.417 (70)		73678
Manganese	6.5	4.417 (70)		2475
Acidity	293.9	4.417 (70)		11211212
Alkalinity	136.0	4.417 (70)		51860
Sulfate	1681.7	4.417 (70)		641791

1. “Lake” Samples collected in 1988 by the Land Reclamation Program. “Inlet AMD” is an average of State and OSM values collected as of the 1999 dilution option studies and approximately represent the inlet quality at the time this paper was prepared.

The VFWS cells, designed for a 20-year effective life, contain a 1.3-meter (4-foot) thick layer of limestone in VFWS #1 and a 0.91-meter (3-foot) thick layer in VFWS #2. Overlying the limestone beds are a 0.46-meter (1.5-foot) thick layer of organic matter and then a 0.61-meter (2-feet) of water. Because of the limited amount of elevation head available at these sites the latter two layers are slightly thinner than the standard VFWS design. Most of the organic matter is mushroom compost shipped from the Miami, Oklahoma area. The VFWS units are constructed with 15.2 cm (6-inch) and 20.3 cm (8-inch) Schedule 80 PVC underdrain piping and Agri Drain Corporation's (Adair, IA) *Inline Water Level Control Structures*³. 20.3 cm (eight-inch) Schedule

80 PVC piping and control valves provide a flushing capability to each VFWS unit (Figure 7) as suggested by Skovan and Clouser (1998) and Cavazza (1999). The retention time in VFWS #1 is 15 hours and VFWS #2 is designed for 12 hours. The aerobic wetlands are designed with 0.46 meter (1.5-foot) thick layer of compost, which is mostly composed of a manufactured product from Chamness Technologies (Eddyville, IA). The aerobic wetland cells are also designed for a 12-hour retention time. Water depth of aerobic wetland cells is variable, ranging about 6.35 mm (0.25 inches) to 30.5 cm (12 inches) thick. Underlying Aerobic Wetland #3 is a 15.2 cm (0.5-foot) thick limestone layer. A small anoxic limestone drain (ALD) was constructed along the western edge of the reconstructed wetland to collect AMD seepage, with outlets into Cells #4 (oxidation pond #2) and #7 (aerobic wetland #3, Figures 6 and 7). This ALD is designed with a 12-hour retention time.

Table 4. Design Parameters: Untreated AMD Quality and Contaminant Load.

Parameter	Value	Units	Comments
pH	5.8	S.U.	typical value
Eh (estimated) 73	mv	typical	value
DO	0.48	mg/L	average values
Total Fe	450	mg/L	average value
D. Fe	400	mg/L	average value
D. Fe+3	20	mg/L	by subtraction
D. Fe+2	380	mg/L	average value
Al	0.4	mg/L	average value
Mn	15.0	mg/L	average value
Acidity	761.7	mg/L	average value
Alkalinity	180.0	mg/L	average value
Net Acidity	581.7	mg/L	by subtraction
Sulfate	3400	mg/L	average value
Flow 1	1.89	L/sec.	(30 GPM) from existing AMD line, average value
Flow 2	0.63	L/sec	(10 GPM) est. added from Western extension
Flow 3	0.32	L/sec	(5 GPM) est. to be collected seep adjacent to the wetland
Total Flow @ Inlet	2.52	L/sec	(40 GPM) @ 1st thru 5th cells
Total Flow w/ Seep	2.84	L/sec	(45 GPM) @ 6th and last cells

Contaminant Load Calculations

Acid loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/d} \times 581.7 \text{ mg/L} \times 1 \text{ g/1000 mg} = 126,853 \text{ g/d}$

Fe loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times 450 \text{ mg/L} \times 1 \text{ g/1000 mg} = 98,133 \text{ g/d}$

Mn loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times 15 \text{ mg/L} \times 1 \text{ g/1000 mg} = 3,270 \text{ g/d}$

g/dSO_4 loading = $2.52 \text{ L/sec} \times 60 \text{ sec/min} \times 60 \text{ min/hr} \times 24 \text{ hr/day} \times 3,400 \text{ mg/L} \times 1 \text{ g/1000 mg} = 741,254 \text{ g/d}$

PHASE II CONSTRUCTION

The Old Bevier II Project construction activity was between the summer and fall of 2001 with the new system treating the AMD since early October, 2001. Seven treatment cells are constructed, which includes, from the system inlet: oxidation pond #1, aerobic wetland #1, VFWS #1, oxidation pond #2, aerobic wetland #2, VFWS #2, and aerobic wetland #3 (Figures 6 and 7). To date, no cattails have been planted in the aerobic cells, but Missouri LRP plans on establishing cattails in the aerobic wetland cells in the spring of 2002.

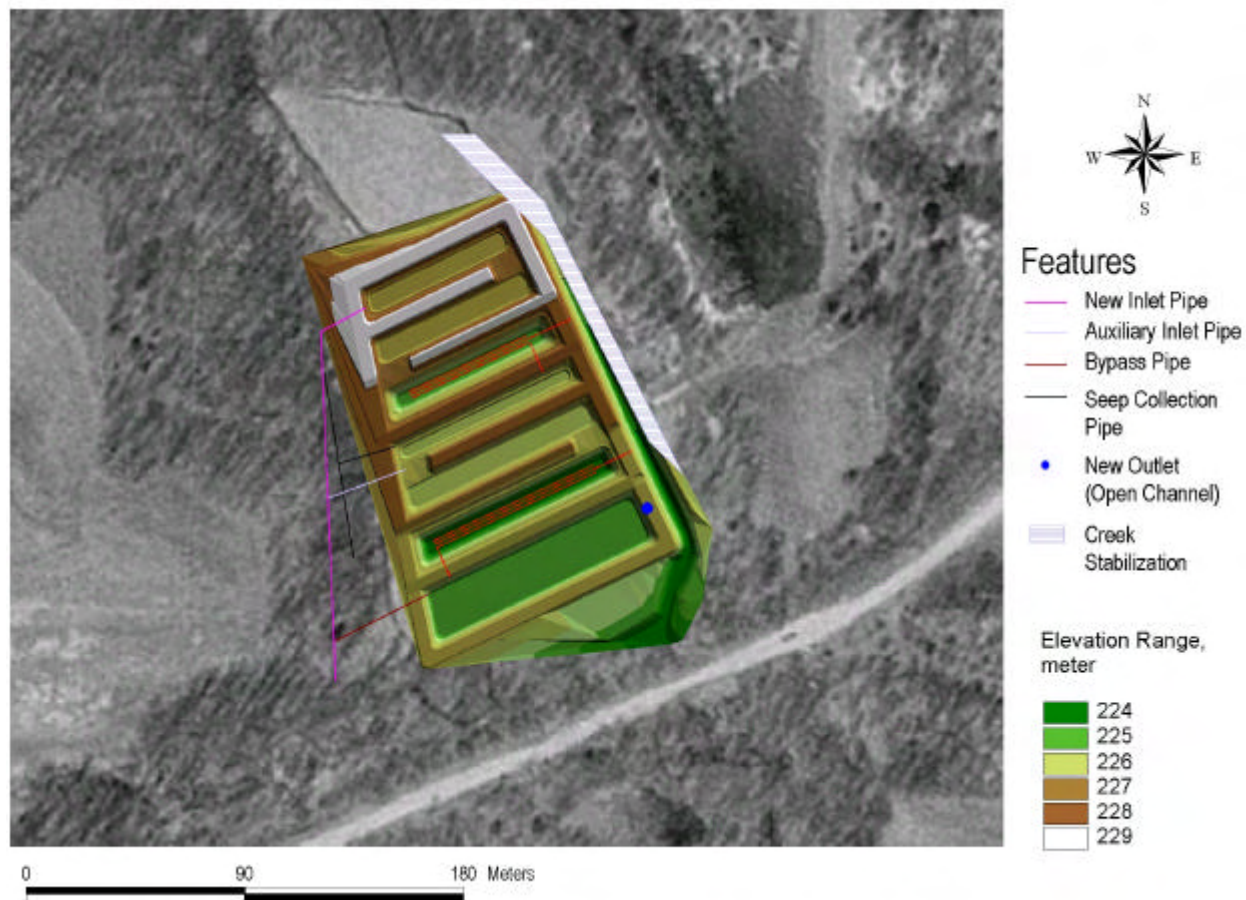


Figure 7. Topographic Model of the Old Bevier II Project (Note: Pipeline and N to S Creek Stabilization Locations).

SYSTEM EVALUATION

Preliminary post-remediation water samples were collected October 2001 through February 2002 and analyzed both by OSM-MCRCC and a commercial laboratory (Table 5). Water analyses indicate the system is operating as expected with a high iron removal rate initially, followed by reduced performance during the winter. Initially, the system was removing about 99% of the iron of a near neutral pH (6.95 S.U.) as measured at the system outlet. In October 2001, discharge was net alkaline at 152 mg/L. This amount of alkalinity is capable of neutralizing additional downstream AMD seeps. While the system was not specifically designed to remove manganese, measurements indicated that about 50% of the manganese was being removed. After three rounds of water tests, the mean iron removal is about 93% (Table 5) and

the mean discharge alkalinity is 119 mg/L. Given an estimated mean acidity of about 108 mg/L, a slight net alkalinity is expected in winter months with improvements anticipated during the summer when biotic activity, such as sulfate reduction, increases.

A collection system was added to the project to intercept small seeps from underground mines immediately west of the treatment cells. This water flows through a small ALD, and then because of elevation constraints of the seep outlets, flows directly into VFWS #2. The constructed collection system appears to capture only a small amount of AMD, and although discharge from the ALD is small, the increase in contaminant levels of the lower cells is measurable.

Performance of individual treatment system modules can be illustrated by plotting key chemical parameters against the linear distance along the system (Figures 8 – 12). The pH levels, which are reduced by metal oxidation and hydrolysis in the oxidation cells and aerobic wetland cells, receive a boost by the VFWS cells (Figure 8). The VFWS #1 mean pH increases about 1.3 standard units and VFWS #2 increases mean pH about 2.3 standard units. The estimated redox potential (Eh) acts in reverse with low values at the outlets of the VFWS underflow piping and higher values in the oxidizing environment of the aerobic wetlands (Table 5, Figure 10). The first oxidation pond and aerobic wetland remove iron. Then, after alkalinity is added with VFWS #1, additional iron precipitates (Table 5, Figure 11). Mean total iron levels at the discharge remain high at about 31 mg/L. Improvement in the iron removal rate is anticipated after emergent vegetation is established and biological activity seasonally increases. The oxidation cells are removing iron at a rate of between 13.9 and 17.5 g/day/m². Total alkalinity trends follow pH with reduction as the metal oxidation and precipitation reactions “use up” alkalinity (bicarbonate) and increase from each VFWS unit to about a level of 160 mg/L (Figure 12). Because of its gradual drop in concentration, along the system, manganese reduction does not appear to be co-precipitating with iron hydroxide. Most of the manganese reduction occurs in the latter cells as where iron is already at a lower concentration. Mean total manganese remains at about 7.9 mg/L at system outlet. Again, significant improvements in the system’s capacity to remove manganese are anticipated in summer after establishment of emergent vegetation. A limited amount of sulfate removal is occurring. Sulfate is lowered from a mean value of 2,355 mg/L in the inlet to 1,875 mg/L at the outlet of aerobic wetland #2. Seepage from the AMD seeps on the west end of VFWS #2 bumps up sulfate level to a mean value of 1,960 mg/L

Table 5. AMD Water Quality at the Old Bevier South Site following Rehabilitation¹

Parameter	Inlet	Oxidation Pond 1 Outlet	Aerobic Wetland 1 Outlet	VFWS #1 Outlet	Oxidation Pond 2 Outlet	Aerobic Wetland 3 Outlet	VFWS #1 Outlet	Aerobic Wetland: System Outlet	Units
Distance from Inlet	0.03 (0.1)	70.1 (230)	146.3 (480)	231.6 (760)	307.8 (1010)	393.2 (1290)	496.8 (1630)	588.2 (1930)	m. (ft.)
Mean pH	5.93	6.11	5.12	6.42	4.16	4.09	6.39	5.73	S.U.
pH Range	5.7 ~6.3	5.97 ~ 6.27	4.8 ~ 6.32	6.3 ~ 6.6	3.68 ~ 6.6	3.89 ~ 6.8	6.29 ~ 6.7	5.3 ~ 6.95	S.U.
Mean Eh	66	83	95	40	121	183	34	38	mV
Eh Range	45 ~ 80	78 ~ 88	46 ~ 143	29 ~ 49	59 ~ 183	172 ~ 194	30 ~ 39	20 ~ 60	mV
Mean DO	0.76	0.31	0.21	3.64	5.90	10.76	0.91	6.80	mg/L

DO Range	0.44 ~1.1	0.31	0.21	0.89 ~ 6.39	5.9	10.76	0.82 ~ 1	5.99 ~ 7.9	mg/L
Mean Alkalinity	178	105	59	154	73	30	162	119	mg/L
Alkalinity Range	164 ~195	88 ~ 115	16 ~ 84	131 ~ 178	0 ~ 150	0 ~ 90	149 ~ 184	71 ~ 152	mg/L
Lab Alkalinity	217							132	mg/L
Mean Acidity _{cal2}	823	618	555	442	306	111	180	108	mg/L
Acidity _{cal} Range	653~ 1163	543 ~ 762	447 ~ 730	272 ~ 604	222 ~ 353	57 ~ 165	140 ~ 219	62 ~ 154	mg/L
Net Acidity	645	513	496	288	233	81	18	-11	mg/L
Lab Acidity	683	470	680	440	390	79	35	20	mg/L
Mean Sulfate	2355	2263	2353	2223	2350	1875	2070	1960	mg/L
Sulfate Range	1800 ~3000	1800 ~ 3040	1900 ~ 3160	1900 ~2600	2000 ~ 2650	1550 ~ 2200	1650 ~2360	1520 ~ 2200	mg/L
Lab Sulfate	2900							2070	mg/L
Mean T. Fe	420.3	334.7	283.0	205.0	143.7	36.8	67.7	30.6	mg/L
T. Fe Range	352 ~ 514	298 ~ 364	234 ~ 352	148 ~ 251	115 ~ 175	12.4 ~ 85	28.5 ~ 111	4.5 ~ 56	mg/L
Lab T. Fe	474	434	439	328	246	22.8	115	71.9	mg/L
Cumulative Fe removal	0.0	20.4	32.7	51.2	65.8	91.2	83.9	92.7	%
Mean T. Mn	10.0	10.2	11.2	9.5	10.2	7.7	8.9	7.9	mg/L
T. Mn Range	7.8 ~ 12	7.5 ~ 12	7 ~ 13.5	7.4 ~ 12	6.4 ~ 16	7.5 ~ 7.8	6.5 ~ 10.75	6.8 ~ 8.74	mg/L

1. Samples were collected by OSM-MCRCC 9/26/01, 10/22/01, 1/23/02, and 2/21/02. On 9/26/01, the water b level in cell #6 was below the discharge level, and cell #7 was dry. Lab samples were collected on 1/23/02. Metals and sulfate values were determined using HACH DR890 colorimeter except lab value; field alkalinity was measured using HACH digital titration.
2. Calculated from pH and dissolved metal values using the formula:

$$3: \text{Metal Acidity (calc.)} = 50[2 \text{ Fe}^{2+}/56 + 3\text{Fe}^{3+}/56 + 3\text{Al}/27 + 2\text{Mn}/55 + 1000(10-\text{pH})].$$

CONCLUSIONS AND LESSONS LEARNED

Additional rounds of water sample collection with analysis by an EPA-certified laboratory are planned for in the spring and summer of 2002 to evaluate the success of the remediation effort and to investigate seasonal variations in both treatment and flow. The LRP may consider adding a bacteria-assisted manganese removal cell such as in inoculated limestone beds as suggested by Brant and Ziemkiewicz (1997) and in Robbins and others (1999). Future AMD treatment projects in Missouri which require VFWS technology should consider inclusion of: 1) either an aerobic wetland or limestone-lined drop structure before the oxidation pond to allow for more rapid aeration, 2) a schedule for construction that allows completion before winter to allow transplanting of locally-derived emergent plants, and 3) the transplanting of at least two species of emergent plants to limit impacts of infestation and disease. The experience gained in the original Old Bevier project showed that maintenance problems of a dilution supply pipeline,

particularly a pipeline positioned in an area that supports multiple land uses, may cause premature failure of an AMD passive treatment system. The Project Team plans additional evaluations through 2002.

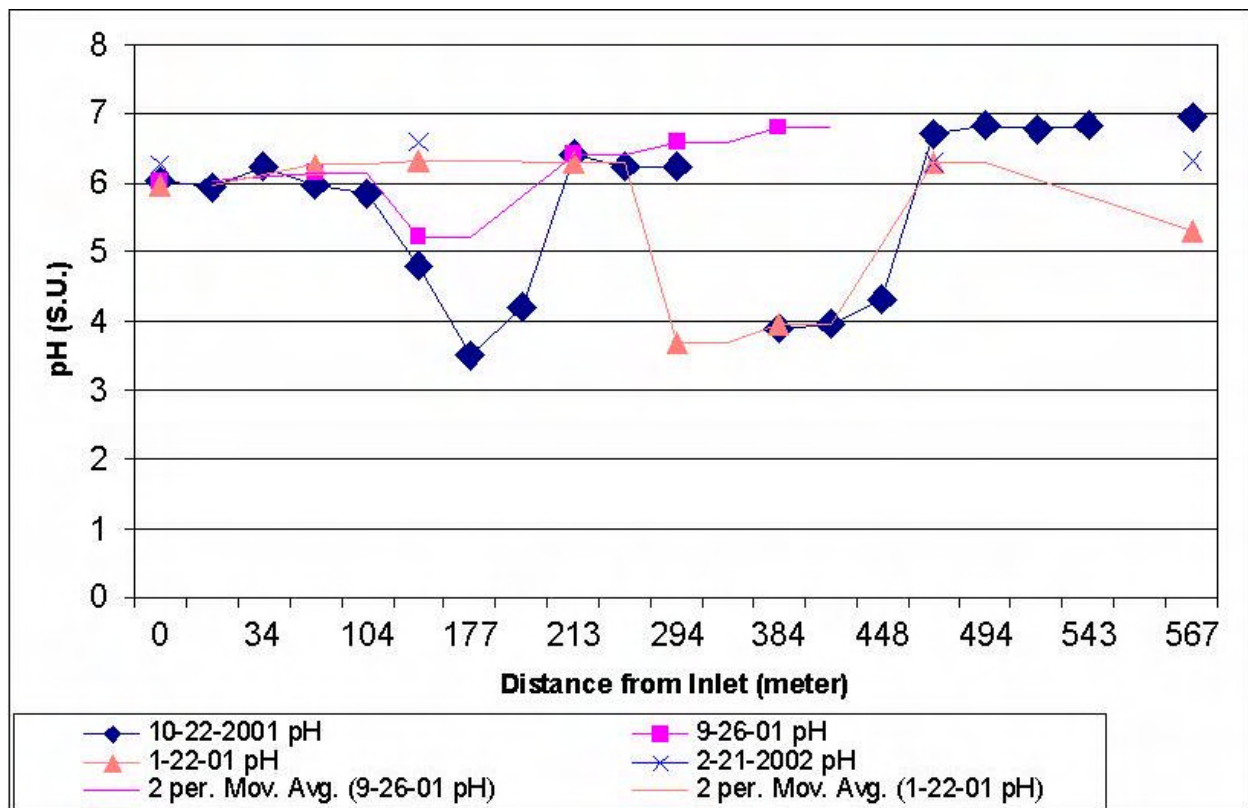


Figure 8. Changes in pH within the Old Bevier II Passive Treatment System.

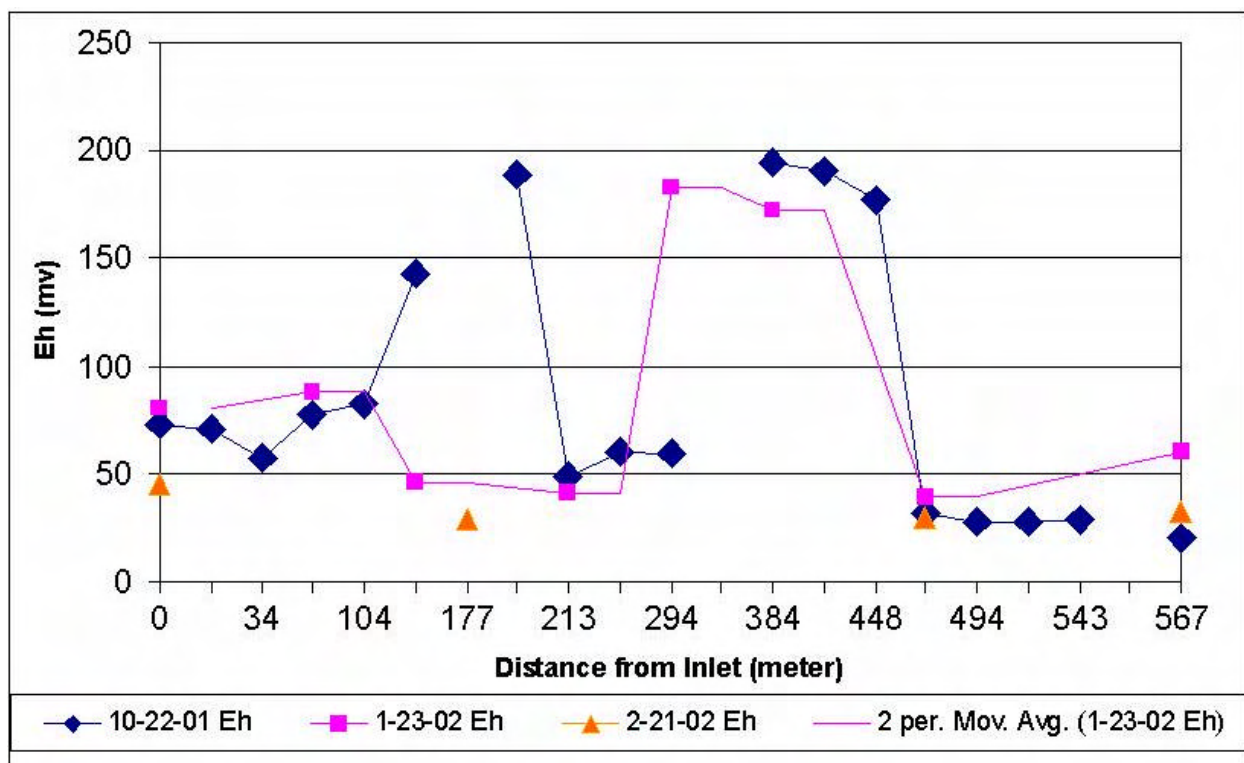


Figure 9. Changes in Eh within the Old Bevier II Passive Treatment System.

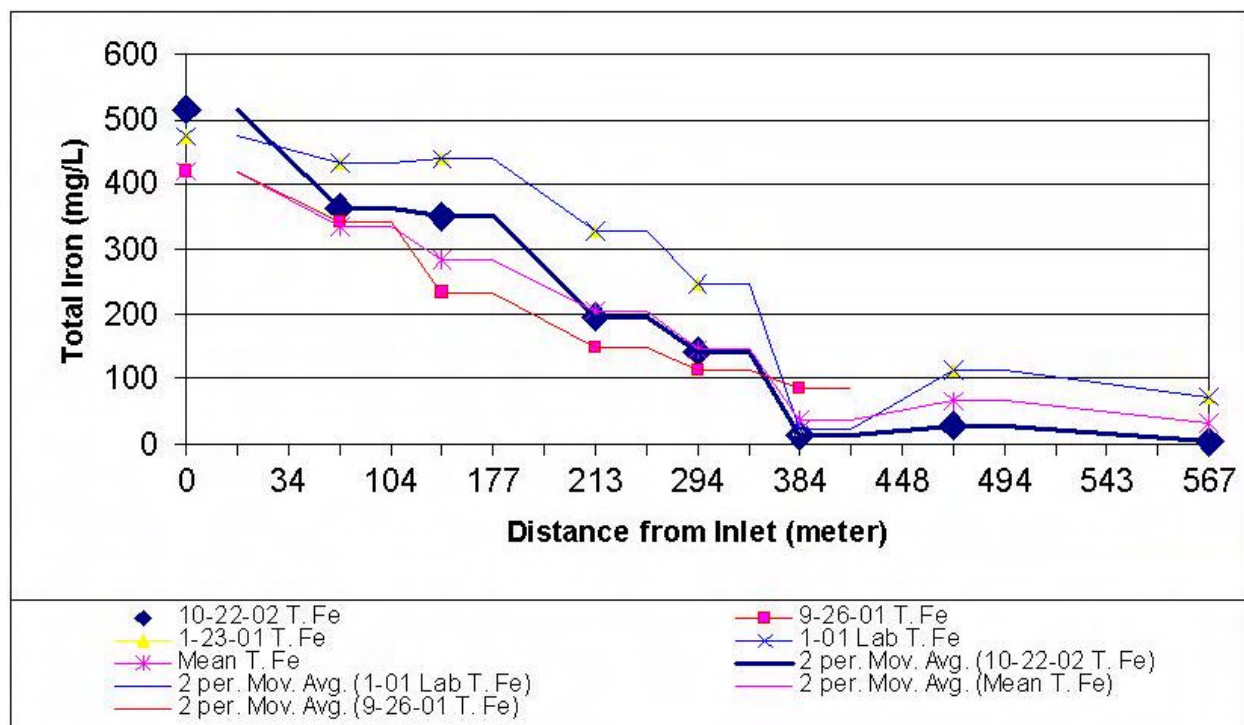


Figure 10. Changes in Total Iron within the Old Bevier II Passive Treatment System.

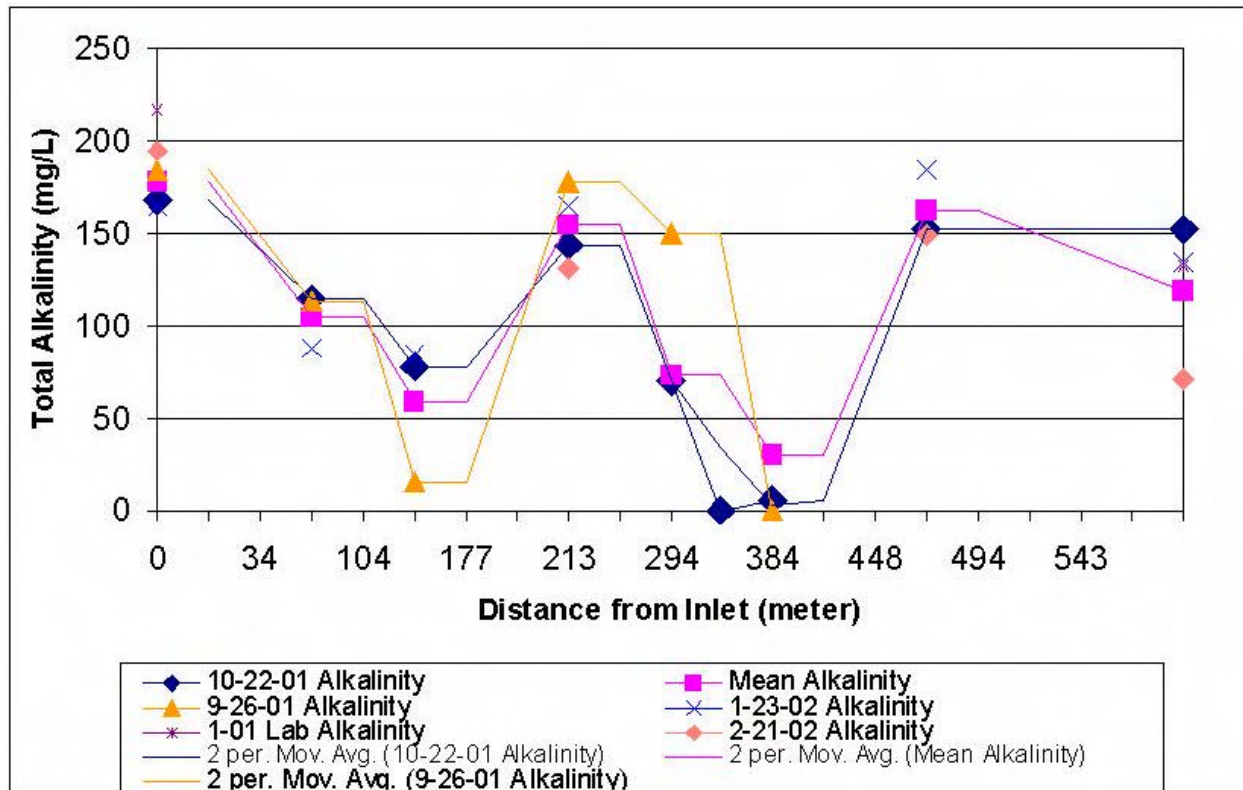


Figure 11. Changes in Total Alkalinity within the Old Bevier II Passive Treatment System.

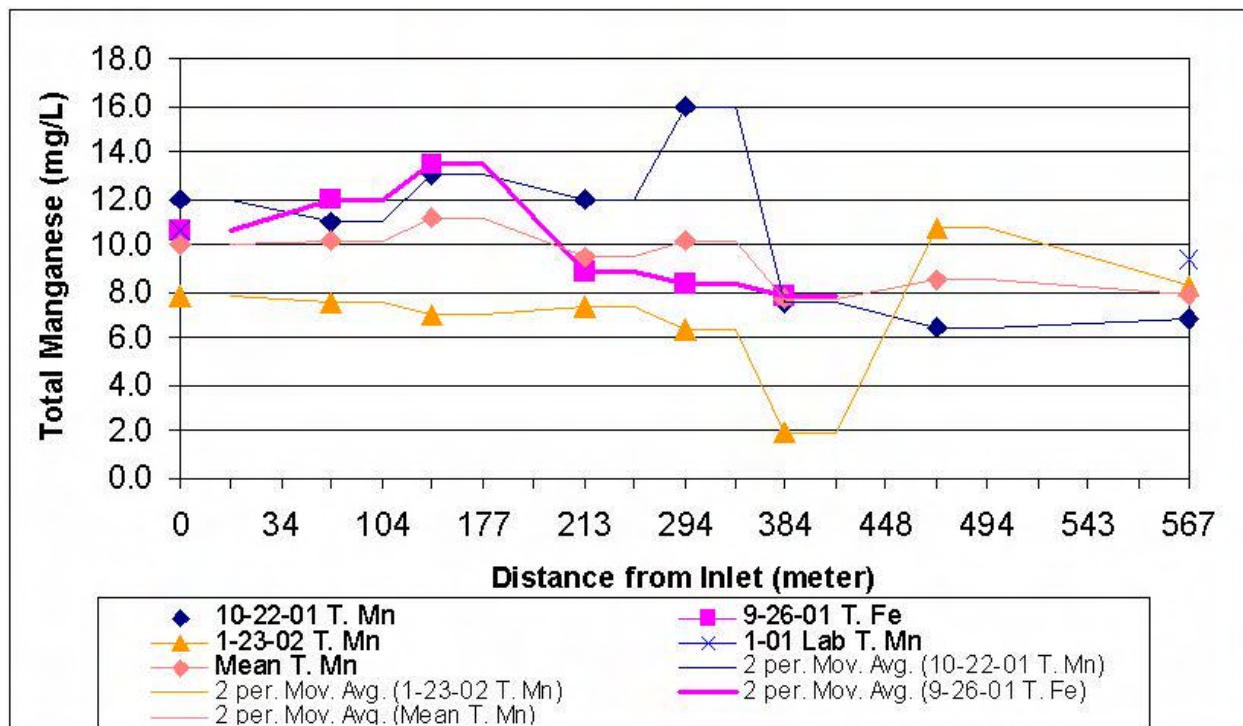


Figure 12. Changes in Total Manganese within the Old Bevier II Passive Treatment System.

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PROGRESS OF BLM-FUNDED ACID MINE DRAINAGE RESEARCH

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ABSTRACT

The environmentally sound management of abandoned, existing, and future metal mine wastes on public lands has been identified as the most difficult and costly reclamation problem facing federal and state land-managing agencies. Drainage-quality prediction is essential to environmentally sound mine-waste management. The U.S. Bureau of Land Management (BLM), in association with the Minnesota Department of Natural Resources Division of Lands and Minerals (MN DNR) and University of Utah Chemical and Fuels Engineering Department (University), continued sponsorship of research on predictive modeling of contaminated drainage from metal-mine waste after the U.S. Bureau of Mines closed.

A well-defined kinetic test protocol was developed and approved as an ASTM method with funding from the USBM and the BLM. BLM-sponsored research showed that the ASTM humidity-cell protocol produced highly reproducible drainage quality, within and among laboratories, on four waste-rock lithologies (MN DNR). A simplified humidity-cell method produced results similar to those from the ASTM protocol with comparable intralaboratory replication. Mine-waste characterization and accelerated-weathering (humidity cell tests ranging from 20 to 278 weeks) were conducted on 63 samples from eight different mine-waste lithologies (MN DNR). For three lithologies with at least moderate amounts of calcium and magnesium carbonates, 24 to 60 percent of the neutralizing carbonates were available in samples with neutralization potentials of 21 to 42 g CaCO_3 (kg rock)⁻¹. Acid production thresholds were identified based on the sulfur content of two mine-waste lithologies with very low calcium and magnesium carbonate contents. Drainage pH values less than 4.5 were produced by Duluth Complex samples with $\text{S} \geq 0.41\%$ and field test piles yielded drainage pH values similar to laboratory values for samples of similar sulfur content. Drainage pH values less than 4.5 were also produced by Archean greenstone samples with $\text{S} \geq 0.2\%$. Field rates of chemical release from Duluth Complex and Archean greenstone rocks typically ranged from 10 to 45 percent of those for laboratory samples of similar sulfur content.

The University's laboratory model demonstrated reasonable agreement between modeled output and actual pH, sulfate, and calcium concentrations from weekly humidity-cell drainage produced from accelerated weathering of five different waste-rock lithologies. The field model linked governing geochemical reactions to transport phenomena in porous media and produced concentration profiles for multiple species in a simulated symmetrical test pile.

Results from the BLM-sponsored research are published in 5 peer-reviewed journal papers, 2 M.S. theses, and 19 contract reports.

INTRODUCTION

Significance and Need for Continued Research

Generation of contaminated drainage from abandoned, existing, and future mine sites has been identified by the US Forest Service (USFS) “as the most difficult and costly reclamation problem it faces with western metalliferous mining operations” (USFS 1993). According to the Abandoned Mine Land Task Force (1996), more than 100,000 abandoned mines in the western U.S. are located on BLM and USFS lands; additionally, several thousand are reported on National Park Service (NPS) lands. Based on state 303(d) listings of affected streams, as many as 15,910 miles of stream length have been affected by contaminated drainage from metal-mining activities. USFS (1993) also identified more than 1500 mining sites on National Forest Lands that have been affected by contaminated drainage. Contaminated drainage adversely affects water quality, damages aquatic and riparian habitats, and consequently has the potential to impact wildlife and human health, and limit use and enjoyment of some of the more scenic portions of the Public Lands.

Federal and state land-managing agencies are (and will continue to be) challenged with making environmentally-sound decisions on how to best manage millions of tons of mine waste from abandoned, existing, and future metal-mining activities without adversely impacting existing surface and groundwater quality. Abandoned-mine wastes can produce drainage that is neutral for years and then acidifies. Based on neutral drainage observed in the field, remediation of such wastes may be ignored. However, subsequent generation of acidic drainage could result in severe impacts to water quality. Thus, without knowledge of future drainage quality, a mine waste with potential to adversely impact drainage quality for decades might be left unremediated, while financial resources were expended toward reclaiming less reactive wastes.

Mine-waste management decisions for developing mines are largely based on the predicted quality of drainage from the mine waste. While suites of laboratory-predictive tests and their results are commonly used by industry and reviewed by land-managing agencies to help forecast mine-waste drainage quality, no consensus exists regarding how well these tests predict future drainage quality in the field. Because of the complexity of the problem and the uncertainty of predictive-test accuracy, land-managing agencies are most concerned that decisions made in good faith today will return to haunt them in future. USFS (1993) acknowledged that “technical uncertainties are associated with the prediction of acid drainage potential at the time of mine plan approval.” The agencies want to solve the contaminated-drainage problem, not add to it by making improper decisions on mine-waste management due to errors in drainage quality prediction. Their major concern is the prospect of having contaminated drainage develop 25 to 50 years in the future from mine-waste tonnages that they allowed to be placed on public lands based on their current level of knowledge.

To avoid such a scenario, BLM, USFS, and NPS need reliable laboratory predictive tests, a systematic compilation of predictive test data, and predictive mathematical models that reliably forecast mine waste drainage quality. These components are essential for making scientifically based decisions on the environmentally-sound management of mine wastes from abandoned, existing, and future mines. They are also the focus of the current BLM-sponsored research.

Research Chronology

Federally-sponsored research to predict drainage quality from waste rock associated with U.S. metal mining has been conducted since October 1990 (beginning of Fiscal Year 1991), and continues today. U.S. Bureau of Mines sponsored the research for 5 years, and U.S. Bureau of Land management continued sponsorship of the research after closure of the Bureau of Mines in 1996.

Bureau of Mines Sponsored Research (1991-1996)

Acid-Rock Drainage (ARD) prediction research was initiated by the U.S. Bureau of Mines Salt Lake Research Center (USBM), and was conducted jointly with University of Utah Chemical and Fuels Engineering Dept. (University), and Minnesota Dept. of Natural Resources (MN DNR) from October 1990 to the end of January 1996 when the USBM was abolished by Congress.

Two components comprised the research, kinetic testing and mathematical modeling. Kinetic testing provided empirical data on the variation of drainage quality as a function of compositional variations within individual mine-waste lithologies. This information also provided the empirical database required for the calibration of the developing mathematical predictive models. The kinetic or laboratory accelerated-weathering and field test-pile testing were conducted by MN DNR and USBM, and the mathematical predictive modeling was performed by the University. The broad objectives of the research were to 1) identify and describe the chemical reactions that govern the formation of ARD from samples of metal-mine waste rock subjected to accelerated weathering in laboratory humidity-cell experiments, 2) develop geochemical-kinetic models that would predict the rate of acid generation and trace-metals release in drainage from metal-mine waste rock, and 3) calibrate the developing models by matching modeled output with experimental data from humidity-cell tests and drainage from waste-rock test piles.

By early 1996, USBM had invested nearly \$1.5 million in this research (USBM 1995, p. 138).

Research products included: 1) up to 4 years of empirical data from laboratory accelerated-weathering tests of ten samples from two different rock types, 2) an American Society for Testing and Materials (ASTM) standard method (D-5744-96) for accelerated weathering of mine-waste samples in a modified humidity cell, and 3) two preliminary geochemical-predictive models. The models included a laboratory humidity-cell model and a field test-pile model (Lin 1996; Lin and others 1997; White and Jeffers 1994; White and others 1994). At this point, the laboratory humidity-cell model had been calibrated with experimental data from two different waste-rock lithologies, and the field test-pile model had been mathematically tested but not calibrated.

Bureau of Land Management Sponsored Research (1997-present)

When Congress abolished the USBM in early 1996, the ARD-prediction research was transferred to the Bureau of Land Management (BLM) Utah State Office (USO) with limited funding of \$125,000. USBM's objective was to enable limited research to continue until September 30, 1996 so that the project database could be preserved and some conclusions published. Because BLM considered ARD to be one of its land-management priorities, USO decided to continue the research and provided a total of \$308,000 to the project from October 1, 1996 through September 30, 2001

(Fiscal Years 1997-2001). MN DNR also contributed \$338,000 during 1998-2001 to support humidity-cell experiments and the construction and sampling of four waste-rock test piles.

In addition to BLM and MN DNR funding, American Assay Laboratories (AAL) and a private mining company have provided nearly 5 years of humidity-cell testing and samples of metal-mine waste rock. AAL's cost to test five samples for 5 years was \$90,000 to \$100,000. The private mining company's contribution was approximately \$15,000. This combination of BLM and MN DNR funding and private-industry "in-kind" support has totaled about \$746,000 since October 1, 1996, and has enabled University and MN DNR to continue the joint research that was originally started with USBM to benefit the land managing agencies.

Currently, 63 samples from 8 different waste-rock lithologies have been subjected to accelerated-weathering tests in modified humidity cells. Periods of record for these laboratory tests ranged from 20 to 278 weeks. Solid-phase chemical and mineral characterization, and aqueous-phase (drainage quality) chemical analyses from these kinetic tests have been archived in 14 MN DNR contract reports. Summaries of the BLM-funded laboratory studies have been published in 2 peer-reviewed journal papers.

BLM sponsorship of the research since FY 1997 has enabled the University to increase the number of chemical species in the laboratory humidity-cell model from 28 to 57, and increase the chemical reactions from 21 to 48. Additionally, the laboratory model operates under both acid and alkaline conditions. Currently, the humidity-cell model has been calibrated with samples from 5 different waste-rock lithologies. Fifteen chemical reactions have been added to the field test-pile model since the beginning of FY1997, and of the 15 new reactions 7 have been mathematically tested.

BLM-supported University modeling progress has been summarized in 5 contract reports, 2 M.S. theses, and 3 peer-reviewed journal papers.

OBJECTIVES

The initial objective of our research was to be able to predict drainage quality from metal-mine waste rock. However, because a variety of lithologies commonly comprise waste-rock dumps, we recognized that this prediction had to be made through conducting and mathematically modeling accelerated-weathering tests of individual waste-rock lithologies. This generated several additional objectives that included:

- Assessing laboratory-test methods used for classifying mine waste,
- Identifying problematic waste-rock lithologies by subjecting sample suites from selected lithologies to commonly used laboratory accelerated-weathering tests,
- Correlating resulting laboratory-test drainage quality with corresponding sample mineral- and chemical-characterization data,
- Conducting field tests of individual waste-rock lithologies to 1) determine field rates of chemical release, and 2) assess the efficacy of extrapolating laboratory drainage pH to that of field tests of the same lithology, and
- Generating mathematical models that provide predictive tools to help ensure environmentally sound management of mine waste on the public lands.

METHODS

Laboratory and Field Testing

Laboratory Kinetic Tests

Materials

The current study includes 63 waste-rock samples that comprise eight lithologies. Twenty-one of the 63 samples were from a single lithology, siltite-argillite rock. The other 42 rock samples were from the remaining seven waste-rock lithologies: Duluth Complex gabbro (1), mafic-intrusive (7), tuffaceous-sedimentary (9), weathered carbonate-hosted, base-metal-sulfide bearing waste rock from a 75- to 100-year old oxidized metal-mine waste-rock dump (1), Archean greenstone (14), syenite porphyry (4), and selenium-bearing rhyolite (6).

The siltite-argillite samples were collected from blast-hole drill-cuttings, bulk samples, and from a bench surface at an open pit mine (Lapakko 1998a). The Duluth Complex gabbro rock was collected from a test pile that had been exposed to weathering for 15 years (Lapakko 1994, Eger and Lapakko 1985). The mafic-intrusive and three tuffaceous-sedimentary rocks, were segregated from a “sulfide-carbonate mixed waste” bulk sample from an open-pit metal mine; six additional low neutralization potential tuffaceous sedimentary rocks were collected from the same mine (Lapakko and others 2002a). The weathered waste rock sample is a carbonate-hosted, base-metal-sulfide bearing waste rock from a 75- to 100-year old oxidized metal-mine waste rock dump, and was provided by Kathleen Smith of the U.S. Geological Survey (USGS) (Lapakko and others 2002a). This sample is referred to as the USGS abandoned mine land waste rock sample (USGS AML). The Archean greenstone samples were collected from core drilled in preparation for constructing a cavern for purposes unrelated to mining (Lapakko and others 2002b). The syenite porphyry samples were collected from a bench surface and its exposed highwall at an open-pit metal mine (Guard 1997). Bulk samples of selenium-bearing rhyolite samples were collected from two different hydrothermal-alteration zones at an open-pit metal mine (Trujillo and others 2000).

Procedures

ASTM Method D 5744-96 (Accelerated Weathering “Modified-Humidity Cell” Protocol) - A 16-cell array identical to that illustrated in the standard method was used (ASTM 2000, Figure 2, p. 262). This accelerated weathering test method is designed to increase the geological-chemical-weathering rate for selected 1000-g solid material samples and produce a weekly effluent that can be characterized for dissolved weathering products. This test method is performed on each sample in a cylindrical cell. Multiple cells can be arranged in parallel; this configuration permits the simultaneous testing of different solid material samples. The test procedure calls for weekly cycles comprised of three days of dry air (less than 10% relative humidity) and three days of water-saturated air (approximately 95% relative humidity) pumped up through the sample, followed by a leach with water on Day 7 (ASTM 2000, pp. 257-269; White and Lapakko 2000).

MN DNR Method - A kinetic test method similar to ASTM Method D 5744-96 was designated as the MN DNR method. The MN DNR method uses the same humidity-cell diameter, waste-rock charge, and rinse volume and application method as described in the ASTM method D 5744-96, section 6.1 (ASTM 2000, p. 259). The MN DNR cell was about 3 cm shorter than the ASTM cell. The latter had a thicker base plate; a larger space, to accommodate a fitting for introducing air flow, between the base plate and perforated plastic support; and a thicker cover. As was the case for the ASTM method used in this project, a week-0 rinse volume of 1.5 L is used rather than the 0.5 L volume described in the standard method (0.5 L was used in all succeeding rinses). However, instead of subjecting the humidity cell apparatus to the humid or dry air flow into the cell, the cells were stored in a controlled temperature and humidity room between weekly rinses. It should be noted that the relative humidity readings were from the room itself. The humidity within the cells was probably near 100%, since the water retained in the cells was fairly constant during the weekly cycles (i.e. water did not evaporate).

ASTM and MN DNR Rinse Alternatives - Two cells, one ASTM and one MN DNR, containing Duluth Complex gabbro rock were also run to examine the effect of using a “flood” rinse rather than the “drip-trickle” rinse described in the standard method. During the flood rinse, water was dripped into the cell (to avoid disturbing the solids) from the separatory funnel until about two cm of water accumulated above the rock. Water was then added in a steady stream. The 500-mL rinse volume was used in all tests.

Greenstone Field Test Piles

Four 50 cubic yard piles (63 metric tons) were constructed to examine the dissolution of greenstone rock under field conditions (Figure 1).

Dimensions of the piles were the same, with bases 20 feet square, tops eight feet square, and a height of six feet. The rock was analyzed for particle size distribution and chemistry, and mineralogical analyses are planned. The sulfur contents of the four piles were 0.02, 0.20, 0.39 and 0.67 percent.

Precipitation at the site was measured using a US Standard rain gage. Precipitation falling on the piles, passed through the rock and an underlying sand layer (six inches), and flowed along a 36 mil reinforced polypropylene (RPP) liner to a slotted PVC collection pipe. The drainage then flowed to a sump equipped with a pump activated by the water level in the sump. Sump discharge passed through a flow meter, after which a sample was automatically deposited in a collection bottle for subsequent analysis for pH, alkalinity/acidity, sulfate, and major and minor cations. The piles were also equipped with instrumentation to determine temperature and oxygen



Figure 1. - MN DNR field test piles of Archean Greestone rock.

concentrations within the pile at the bottom of the pile and at a height of three feet above the bottom.

Analyses

Solid Phase

Particle size distributions of the mine waste samples were determined by Lerch Brothers, Inc., Hibbing, MN. The mine waste samples were analyzed for sulfur, sulfide, sulfate, evolved carbon dioxide, as well as whole rock and trace constituent concentrations by ACTLABS, Inc., Tucson, AZ. Analyses to determine mineralogic composition and degree of liberation of sulfide and carbonate minerals were conducted on selected siltite-argillite samples (Lapakko 1998a) and the mafic-intrusive, tuffaceous-sedimentary, and USGS AML samples (Lapakko 1999c). These analyses were conducted using x-ray diffraction, optical microscopy, and SEM by Barry Frey of Midland Research (Nashwauk, MN) and Louis Mattson, Mineralogical Consulting Service (Pengilly, MN). Mineral content of the greenstone samples was determined by Louis Mattson using sample chemistry, optical microscopy, and previous x-ray diffraction data on drill core samples.

Aqueous Phase

Water samples were analyzed for specific conductance, pH, alkalinity, acidity, and Eh at the MN DNR in Hibbing. Specific conductance was analyzed using a Myron L conductivity meter, and an Orion SA720 meter, equipped with a Ross combination pH electrode (8165), was used for pH analyses. Alkalinity (for pH $\geq$ 6.3) and acidity were determined using standard titration techniques for endpoints of 4.5 and 8.3, respectively (APHA and others. 1992). Eh readings were taken using a Beckman model 11 meter with an Orion electrode (9678BN).

Prior to 23 August 1999, metals were determined with a Varian 400 SPECTRAA; a Zeeman GFAA furnace was attached for low concentrations. Subsequent analyses were conducted using inductively coupled plasma mass spectrometry (ICP-MS, Hewlett Packard HP4500 Series, model #G1820A). Sulfate concentrations exceeding five mg/L were determined using a Technicon AA2 automated colorimeter. Lower concentrations were determined using a Dionex ion chromatograph and, after 10 November 1998, a Lachat QuickChem 8000.

Mathematical Modeling

Rationale

The overall objective of the joint research was to be able to predict water quality from metal-mine waste by developing predictive tools that would help ensure environmentally sound management of mine waste on public lands. To accomplish this objective, the developing mathematical-predictive model needed to be:

- Based on robust scientific foundation,
- Calibrated with long-term laboratory accelerated-weathering test data, and

- Supported by laboratory tests performed on multiple mine-waste lithologies

Accelerated weathering in humidity cells has been a laboratory-test method commonly used in the U.S. and Canada to estimate drainage quality from mine-waste samples (Bradham and Caruccio 1991; Ferguson and Morin 1991; White and Jeffers 1994). Because of the method's widespread use, we wanted to determine if it was possible to mathematically model the weekly drainage chemistry resulting from this laboratory test. While conditions common to humidity-cell kinetic tests differ from those encountered in actual waste-rock dumps, reaction-controlling conditions within each cell can be fixed at predefined limits. Humidity-cell experiments (1) are essentially isothermal, (2) have an ample supply of oxygen, and (3) are characterized by well-defined gas-transport and water-flow systems. These conditions not only accelerate the weathering process but also have potential to identify rate-limiting steps characteristic of both chemical and physical processes that occur with oxygen in abundance (White and others 1994). Therefore, the modified humidity-cell protocol was selected as the laboratory method to model.

Our objective in successfully modeling drainage quality from humidity cells was to 1) identify the controlling geochemical reactions responsible for generation and neutralization of contaminated drainage from a variety of mine-waste lithologies, and 2) use these controlling reactions to develop a more complex three-dimensional model that could simulate drainage quality from a waste-rock dump composed of metal-mine waste under more realistic environmental conditions.

To provide empirical data to the USBM for the modeling effort, modified humidity-cell tests were conducted by USBM from 1991 through 1995 on two different mine-waste lithologies. The consequent protocol refinement and resulting empirical data were the basis for identifying the controlling geochemical reactions used in the mathematical modeling. By the time USBM was closed in early 1996, two kinetic models had been developed, a laboratory humidity-cell model, and a field test-pile model. Since 1996, humidity-cell testing of six additional lithologies and the consequent improvement of both kinetic models has been continued by MN DNR and the University under BLM sponsorship. The following sections describe the first principles of each model and the evolution of their respective development.

Laboratory Conceptual Model

Description

The University, which was under contract to the USBM from 1992 through 1995, designed a preliminary model that simulated chemical changes that occur in the weekly interstitial water remaining in each humidity cell (Lin 1996; White and Jeffers 1994; White and others 1994). Rather than solve the customary diffusion and convective-transport equations for a packed column of reacting particles, a different approach was taken. The humidity cell was conceptualized as 20 continuous-stirred tank reactors (CSTR's) in series. Twenty CSTR's were used because this number approached the same effluent results as a packed-bed model with axial dispersion.

As of 1994, the model used 10 simultaneous chemical reactions and 14 different chemical species to describe the generation and neutralization of acid in the humidity cell. Solid species

included pyrite, calcium carbonate, ferric hydroxide, jarosite, and feldspar. Aqueous species included sulfate, ferrous and ferric ion, oxygen, calcium, potassium, carbonate ion, and hydrogen ion (pH). Bacterial catalysis of acid production was modeled using a modified Monod-type relationship for the growth phase that accounted for pH dependency and included a term that accounted for the death phase. The weekly cycle of leaching with 500 mL of de-ionized water (1 day), pumping dry air (3 days) and then water-saturated air (3 days) was modeled, taking into account the volume change in interstitial water and the resulting evaporation.

Because air is pumped continuously through each humidity cell at 1.0 L/min for both the wet- and dry-air cycles, the concentration of oxygen in the interstitial water was assumed to be constant at saturated conditions during this time period. During the leaching step, however, air is not being pumped and oxygen in the aqueous phase was allowed to decrease in accordance with its consumption for the designated chemical reactions. The solid-phase reactions include the effects of oxygen diffusion through the reacted portion of the particles.

The kinetic constants in the model were assumed to be fixed and dependent only on temperature, which was not considered to be a variable in these experiments. Kinetic constants were obtained by comparing the experimental effluent compositions collected during the water-leaching phase of the weekly cycle with those predicted by the model (Lin 1996; White and others 1994).

Basic Model Components

Two commonly-used chemical models comprise the University's conceptual laboratory humidity-cell based model, and are considered to be operating simultaneously:

- Shrinking core model - describes the solid-liquid reaction of rock particles with interstitial water remaining in the mine-waste sample during and after each weekly leach.
- Continuous-Stirred Tank Reactor (CSTR) model - 1) describes the mixing and reaction of dissolved and undissolved components in water as a whole, and 2) when used in a series of reactors, describes the transport and resultant concentration gradient from top to bottom of the waste rock sample in the humidity cell as a result of each weekly 500-mL leach.

General Assumptions

Rock particles in the sample are assumed to be uniform and spherical and have a constant porosity. Each rock particle is considered a composite of all the minerals comprising the mine-waste sample. Rock particles and interstitial water remaining after the leach are simulated to be well mixed in the series of CSTRs. Initial composition of the interstitial water in all CSTRs is assumed to be the same as the first recovered leach composition.

During the 6 days of the weekly cycle following the 2-hour leach, it is assumed that sample rock particles react with the new interstitial water according to the shrinking-core model, and the rock particles and interstitial water are well mixed according to the CSTR model. Based on experimental data collected by USBM, the pore-water volume remaining after the leach decreases with time during the 3-day dry air step. Evaporation reduces the post leach interstitial-water volume

by about one half, which causes an increase in the dissolved species concentrations. This is accounted for in the model by the mass balance equations that describe the aqueous species concentrations in the stacked CSTRs during the dry-air step (Lin 1996).

Evolution of the Laboratory Model

Since all mathematical models are simulations of the actual event under a given set of assumptions, the model must be compared to experimental data in order for verification. To develop and calibrate the humidity-cell based laboratory model, modeled output was compared with weekly drainage-quality data from long-term humidity-cell tests of waste-rock samples. Weekly drainage-quality data included pH, specific conductance, and major ion and trace-metal concentrations (e.g., iron, sulfate, calcium, magnesium, arsenic, copper, selenium, uranium, and zinc). Eight different waste-rock lithologies were subjected to humidity-cell tests during the 1991 - 2002 period and modifications were made to the humidity cell model during this same time period. The period of record for these humidity-cell tests ranged from 20 to 247 weeks (Table 1).

Table 1. - Summary of eight waste-rock lithologies subjected to humidity-cell tests from 1991 to 2002.

Lithology	Number of Samples	Period of Record, Weeks
1991-1995:		
Siltite Argillite	2	218
Duluth Complex	8	60-137
1996-2002:		
Siltite Argillite	21	20-278
Mafic Intrusive	7	102-168
Tuffaceous Sedimentary	9	20-168
Duluth Complex	1	265
USGS AML	1	158
Archean Greenstone	14	100
Syenite Porphyry	4	32
Se-bearing Rhyolite	6	52

To date, modeled output has been compared with weekly drainage quality from humidity-cell testing of samples of siltite-argillite, Duluth-Complex, syenite-porphyry, and Se-bearing Rhyolite lithologies (Lin 1996; Guard 1997; Trujillo and others 2000; White and others 1994).

The model was also recently used to simulate drainage quality from a pyritic quartz-carbonate

tailings sample that had been subjected to 520 weeks of laboratory accelerated-weathering tests, and whose actual drainage quality transitioned dramatically from neutral to acid pH. Our objective was to see if the model could also predict a similar pH transition. The laboratory data are from a tailings sample comprised of relatively uniform, small particle size and well-liberated minerals. Input to the model was based on converting the tailings' particle size distribution to an average particle diameter and using the same amount and configuration as a waste rock sample (i.e. 1000 g). Since not all minerals are represented in the model some approximations had to be made. Table 2 shows the comparison between actual tailings parameters and simulated waste-rock parameters for the quartz-carbonate tailings sample T9.

Although arsenopyrite is included in the current model, it was not used to simulate these samples. Sphalerite was also not included in the model since it was not present in a significant amount. The other minerals, from barite to apatite, are not included in the model. Quartz is considered to be an inert mineral in the present version of the model and is a good approximation as long as the pH does not fall below 2.0 or so and the temperature is low. Thus, in order to bring the total percentage up to approximately 100 percent, the other minerals are combined into the quartz value for the model input. This procedure isn't really necessary but serves as check to make sure all components of the sample are accounted for in one way or another.

Table 2. - Mineralogical data for quartz-carbonate tailings sample T9, and corresponding model input values

Mineral	T9, Weight Percent	
	Experimental Data	Model Input
Pyrite	6.57	6.57
Pyrrhotite	0.13	0.13
Chalcopyrite	0.01	0.01
Calcite	1.4	1.4
Siderite	ND	0.1
Feldspar	27.6	27.6
Olivine	-	1.0
Quartz	27.5	63.3
Barite	14.22	
Arsenopyrite	0.05	
Molybdenite	0.19	
Galena	<0.01	
Stibnite	0.04	
Sphalerite	0.02	
Dolomite	ND	
Ankerite	<0.3	
Mica	16.2	
Chlorite	2.1	
Amphibole	2.9	
Magnetite	<0.1	
Apatite	<0.3	

Because the major mineral constituents comprising each sample were the primary input to the laboratory model, mineral weathering reactions and their associated rate laws were gradually added to the model over time. During 1991-1995, abiotic and biotic iron-sulfide mineral oxidation and consequent acid production were the initial reactions incorporated into the model. Carbonate- and

silicate-mineral acid neutralization reactions, and secondary mineral precipitation reactions (i.e., jarosite, gypsum, and iron hydroxide) were also included during this period (Lin 1996; Trujillo and others 1994; Trujillo and others 1996a; White and Jeffers 1994; White and others 1994).

The additional metallic-mineral weathering reactions for zinc and uranium were added in 1996-1997 (Guard 1997; Trujillo and others 1996b). Because the initial model was confined to simulate acid conditions, and contaminated drainage includes mobilization of arsenic, selenium and uranium oxyanions under alkaline conditions, the model was modified to simulate both acid and alkaline conditions during 1996-2000. Arsenic- and selenium-mineral weathering reactions were also incorporated into the model during this time (Trujillo and others 1998; Trujillo and others 2000). More recent changes have included adding siderite as a shrinking core species that can act as a neutralizing mineral but releases ferrous ion as well. These modifications were developed by the University so that 1) drainage quality from a larger variety of waste-rock lithologies could be modeled, and 2) the model would be more robust and applicable to a wider range of waste-rock types under both acid and alkaline conditions.

Field Conceptual Model

Description

Prior to USBM's closure, five geochemical reactions selected from the 23-reaction suite identified during the 1995 humidity-cell modeling effort were used by the University to develop a three-dimensional, three-phase geochemical model that would describe the drainage quality from test piles of discrete rock types (i.e., individual lithologies) when exposed to actual field conditions. This effort was made in order to develop a more realistic model that could be used to predict drainage quality from field operations.

Basic Model Components

The rate laws and associated parameter values of these five governing-geochemical reactions were linked with equations that describe transport phenomena in porous media with three phases (i.e., mass, momentum, and energy balances for solid, liquid and vapor phases). The resulting equations were incorporated into a three-dimensional test-pile simulation. A truncated pyramid-shaped waste-rock test pile was computer simulated and assumed to be composed of a single rock type (lithology). The simulated test pile was represented by multiple layers, and each layer was comprised of multiple building blocks with block dimensions dictated by the size of the test pile and the number of blocks used. The number of blocks used is only limited by the computational resources available. Recent efforts have been made to run large block systems on the supercomputer at the University of Utah.

General Assumptions

Each building block was considered to be a uniform grid point where a specific rock composition and solid-liquid-phase permeabilities could be fixed, and the initial aqueous saturation levels, bacterial populations and oxygen concentrations could be varied. The governing geochemical

and transport equations were operative in each building block, and each block was linked to adjacent blocks. More details of the model can be found in the literature (Lin 1996; Lin and others 1997).

RESULTS AND DISCUSSION

Laboratory and Field Testing

Development of Kinetic Test Protocols

ASTM Method D 5744-96

Introduction - A “modified humidity cell” kinetic-test protocol, incorporating the humidity cell design and weekly protocol by Lawrence (1990), was augmented by the U.S. Bureau of Mines (USBM) at its Salt Lake City Research Center. Based on this protocol, and using data generated by long-term USBM humidity-cell tests (White and Jeffers 1994), a draft standard test method for the modified humidity cell was initiated in 1992 by USBM and the American Society for Testing and Materials (ASTM). The intent of the method’s authors was to provide in one readily accessible document (i.e., the Annual Book of ASTM Standards, v. 11.04) a more detailed description of the modified humidity cell protocol than was previously available in the literature. The ultimate goal of the authors was to promote method consistency and provide a helpful guide to new users of the modified humidity-cell protocol, not to impose a prescriptive protocol upon the acid-mine drainage research and practitioner community. Subjecting various rock types to a well-defined standard test makes results more useful, since data can be more readily compared, interpreted and extrapolated. One effort on compiling kinetic test data is presently in progress (Morin and Hutt 1999; Morin and others 1996).

ASTM Method Approval Process - Creating a standard method through ASTM is a consensus process that involves multiple steps. Eight drafts of the modified humidity cell protocol were peer reviewed by ASTM task group, subcommittee, main committee, Society, and editorial staff members during a four-year period. Also during this period, more advanced versions of the draft method were reviewed by several members of U.S. state and federal regulatory agencies, as well as selected Canadian and U. S. researchers of contaminated drainage from metal-mine wastes. The ASTM consensus process designated the augmented protocol as ASTM Method D 5744-96 in March 1996 (ASTM 2000).

An ASTM requirement for standardizing test methods includes the determination of intralaboratory (repeatability) and interlaboratory (reproducibility) replication of test results. This determination of precision is best accomplished through an interlaboratory study (ILS). At the time D 5744-96 was accepted as an ASTM standard method, it contained a preliminary precision statement based on intralaboratory replication from two different samples tested by USBM in duplicate humidity cells. To make the ASTM Method D 5744-96 precision statement more robust, an ILS was initiated in 1996 by the Bureau of Land Management (BLM continued the USBM's metal-mine waste studies after the 1996 closure of USBM).

An ILS is usually conducted by no fewer than six laboratories, and performed on at least three materials representing different test levels. After closure of USBM, only two laboratories (American

Assay Labs - AAL, and Minnesota Department of Natural Resources - MN DNR) were available to participate in a long-term study of the method (i.e. test duration \$ 20 weeks). Therefore, comparisons of humidity-cell data generated from waste-rock samples duplicated by these two laboratories were used to present preliminary indications of the method's repeatability and reproducibility. Whereas this study was unable to involve the number of laboratories prescribed by a formal ILS, it does provide a substantial amount of information on kinetic test replication, an area that has been recognized as lacking quantitative description (Mills 1999).

Assessment of Test Methods

The present study 1) assessed the repeatability and reproducibility of the ASTM method; 2) assessed the repeatability of the MN DNR method; 3) compared results from “flood” rinse alternatives to the standard “drip” rinse approach for the two methods; and 4) compared results from the ASTM method and the MN DNR method. It was recognized that replication of results for a given kinetic test method and comparative results between methods could vary with rock type. Consequently, a repeatability- and reproducibility-testing program was initiated using six of the eight waste-rock lithologies studied so far (siltite-argillite, Duluth Complex, mafic intrusive, tuffaceous sedimentary, Archean Greenstone, and USGS AML). However, not all six lithologies were used for every evaluation. Comparisons were usually based on drainage pH and rates of sulfate, calcium, and magnesium release over time, although in some cases were limited to drainage pH and sulfate release rate (Lapakko 1998b, 1999b; Lapakko and Antonson 2000c; Lapakko and White 2000; White and Lapakko 2000; Lapakko and others. 2002a, 2002b, 2002c).

Previous publications have used the terms “drip-trickle leach” and “flood leach” to describe the addition of water to the cells to remove reaction products. For this report “drip” is used in place of “drip-trickle.” This term describes the water addition and eliminates any presumption of describing, perhaps erroneously, the subsequent flow through the rock in the cell. The term “rinse” is used in place of “leach”.

The ASTM method drip and flood alternatives demonstrated very good repeatability (intralaboratory replication) and good reproducibility (interlaboratory replication). Reproducibility tended to decrease with test duration. Differences in reaction environment temperature among laboratories resulted in difference in rates of sulfate release, with sulfate release rates increasing with temperature. This dependence also produced cyclic variations in sulfate release rates with seasonal temperature variations within a laboratory. Results from the flood rinse alternative were not substantially different from those of the drip rinse alternative.

The MN DNR method drip alternative demonstrated very good repeatability and was not subjected to reproducibility evaluation. The flood alternative produced results similar to the drip alternative but was not tested for either repeatability or reproducibility.

The ASTM and MN DNR methods produced similar results with regard to classifying mine wastes for remediation purposes. That is, the relatively small differences observed in drainage pH values would not lead to different conclusions for mine waste management. Differences in magnesium release rates were attributed to differences in the amount of residual water in the cells during the weekly cycle. The ASTM method dry cycle tended to reduce the amount of residual water and, consequently, yield lower rates of magnesium mineral dissolution than the MN DNR method.

Furthermore, the amount of residual water in the ASTM method tended to vary more than in the MN DNR method.

Modifications to the ASTM method should be considered based on the data generated. Temperature apparently affected rates of sulfide mineral oxidation, and acceptable ranges should be established to increase test repeatability and reproducibility. The possible effects of variable and excess drying during the dry air cycle should also be considered.

Dissolution of Waste Rock Lithologies

Introduction

The purpose of conducting dissolution tests on well-characterized solids is to determine relationship between solid-phase composition and drainage quality. This information will improve the accuracy of drainage quality prediction, increase the value of solid-phase compositional data for predicting drainage quality and reduce the time required for conducting kinetic tests. In summary, it will increase the accuracy and efficiency of generating data necessary to make decisions on the environmentally sound management of mine wastes.

This project examined dissolution as a function of solid-phase composition of siltite-argillite (Lapakko 1996, 1998a, 1999a, 2000), Duluth Complex gabbro (Lapakko 1996, 1998a, 1998b, 1999b; Lapakko and Antonson 2000b), mafic-intrusive, tuffaceous-sedimentary, weathered carbonate-hosted base metal sulfide (USGS AML) (Lapakko 1998c, 1999c; Lapakko and Antonson 2000a; Lapakko and others 2002a), and Archean greenstone (Lapakko and others 2002b) rocks. The project also considered previously generated data on laboratory and field dissolution of Duluth Complex gabbro (Lapakko 1988, 1994; Lapakko and Antonson 1994) and laboratory dissolution of quartz-carbonate tailings (Lapakko 1992; Lapakko and Wessels 1995).

USGS AML Rock

The USGS abandoned mine land sample (AML) had a sulfide content of 13 percent and elevated concentrations of lead and zinc. The acid production potential associated with iron sulfide was calculated as 334 g CaCO₃ eq (kg rock)⁻¹, and was calculated assuming all sulfide was associated with lead, zinc and iron. The CO₂ content of the sample was 20.9%. Calcium and magnesium present in siderite (52.1 weight percent of rock) and a small amount of calcite (0.2%) yielded a total NP[(Ca+Mg)CO₃] of 55 g CaCO₃ eq (kg rock)⁻¹. Substantial amounts of sphalerite (10%) and goethite (8%) were present. Minerals present at levels of 1 to 3 percent include melanterite, quartz, kaolinite, galena, and gypsum.

Drainage quality data indicated that the dissolution of carbonate minerals in the USGS AML sample was adequate to neutralize the acid produced by iron sulfide mineral oxidation. Drainage pH increased from values near 6.7 in the initial rinse to about 7.9 at about week 80 then typically remained in the range of 7.8 to 8.0 through the 158-week period of record. Elevated concentrations of alkalinity, magnesium and, to a lesser extent, calcium indicated magnesium and calcium carbonates were responsible for acid neutralization. The magnesium and calcium release further indicated that roughly 30% of the NP[(Ca+Mg)CO₃] has been depleted. The estimated times to depletion range

from 0 to 450 weeks (respectively calculating availability using only liberated carbonates or total carbonates).

It should be noted that if management decisions for proposed or abandoned mine wastes were based on the existing drainage pH data (which is well within limits often required for discharges), potentially acid-producing mine waste could be erroneously classified. The abandoned mine waste sample did not produce acidic drainage during the dissolution test, and it is likely that the drainage from this rock in the field was neutral for 75 to 100 years. Based on its field behavior alone, rigorous remediation measures would probably not be prescribed. However, its Net NP was -280 g CaCO₃ equivalent (kg rock)⁻¹ [Net NP = NP[(Ca+Mg)CO₃] - AP(FeS)], suggesting that the rock has a high potential to produce acidic drainage for decades. Thus, in the absence of characterization and long-term predictive testing, a mine waste which could adversely impact drainage quality might be left unremediated, while financial resources were expended toward reclaiming less reactive mine wastes.

Other High-Carbonate Iron Sulfide-Bearing Rocks

As indicated by the USGS AML sample, rocks with even small percentages of calcium and magnesium carbonate minerals may produce neutral drainage for an extended period. After these long “lag times” the samples can produce acidic drainage. For example, hydrothermal quartz-carbonate gold tailings containing 1.4% calcite produced drainage pH values above 6.0 for 122 weeks. At this time values decreased below 6.0 and reached a minimum of 2.94 after 220 weeks (Lapakko and Wessels 1995).

For samples containing even moderate amounts of calcium and magnesium carbonate minerals, the potentially long “lag times” require kinetic tests of extended duration to empirically simulate field drainage over the long term. Drainage pH will remain circumneutral as long as acid neutralizing minerals are available for reaction and dissolve at a rate greater than or equal to the rate of acid production. A critical question regarding these mine wastes is the amount of acid producing and acid neutralizing minerals that will be available to react, as opposed to the total amount of these minerals present.

Three of the lithologies tested in the present project have provided initial preliminary data on the availability of calcium and magnesium carbonate minerals to dissolve and maintain drainage pH of at least 6.0. This availability was determined by continuing dissolution tests until drainage pH decreased below pH 6.0 and determining the amount of calcium and magnesium carbonates dissolved at this time. In addition to the USGS AML sample, three siltite-argillite, four tuffaceous-sedimentary, and seven mafic-intrusive rocks contained substantial amount of calcium and magnesium carbonate minerals in addition to iron sulfides.

Using the ASTM D5744-96 method, 24% of the neutralization potential present as calcium and magnesium carbonate (NP[(Ca+Mg)CO₃]) in a siltite-argillite sample dissolved to maintain drainage pH above 6.0. This sample had an initial NP[(Ca+Mg)CO₃] of 28 g CaCO₃ eq/kg and its drainage pH decreased below 6.0 after 25 weeks. Using the MN DNR method 31% of the NP[(Ca+Mg)CO₃] present in a tuffaceous-sedimentary rock dissolved to maintain drainage pH above 6.0. This sample had an initial NP[(Ca+Mg)CO₃] of 19 g CaCO₃ eq/kg and its drainage pH decreased below 6.0 after 20 weeks. The pH of drainage from one of the mafic-intrusive samples tested recently decreased below 6.0 and testing is continuing to determine if it will remain below 6.0. The initial

NP[(Ca+Mg)CO₃] of this sample was 42 g CaCO₃ eq (kg rock)⁻¹ and drainage pH decreased below 6.0 after 204 weeks of testing. Preliminary estimates suggest approximately 60% of the NP[(Ca+Mg)CO₃] was available to dissolve and maintain drainage pH above 6.0. It is clear that the fraction of initial NP[(Ca+Mg)CO₃] that is “environmentally effective” varies among lithologies. Additional solid-phase examination of carbonate phases in fresh and leached solids has been initiated to determine variables controlling this fraction.

Low-Carbonate Iron Sulfide-Bearing Rocks

The calcium and magnesium carbonate contents were very low in the Duluth Complex gabbro and Archean greenstone rocks examined. Consequently, silicate mineral dissolution played a major acid-neutralizing role in these rocks. Since these minerals neutralize acid much slower than carbonate minerals, acid conditions were generated sooner than in rocks containing substantial amounts of calcium and magnesium carbonates. The pH of drainage from both rock types tended to decrease with increasing sulfur content and dissolution time. With both the Duluth Complex rock and Archean Greenstone rocks tested, the laboratory data generated to date are adequate to provide guidance for environmentally sound mine-waste management decisions.

Duluth Complex Rock - At the MN DNR 16 samples of ground Duluth Complex rock (0.053 < d # 0.149 mm, 0.18% #S # 3.12%) were subjected to dissolution testing (Lapakko and Antonson 1994). Sulfur present in the rock occurs largely as pyrrhotite and the major host rock minerals are plagioclase, olivine and pyroxenes. Periods of record reported ranged from 69 to 150 weeks and tests were continued, with present records as long as 700 weeks.

Drainage pH values decreased with increasing sulfur content during approximately the first 300 weeks of testing. Influence of test duration on this relationship is especially evident when comparing 300-week with 150-week results for the same suite of samples, as 300-week pH values were generally lower. Duluth Complex rock with sulfur contents less than or equal to 0.22% produced drainage pH values above 6.0 (Lapakko and Antonson 1994). The next highest sulfur contents tested were 0.40% and 0.41%. The former produced drainage pH values above 6.0 and the latter produced values below 4.5 (MN DNR unpublished data). Due to the uncertainty of the drainage quality from rock with sulfur contents near 0.4%, it can only be concluded that “critical sulfur content” for this Duluth Complex gabbro, below which drainage pH will be above 6.0 and above which drainage pH was less than 6.0, falls in the range of 0.22% to 0.4% sulfur. The MN DNR plans to test rock in this range and to more closely examine the influence of individual silicate minerals present in the Duluth Complex on acid neutralization.

Drainage pH values, and rates of sulfate, calcium, and magnesium release in the laboratory were compared to those generated by field test piles [830 to 1300 metric tons; 0.63% S (three piles), 0.79% S, 1.41% S] over 12 to 14 years (Lapakko and Antonson 1994). Field values for the 0.63% S pile were in close agreement with those observed for laboratory solids of similar sulfur content. Drainage pH values observed for the 0.79% S and 1.41% S were about one unit lower than those observed for laboratory solids of similar sulfur contents. Laboratory drainage pH values continued to decrease and approximated the field values for these two piles after 300 weeks of dissolution. Rates of sulfate, calcium, and magnesium release in the field were roughly 10 to 40 percent of those observed in the laboratory.

Archean Greenstone Rock - Fourteen samples of Archean greenstone rock were characterized (particle size, chemistry, mineralogy) and subjected to dissolution testing in the cooperative study between the US BLM and MN DNR (Lapakko and Antonson 2001, 2002; Lapakko and others 2002b). Sulfur content ranged from 0.04 to 1.22%, and occurred almost exclusively as pyrite. Major host rock minerals were quartz, chlorite, and sericite, and constituted 90 to 98 weight percent of the mineral content in 13 of the 14 samples. Substantial siderite (4.6 and 17.9 weight percent), containing magnesium and much lesser amounts of calcium, was present in two samples having sulfur contents of 0.50 and 0.72%.

During 100 weeks of dissolution testing, all but one of the samples with sulfur contents greater than or equal to 0.20% produced minimum drainage pH values less than 4.5. The single exception was a sample containing small amounts of magnesium and calcium carbonates. Two different samples with sulfur contents of 0.16% were tested. The minimum drainage pH values observed for the two samples were 5.83 and 6.15. This indicates that 0.16% S approximates a critical sulfur content for this rock, above which acidic drainage will be produced (Figure 2). Testing is continuing to determine, in part, if drainage pH values from the seven samples with S $\geq$ 0.16% will decrease.

If these values remain in an acceptable range, the greenstone rock sulfur content alone will provide a strong indicator of how wastes should be managed. For example, greenstone waste rock containing more than 0.16% sulfur would require greater precautions for mitigation of drainage quality. A safety factor would likely be applied to this value to account for potential errors in analysis and handling.

Additionally, chemical, petrologic and mineralogic data were combined to calculate the pyrite surface area exposed (Lapakko and Antonson 2002). These values were combined with sulfate release data to determine rates of pyrite

oxidation. The values determined were in good agreement with published rates for the abiotic oxidation of pyrite by oxygen (Williamson and Rimstidt 1994).

Four greenstone field test piles operated for the first full season in 2001. The sulfur contents of these piles are 0.02%, 0.20%, 0.39%, and 0.67%. To date, the drainage from all piles has been in the neutral range. Sulfate concentrations in all drainages indicate the pyrite present is oxidizing. For samples of similar sulfide content, sulfate release rates observed during the first year of field testing were 5 to 50 percent of those in the laboratory. Elevated concentrations of alkalinity, calcium and magnesium in the drainages indicate calcium and magnesium carbonates were dissolving to neutralize the acid produced. Testing will continue to 1) determine if drainages will acidify, and 2) increase the period of record and consequently enlarge the field database for comparison with laboratory rates.

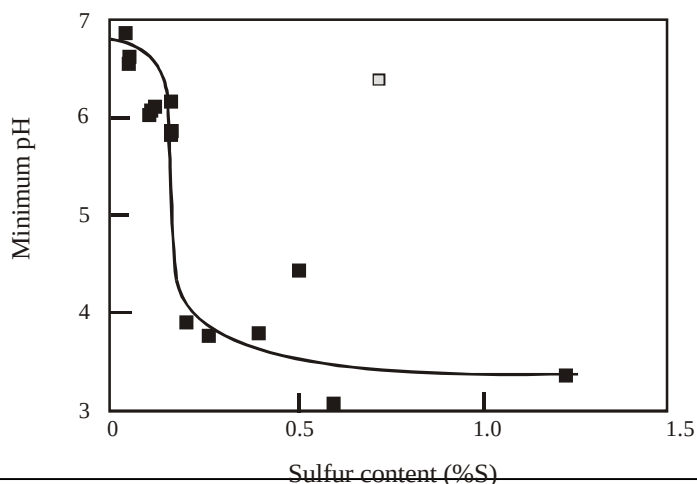


Figure 2. - Laboratory Archean Greenstone samples showing decrease in drainage pH with increase in solid-phase sulfur content.

Mathematical Modeling

Laboratory (Humidity-Cell Based) Model

Modeling Progress

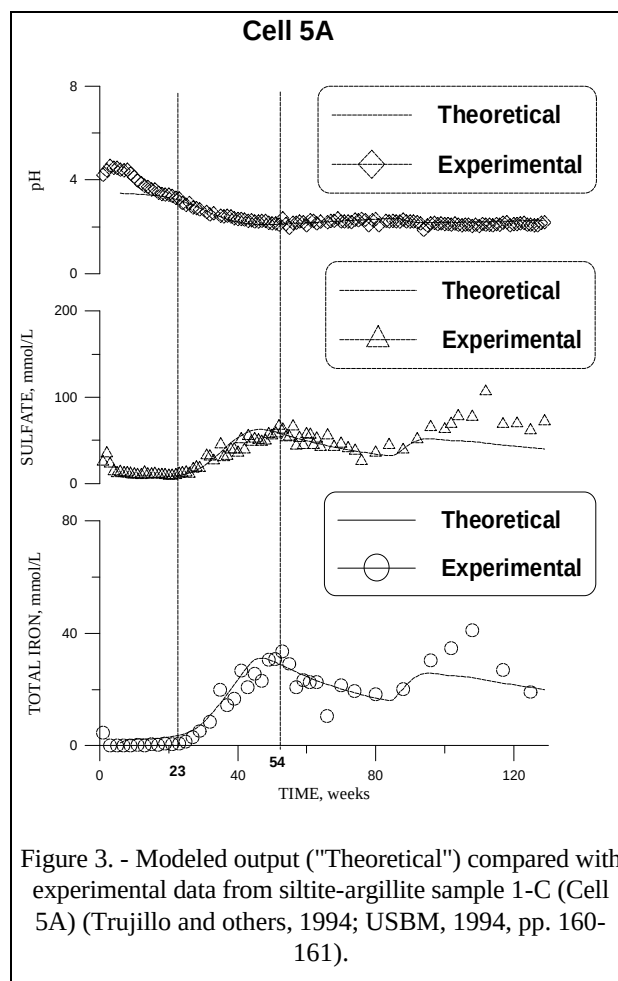
The University laboratory model AMDHC, v. 4.19 is now being used to predict weekly drainage chemistry from several samples of metal-mine waste rock that have been, or are currently being subjected to accelerated weathering in humidity cells (Trujillo and others 1994; Trujillo and others 1996a; Trujillo and others 1998).

Modeled weekly drainage chemistry exhibited good agreement with that of humidity-cell tests of samples from siltite-argillite (Lin 1996; Trujillo and others 1994; USBM 1994; White and others 1994) and hydrothermal quartz carbonate lithologies (see figures 4-6). As of FY 1995, the model duplicated three critical experimental responses observed in humidity-cell tests: 1) transition from abiotic to biotic iron-sulfide mineral oxidation; 2) precipitation of jarosite and concurrent reduction of total iron and sulfate concentrations because of precipitate coating of rock particles; and 3) participation and possible influence of two acidophilic bacterial populations on cyclic aqueous iron and sulfate concentrations (Figure 3).

There was also reasonable to fair agreement of modeled output with experimental drainage quality from Duluth Complex (USBM 1994), syenite-porphyry, and selenium-bearing rhyolite samples (Guard 1997; Trujillo and others 2000). However, additional kinetic testing of these lithologies is being conducted so that 1) the model can continue to be calibrated, and 2) the modeled fit to the experimental data can be improved.

Latest Modeling Results

The latest simulation has been conducted with the pyritic hydrothermal quartz-carbonate



tailings samples described earlier. Figures 4 and 5 show comparisons between experimental data and computer simulations for the T9 sample (mineralogy given in Table 2) for pH, sulfate and calcium. For this simulation only 14 of the 48 reactions were used and the constants for those reactions are given in Table 3.

Remarkably, the pH drop seen in the experimental data was also observed in the simulation (Figure 4).

According to the model, once calcite was depleted the pH reached a new level due to the neutralization by the feldspars and the siderite. Because the rate of neutralization by feldspars and siderite is less than that of calcite the pH dropped to a new level. The point at which that occurred depended primarily on the rate of oxidation of pyrite by oxygen and the rate of neutralization of the calcite. At the new level of pH, about 3.2 (3.7 in the model), the simulation indicated a gradual increase in the concentration of ferric ions, due to a gradual increase in bacteria concentration (catalyzing the conversion of ferrous ions to ferric). Eventually the ferric ion concentration reached a point where the oxidation of pyrite by ferric ions became important. At this point, the pH dropped even lower and then bacteria concentrations started to increase further, increasing the rate of

oxidation even further. This caused a sharp drop in pH and pyrite was quickly depleted. Once this happened, the pH started to rise since acid was no longer being generated. The rise in pH was much sharper in the model than experimental data indicate, perhaps due to adsorption/desorption or ion exchange effects not considered in the model. We are investigating this further.

The results for sulfate and calcium (Figure 5) also match experimental data fairly well for the same simulation. The maximum concentrations for both sulfate and calcium are occurring roughly at the same time as the experimental data but the peak concentrations for the simulation are considerably higher. This is consistent with the larger amount of material used for the simulation (1000 g versus 75 g). Experimentally, the total amount of sulfate and calcium released is consistent with all of the pyrite and calcite being depleted for the 75 g sample. Again, much sharper drops are observed in the simulation for sulfate and calcium than the data indicate, probably due to the reasons stated above for

Table 3. - AMDHC Version 4.19 Rate Constants – Hydrothermal quartz-carbonate tailings sample T9.

T9 – Modeling Run #463			
Reaction	Constant	Units	
(1) oxidation of pyrite by oxygen	KSO(1)	L/cm ² -s	0.7 x 10 ⁻¹¹
(2) oxidation of ferrous ion	KF(2)	L ³ /mmol ³ -hr	3.0 x 10 ⁻²⁵
(4) oxidation of pyrite by ferric ion	KSF(1)	L/cm ² -s	2.0 x 10 ⁻¹⁰
(5) Calcite reaction with acid	KSH(5)	L/cm ² -s	2.0 x 10 ⁻⁷
(7) Bacterial growth and oxidation of ferrous ion	MU1	1/hr	0.0190
	KM7A	mmol/L	1.0
	KS1	mmol/L	1.44
	RMMAX	1/hr	5.0x10 ⁻²⁰
	POW	no units	1.0
	YXFE2	mg-bacteria/mmol-Fe	0.40
(8) Feldspar reaction with acid	KSH(12)	L/cm ² -s	1.0 x 10 ⁻¹²
(9) Siderite reaction with acid	KSH(29)	L/cm ² -s	1.0 x 10 ⁻¹¹
(10) Formation of Jarosite	KF(10)	L ^{0.667} /mmol ^{0.667} -hr	7.0 x 10 ⁻¹⁵
(11) Oxidation of Chalcopyrite by Oxygen	KSO(16)	L/cm ² -s	8.5x10 ⁻¹³
(12) Oxidation of Chalcopyrite by Ferric ion	KSF(16)	L/cm ² -s	4.0x10 ⁻¹³
(14) Oxidation of Pyrrhotite by Oxygen	KSO(18)	L/cm ² -s	7.0x10 ⁻¹⁰
(15) Oxidation of Pyrrhotite by Ferric ion	KSF(18)	L/cm ² -s	5.0x10 ⁻¹⁵
(19) Bacteria II growth with jarosite, formation of ferrous ions	MMAX2		0.015
	RMMAX2		0.001
	POW2	no units	2.0
	YX2JA	mg-bacteria/mmol-Fe	0.5
(21) Reaction of Olivine with acid	KSH(27)	L/cm ² -s	1.0x10 ⁻¹³
Diffusion Coef-O2	D _{O2}	m ² /s	1.0x10 ⁻¹³
Diffusion Coef-O2	D _{Fe}	m ² /s	1.0x10 ⁻¹³
Diffusion Coef-O2	D _H	m ² /s	5.0x10 ⁻¹³
Avr.particle radius	R	cm	0.001800

pH.

It should be mentioned that this simulation is not unique, and other simulations could be obtained using slightly different rate constants and different mechanisms that also match experimental data. For example, a comparable match of the pH was also obtained when the jarosite rate was increased and the formation of jarosite caused the oxidation rate of pyrite to decrease almost to zero. Thus a rise in pH resulted at about the same time as the previous simulation, only this time pyrite was not exhausted (1000 g sample). More mineralogical data and postmortem analyses are needed to determine which simulation more accurately depicts the case for any given set of experimental data. Ongoing and future research will try to correlate the kinetic constants necessary to match experimental data for numerous lithologies to the mineralogy of the sample and other properties. If this is successful, then we should be able to predict what might happen in a standardized humidity cell test over a long period of time for any waste rock or tailings sample.

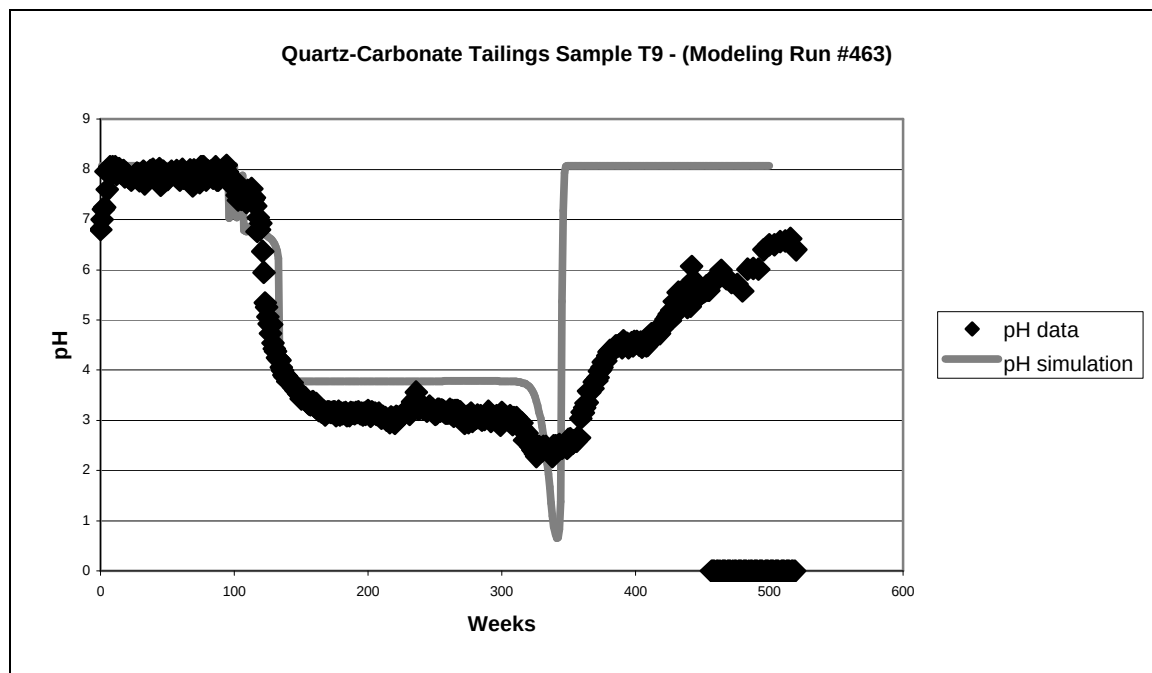


Figure 4. - Comparison between pH experimental data and computer simulation for sample T9.

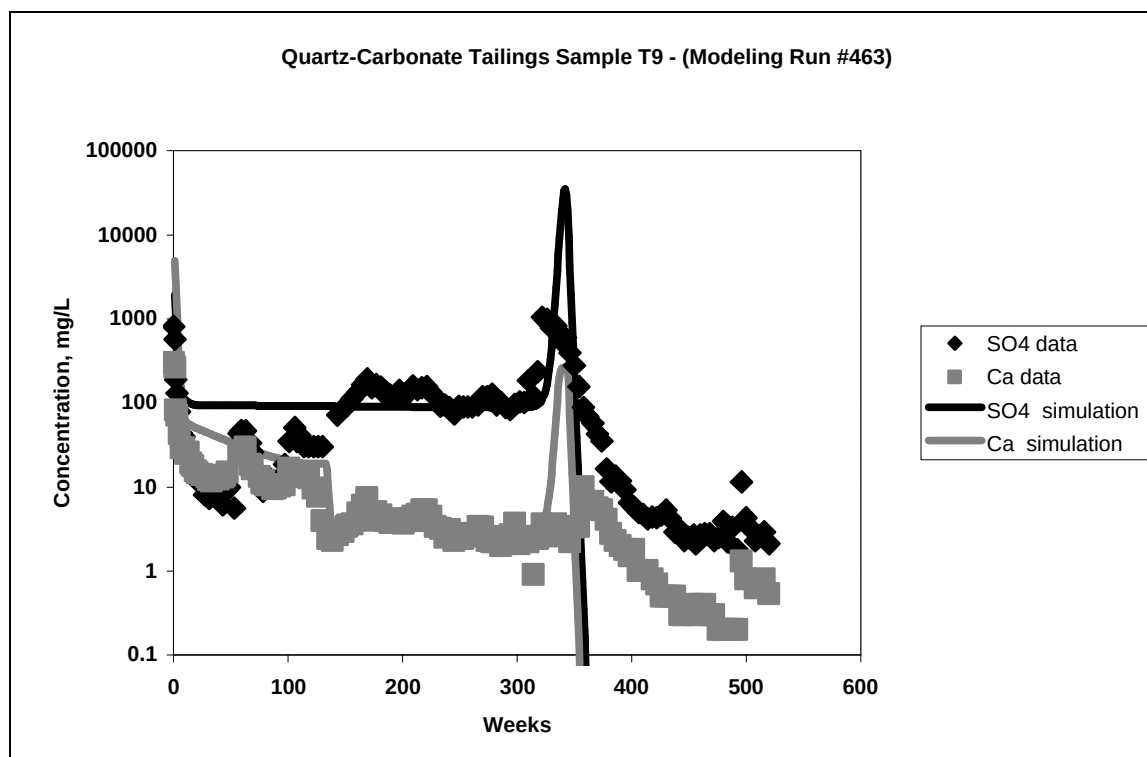


Figure 5. - Comparison between sulfate and calcium experimental data and computer simulation for sample T9.

Although the model is mathematically complex, access to the model is through a user-friendly PC-Windows NT/95/98 software program also developed by the University. Using this software program, the user is able to input data through a series of prompted pull-down "windows" and obtain an understandable output without being required to perform or derive complicated mathematical solutions. However, it has been found that in order to obtain excellent matches for widely varying lithologies, some adjustment of the kinetic constants is necessary and, in certain cases, only the most pertinent reactions should be included in the model. The following are examples of typical input and output:

- **Types of Data Required for Input:** Weight percent of certain minerals comprising the waste-rock type, estimate of initial bacterial concentration, average particle size, aqueous-phase concentrations from first week's humidity-cell drainage (both cationic and anionic), and desired number of weeks for the accelerated-weathering test are required.
- **Output:** Weekly plots of humidity-cell drainage pH, sulfate, iron (both ferrous and ferric), and specific ionic concentrations are provided in a series of Windows "boxes". Other available plots include bacteria concentrations and depletion of iron-sulfide and carbonate minerals.

The model software now contains 57 chemical species involved in 48 reactions and predicts the oxidation of pyrite, pyrrhotite, chalcopyrite, arsenopyrite, and uraninite. Also included are some selenium reactions and updated reactions for the carbonate system. The model has been modified to

accommodate drainage pH that is greater than 7 so it can model system drainages that are alkaline. The model currently simulates a maximum test duration of 500 weeks and creates concentration-versus-time plots for all 57 chemical species. Sixty-eight kinetic parameters are included in the current model for all 48 reactions. The magnitude of each kinetic parameter was initially established by applying trial and error curve-fitting techniques to the experimental data. Sensitivity analysis was then performed to assess the importance of each kinetic parameter on the modeled output. The resulting calculated parameters have been compared with corresponding kinetic parameters available in the literature when it was possible to do so and demonstrate reasonable agreement.

Field (Test-Pile Based) Model

During the initial mathematical testing of the test-pile model in 1995, it simultaneously solved more than 41,000 equations to produce concentration profiles for specified cross sections through the simulated test pile. Examples of symmetrical profiles that were calculated by the model include 1) oxygen in liquid phase, 2) pH, 3) water saturation, and 4) dump temperature (Lin and others 1997).

Since 1996, 15 more chemical reactions have been added to the original 5 reactions contained in the test-pile model. To date, 7 of the 20 reactions have been mathematically tested. It is possible to add more reactions to the field model so it eventually includes all of the 48 reactions contained in the laboratory humidity-cell model. However, computer-computation time increases substantially as the number of reactions are increased and some parameters in the modeled output become less stable (e.g., temperature oscillations have been observed). Before any future additions of reactions are considered, these two effects will need to be investigated. The computer code has been converted to use parallel processing and is now running on the University of Utah's supercomputer.

Recently, mathematical descriptions of lake phenomena (such as stratification, turnover, and other lake hydrodynamics) have been examined to see how they might be incorporated into the current test-pile model. Because the test-pile model links the governing geochemical reactions to transport phenomena in porous media, further linkage of the test-pile model with mathematical descriptions of lake phenomena may enable this multi-linked model to eventually predict metal-mine pit lake chemistry. Approximately 3 more years of research are needed to accomplish this mathematical linkage and initiate calibration with actual test data.

CONCLUSIONS

Four main study areas were examined: 1) assessing laboratory kinetic-test methods, 2) classifying problematic waste-rock lithologies through use of laboratory accelerated-weathering tests, 3) conducting field tests of mine-waste lithologies to determine field rates of chemical release and compare laboratory with field drainage pH, and 4) generating mathematical models to predict drainage quality from waste rock to help ensure environmentally sound management of metal-mine waste. The following conclusions have been derived from these studies:

Assessing Laboratory Kinetic-Test Methods (ASTM and MN DNR Protocols)

A standard accelerated-weathering protocol for mine waste associated with metal mining was established through ASTM's consensus-based process (ASTM Method D 5744-96), and a more

simplified protocol was established and tested by MN DNR (MN DNR Method). Additionally, both methods were subjected to rigorous intra- and interlaboratory studies to determine their repeatability and reproducibility with respect to variation in rinse application and pumped versus ambient air supply.

The ASTM method drip- and flood-rinse alternatives demonstrated very good repeatability and reproducibility. Results from the flood rinse alternative were not substantially different from those of the drip rinse alternative; however, reproducibility tended to decrease with test duration. Differences in reaction environment temperature were noted among laboratories, which resulted in different rates of sulfate release (sulfate release increased with increasing temperature). However, the difference in rates was cyclic, and these cyclic variations in sulfate release were correlative with seasonal temperature variation.

The MN DNR method drip-rinse alternative demonstrated very good repeatability, and the flood-rinse alternative produced similar results to those of the drip alternative. The ASTM and MN DNR methods produced similar results with regard to classifying mine wastes for remediation purposes; however, when compared with the MN DNR method, the ASTM method dry cycle tended to reduce the amount of residual water contained in the sample. This resulted in lower rates of magnesium dissolution and greater variability in interstitial water volume than was observed in samples subjected to the MN DNR method.

Classifying Problematic Waste-Rock Lithologies

Mine waste characterization and drainage quality prediction are essential to environmentally sound management of abandoned mine wastes, as well as prior to mineral resource development. Drainage from mine wastes with substantial calcium and/or magnesium carbonate content can be neutral for decades and then acidify.

In the present project, an abandoned mine sample exposed to weathering in the field for 75 to 100 years was subjected to accelerated dissolution testing for 158 weeks in the laboratory. Although the sample produced neutral drainage in the field and laboratory, solid-phase analyses suggest the rock will eventually produce highly acidic drainage for an extended period of time. Clearly, in the absence of characterization and long-term predictive testing, a mine waste which could adversely impact drainage quality might be left unremediated, while financial resources were expended toward reclaiming less reactive mine wastes.

Estimation of drainage quality from mine wastes with even moderate amounts of calcium and/or magnesium carbonates based on solid-phase composition is difficult. Critical to prediction is the fraction of acid producing and acid neutralizing minerals that will be available to react, as opposed to the total amount of these minerals present. There is presently little published information quantifying this availability. The present study provided data on the availability of calcium and magnesium carbonates in siltite-argillite, mafic-intrusive, and tuffaceous-sedimentary rocks with neutralization potentials of 19 to 42 g CaCO_3 equivalent $(\text{kg rock})^{-1}$. Drainage from these rocks acidified after 20 to 204 weeks and indicated availabilities of 24 to 60 percent. As the project continues, additional information on this availability will further improve the ability to estimate drainage quality based on solid-phase characterization.

Testing of two low-carbonate lithologies yielded data that provide strong guidance on which

to base mine waste management decisions. A critical sulfur range, below which rock produced neutral drainage and above which rock produced acidic drainage, was determined for both Duluth Complex rock and Archean greenstone rock. The critical sulfur range for the former was 0.2 to 0.4 percent and for the latter, 0.16 to 0.2 percent. Field drainage data, summarized below, for Duluth Complex rock support the laboratory data and similar field data are being generated for Archean greenstone rock.

Determining Field Rates of Chemical Release and Extrapolating Laboratory Drainage pH to that of Field Testing

Duluth Complex Rock

Drainage pH values, and rates of sulfate, calcium, and magnesium release in the laboratory were compared to those generated by field test piles. Field values were in close agreement with those observed for laboratory solids of similar sulfur content. Rates of sulfate, calcium, and magnesium release in the field were roughly 10 to 40 percent of those observed in the laboratory.

Archean Greenstone Rock

Sulfate concentrations in the drainages from four greenstone field test piles indicate the pyrite present is oxidizing. Currently, drainage from all piles has been in the neutral range. For samples of similar sulfide content, sulfate release rates observed during the first year of field testing were 5 to 50 percent of those in the laboratory. Elevated concentrations of alkalinity, calcium and magnesium in the drainages indicate calcium and magnesium carbonates were dissolving to neutralize the acid produced. Testing will continue to determine if drainages will acidify, as implied by laboratory data, and to generate additional field data for comparison with laboratory rates.

Generating Mathematical Models to Predict Drainage Quality

Laboratory (Humidity-Cell Based) Model

As of FY 1995, the model (AMDHC) duplicated three critical experimental responses observed in humidity-cell tests: 1) transition from abiotic to biotic iron-sulfide mineral oxidation; 2) precipitation of jarosite and concurrent reduction of total iron and sulfate concentrations due to precipitate coating of rock particles and consequent reduction in iron-sulfide mineral oxidation rate; and 3) participation and possible influence of two acidophilic bacterial populations on cyclic aqueous iron and sulfate concentrations.

A recent application of the model (v. 4.19) to predict drainage chemistry from a hydrothermal quartz-carbonate tailings sample showed good to reasonable agreement with 520 weeks of experimental data including weekly drainage pH, and sulfate and calcium concentrations. The multiple drops in effluent pH were faithfully matched by the modeled output, and the model provided plausible explanation regarding the multiple drops and ultimate rise in pH. The same simulation

conditions showed that modeled results for sulfate and calcium also reasonably matched experimental data. These matches were obtained by limiting the modeled species to those contained in the sample (rather than having the model crunch through its entire inventory of reactions), and by making minimal changes to some selected kinetic rate constants. However, the simulation conditions that resulted in a reasonable modeled match to the quartz-carbonate experimental data were not unique. For example, when the rate of jarosite formation was increased, a comparable match of the pH was also obtained. Therefore, additional pre- and post-leaching mineral characterization is needed to identify which simulation conditions more accurately describe the actual mineralogical and physical conditions that produced the experimental data.

Field (Test-Pile Based) Model

The current version of the field model links governing geochemical reactions to transport phenomena in porous media. Consequently, the field model is able to produce concentration profiles for specified cross sections through a simulated symmetrical test pile. These concentration profiles include 1) oxygen in liquid phase, 2) pH, 3) water saturation, and 4) dump temperature. Further linkage of the test-pile model with mathematical descriptions of lake phenomena is being examined, and may enable this multi-linked model to eventually predict pit lake chemistry.

Although the number of reactions included in the model has been increased from the original 5 to 20, only 7 of these 20 reactions have been mathematically tested to date. Approximately 3 more years of research are needed to test the additional reactions, accomplish the lake-phenomena mathematical linkage, and initiate model calibration with actual test data.

CONSIDERATIONS FOR CONTINUED ASSESSMENT

Considerable progress has been made towards 1) developing predictive tools (e.g. Guard 1997; Lapakko 1998b, 1999b; Lapakko and Antonson 2000b; Lapakko and others 2002c; Lapakko and White 2000; Lin and others 1999; Trujillo and others 1994; Trujillo and others 1996a; Trujillo and others 1998; Trujillo and others 2000; White and Lapakko 2000), 2) furthering the understanding of their application and interpretation (Lapakko 1993; Lapakko 1994; Lapakko and Antonson 2002; Trujillo and others 1997; White and others 1997, 1999), and 3) generating predictive data from long-term accelerated weathering tests of eight different waste-rock lithologies (Guard 1997; Lapakko 1996, 1998a, 1998b, 1998c, 1999a, 1999b, 1999c; Lapakko and Antonson 2000a; Lapakko and others 2002a, 2002b; Trujillo and others 2000).

Despite these advances, large gaps remain in the body of knowledge required for making scientifically based decisions on mine-waste management, and the following tasks need to be continued or expanded.

Accelerated Weathering Tests - Although eight waste-rock lithologies have been subjected to as much as 278 weeks of accelerated weathering in humidity cells, some of the samples have yet to be classified as either acid or non-acid producing. Therefore, selected samples should continue being subjected to accelerated weathering until their drainage quality can be determined. While these eight lithologies have been tested in this study, they are only a small representation of the numerous rock types that comprise metal-mine waste in the Western U. S. More waste-rock types need to be tested

to ensure that our study has examined a representative cross-section of metal-mine waste. The mineral- and chemical-characterization and accelerated-weathering data generated from testing additional rock types will help further the calibration of the two developing models so confidence is increased in the modeled output. The new data, along with data generated from previously tested waste-rock types need to be interpreted and organized into a comprehensive, diagnostic library of waste-rock drainage quality as a function of solid-phase composition. Additionally, several variables that influence rock dissolution in predictive tests (i.e., variation in rock composition, particle size, and pore-water retention time) have yet to be included in the accelerated-weathering-test protocol.

Geochemical Predictive Models - While the laboratory humidity-cell model is nearly complete, it needs to be further calibrated with additional waste-rock types to ensure that modeled output accurately reflects drainage quality from a broader range of waste-rock composition. The field test-pile model will require several years of additional work. Specifically, 13 of its current 20 geochemical reactions require mathematical testing, and additional mathematical testing will be required as more reactions are added. The model also requires calibration with actual test-pile data (MN DNR will provide 17 years of drainage-quality data from four 1000-ton test piles of Duluth Complex waste rock). To modify the field test-pile model to a pit-lake kinetic model, mathematical descriptions of lake phenomena will have to be linked to the model, which will require additional research effort and time. The field test-pile model is also capable of simulating 3-phase concentration profiles in large-scale laboratory column-leach tests and field heap-leach test piles. Further calibration of the model for these additional configurations is recommended.

Addressing these informational gaps and organizing and analyzing information collected in a systematic manner, are key elements of the proposed future work.

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TECHNICAL PAPER SESSION 12 ENGINEERING AND DESIGN

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MANNING CANYON TAILINGS REMOVAL ACTION

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ABSTRACT

The Salt Lake Field Office of the Bureau of Land Management proposed a Special Management Recreation Area (SMRA) in an area referred to as Five Mile Pass. An abandoned mine land inventory was conducted jointly with the Bureau of Land Management Utah State Office and the State Abandoned Mine Reclamation Program. As a result of this inventory effort, the Utah State Office recommended that additional characterization of the Manning Canyon tailings was necessary in order to determine how to appropriately reclaim the tailings on BLM administered lands.

The Manning Canyon tailings are located in Manning Canyon near Fairfield, Utah on property administered by the Bureau of Land Management (BLM) and on land privately owned. The tailings are associated with the historic Manning Canyon gold mill that operated during the early 1900s. Approximately 720,000 cubic yards of arsenic tailings in four historic tailings ponds have migrated over several hundred acres. Nearly half of the tailings volume has migrated through dam breaches and have moved down gradient to the town of Fairfield, prompting an EPA emergency yard soil removal.

Concentrations of arsenic in the tailings range from 2000-10,000 ppm. There is no groundwater within 100 feet of ground surface. The site is heavily used by off-road vehicles and other recreational purposes. Beginning in 1999, BLM performed CERCLA site characterization studies and in 2001, selected a remedy to consolidate the tailings into an on-site repository. The Bureau of Reclamation prepared the design package featuring a capillary barrier engineered cap for the repository. Funding for the \$8 million cleanup project has been obtained from the Department of Interior's Central Hazardous Materials Fund. Construction is scheduled to begin this summer.

SITE DESCRIPTION

The Manning Canyon Mill Site (Site) is an abandoned gold milling facility located in the Oquirrh Mountains of Utah County, Utah, approximately 40 miles south of Salt Lake City. A gravel road that is maintained by the county accesses the Site. This road intersects State Highway 73 about two miles south of Cedar Fort, Utah.

Approximately 720,200 cubic yards of tailings and waste rock have been deposited within the Site. This material was generated by the Manning Mill that processed ore at the site from 1890 until 1937. The waste material from the mill was disposed of in tailings ponds that have breached in the past allowing the tailings to wash downstream. This material is highly susceptible to wind and water erosion and transport downstream by surface water flows in the intermittent drainage channels that drain Manning Canyon. The tailings and waste rock contain elevated levels of arsenic, mercury, and lead that pose a threat to human health and the environment within and downstream of the Site.

An Engineering Evaluation and Cost Analysis (EE/CA) was prepared by BLM (BLM, 2000). The Executive Summary of the EE/CA is an attachment to this Action Memorandum. The EE/CA defines the nature and extent of contamination, assesses the human health and environmental risks posed by the contaminants of concern, identifies response action objectives, treatment technologies, and removal action alternatives, and compares the alternatives on the basis of effectiveness, implementability, and estimated cost. The EE/CA provides a basis for funding determinations and planning to conduct a non-time-critical response action under CERCLA. This action is considered necessary due to relatively high concentrations of arsenic, mercury, and lead at the Site and the potential for these hazardous substances to affect humans exposed to the Site and the environment surrounding the source areas.

The Site encompasses an area of approximately 1,470 acres or 2.30 square miles. There are six (6) defined tailings areas, which cover approximately 66 acres. Of this total approximately 21 acres are on private land, and 44 acres are on public land administered by the Department of the Interior, Bureau of Land Management (BLM). Based on field measurements of the aerial extent and approximate depth of tailings and waste rock on the Site, approximately 305,600 cubic yards of waste material are deposited on private land, and 414,600 cubic yards of waste material are deposited on public land. On a volume basis, 42 percent of the waste material is on private land, and 58 percent of the waste material is on public land. A map showing the features at the Site is provided in Figure 1.

Manning Canyon drains an area of over eight square miles through several ephemeral drainage channels that transect the valley. Drainage from the Site is usually associated with spring snow melt and rain storms. There are two main drainage channels that run parallel and southeasterly to drain Manning Canyon. The tailings and waste rock deposits are generally situated on the floor of the canyon in or near the main drainage channels. These waste deposits are essentially devoid of vegetation. Vegetation surrounding the waste deposits includes pinyon pine, juniper, sage brush, and Indian rice grass.

In addition to the previous industrial uses, over the past 30 years the Site has supported off-road vehicle use and other outdoor recreation. The BLM Salt Lake City Field Office has estimated that over 1,000 persons use the site for recreational purposes per year. The area is undergoing rapid growth and use is increasing substantially each year. Because of the large size of the site, signs and fences have been ineffective in reducing use.

Manning Canyon is located in the Mercur Mining District, adjacent to the West Mercur and Fivemile Pass Mining Districts. The Mercur District was first organized in 1870 as the Floyd Mining District when silver lode discoveries were made. As time went on, gold became the primary commodity produced, causing a production or mining boom from 1898 through 1912. Mines located in the southern Oquirrh Mountains have also produced precious and base metals and clay.

In 1890, the Manning Mill was built to treat ore from the Mercur vein by pan amalgamation. The Manning Mill was remodeled in the summer of 1890 to process ore by the cyanide process. From 1890 to 1900 the crude ores mined at Mercur, Utah, 5 miles northwest of Manning, were transported by team and wagon and later by a privately owned railroad, and were leached in tanks by percolation with solutions of potassium cyanide. The mill expanded to 50 tons daily, then to 100 tons in 1893, to 200 tons in 1896, and then to 500 tons. Following construction of the Golden Gate Mill in 1898, the Manning Mill ceased treating Mercur ores and was used to process tailings. In 1933, a second mill was constructed at the Manning Mill Site to re-treat the estimated 455,000 tons of tailings in large

dumps. From September 1934 to July 1936, an average of 536 tons of material (both tailings and crude ore) were treated per day. In addition to re-treating the tailings dumps left by the operations of the prior Manning Mill, the second Manning Mill operated as a custom plant to treat crude ores from Mercur and some ores from outside the Camp Floyd Mining District. After this second mill completed re-treatment of all the Manning "dumps," the mill was relocated in 1937 to Mercur.

Much of the private land in the surrounding areas includes patented mining claims from the late 1800s and early 1900s. Clay mining on these private lands remains active today. Private land located to the south is used for agricultural purposes, including wheat fields approximately 1.8 miles southeast of the Site. The small town of Fairfield is located 3.5 miles southeast of the Site. The Site has a history of recreational use. Purchased by its current owners in the 1950s, the private portion of the Site hosted national motocross events in the 1970s. Since then, off-road vehicle users and other recreational users have frequented the Site. March through September are high use months, usually receiving six to 10 vehicles per day with multiple passengers. The winter months receive less visitors. The BLM Salt Lake Field Office estimates an annual visitation of approximately 1,050 by tourists and locals. All terrain vehicles (ATVs), bicyclists, campers, and youths shooting paintball guns have been observed on the tailings deposits within the Site.

REMOVAL SITE EVALUATION

A site investigation was conducted in September 1999 to collect data and make observations necessary to develop the EE/CA. The findings of this investigation are summarized in Section 2 of the EE/CA. The tailings piles were sampled extensively on the surface and using soil borings to characterize the metals concentrations and depth of the tailings. Arsenic averages 7,107 ppm in Tailings Area 1, 4,866 ppm in Tailings area 2, 7,436 ppm in Tailings Area 3, 5,580 ppm in Tailings Area 5, and 3,601 ppm in Tailings Area 6. The tailings are unsaturated, and alkaline in their chemistry. Because of the large size of the site, electrical resistivity geophysics was also used to characterize depth of tailings. This effort was to determine the volume and location of tailings that need to be moved from the floodplain. Monitoring wells were installed upgradient and downgradient of the site. No water was encountered at more than 150' below ground surface downgradient of the site. Sampling of sediment in the eastern and western drainages verified the migration of tailings of arsenic from the Site to the railroad right-of-way. Other work performed included a phase 1 cultural clearance and studying the drainages for determining the 100 year flood event and flood plain, and to propose reconstruction of the channels after removal.

RISK ASSESSMENT

Arsenic, lead and mercury are CERCLA hazardous substances. The presence of these hazardous substances within the tailings ponds, the main drainage channels, and downstream of the Site constitutes a release and a substantial threat of release of hazardous substances into the environment as defined by CERCLA. A streamlined risk assessment was conducted and is provided in the EE/CA. This risk assessment identified arsenic as the primary chemical of concern at the Site. Maximum concentrations of arsenic in tailings exceed the risk management

criteria (RMC) for a recreational camper exposure scenario by 76-fold, and would be rated a high-risk according to BLM guidance (Ford, 1996).

Lead and mercury, the two other chemicals of concern at the Site, were found in maximum concentrations that did not exceed human health RMCs, and only slightly exceeded the wildlife RMC. It is expected that lead and mercury exceedances of the wildlife RMC will be eliminated by a response action based upon the camper RMC for arsenic.

There are two types of threats: offsite and onsite. Offsite threats include historic releases that have resulted in migration of arsenic tailings into the town of Fairfield and have caused the emergency removal of yard soils in one residence by EPA. Future releases could occur from the site with major flood events and carry large amounts of arsenic-laden tailings into Fairfield. The tailings are easily eroded in flood events as verified by observation of the extreme gullying and washout of the tailings and tailings dams. A major release could also threaten the water supply for Fairfield as it is a spring that is only protected by small berms.

Onsite threats include health risk to site visitors, especially campers and ORV or ATV users. Campers are exposed to 76 times the acceptable risk to arsenic as a carcinogen, while ATV users are exposed to about 5 times the acceptable cancer risk for arsenic. In addition, these users typically carry tailings dust or mud onto their clothing, vehicles and equipment and may be exposed further to arsenic at home.

Arsenic is toxic to plants above 100 ppm. Currently, at least 50 acres are devoid of vegetation, provide no habitat and do not support life. Exposure to arsenic on the tailings is about 5-6 times the acceptable exposure using BLM's risk management criteria. In addition, the tailings affect surface water quality during precipitation events and may further expose wildlife to high concentrations of arsenic.

Actual or threatened releases of arsenic, lead and mercury from this site, if not addressed by implementing the response action selected in the Action Memorandum, may present an imminent and substantial endangerment to public health, welfare, or the environment.

PREVIOUS ACTIONS

Between 1996 and 1998, BLM and the EPA conducted preliminary assessments of the tailings impoundments, downstream depositional areas, and local springs. Elevated concentrations of arsenic were found and determined to be a potential health risk to recreational users of the Site. Arsenic is toxic to plants and animals, and is a human carcinogen. During 1999, EPA also sampled residential yard soils in the town of Fairfield. During 2000, EPA conducted an emergency removal of yard soils from two residences in Fairfield.

These data have led the BLM to evaluate the need to conduct a non-time-critical removal action to address sources of hazardous substance releases within the Site.

BLM and EPA conducted a joint public meeting in the Town of Fairfield on March 14, 2000 to discuss the release of arsenic from the Site and findings of soil sampling in the Town of Fairfield. BLM addressed its plans for the main site. In addition, BLM has consulted with Town officials and residents, including the manager for the Town water supply. BLM has issued press releases and several articles about the site have been presented in major newspapers and has complied with the community relations requirements of 40 CFR 300.415 (m). A notice was placed in the Deseret News

concerning the availability of the Draft EE/CA for public comment. The only significant comments received were from the State Department of Environmental Quality. The comments and BLM's responses are part of the Administrative Record and were established at the BLM Office, 2370 South 2300 West in Salt Lake City and at Lehi Library.

CURRENT ACTIONS

BLM completed the design plans and specifications using the Bureau of Reclamation's Provo office. Other ongoing activity includes funding requests and negotiations with potentially responsible parties. A construction contractor, the Opal Group, was selected and Phase I of the work will begin during 2002. Phase I consists of constructing run-on controls and removal and consolidation of the upper tailings into the repository area. Phase II, to be conducted in 2003, will consist of ongoing construction of the repository and cap. Phase III, to be conducted in 2004 will consist of removal of the lower tailings area near the railroad right of way and placement into the repository.

The Utah Department of Health was consulted on several occasions and was been sent sampling plans, preliminary assessments and the EE/CA for review and comment. The Utah County Health Department has been consulted for information on the Fairfield water supply. The State and County will be involved in construction of the remedy for the Site. The County and Utah Department of Transportation have been involved in review of design and construction aspects concerning improvements to the County road and other road access.

PROPOSED ACTIONS AND ESTIMATED COSTS

The EE/CA presented a study of the nature and extent of contamination at Manning Canyon, removal action objectives and action levels, a brief risk assessment and various alternatives to remedy the health risks. The overall goal of the response alternatives evaluated in the EE/CA is to reduce the release and threat of release of arsenic, mercury, and lead from the Manning Canyon Site, thereby reducing risks to human health and the environment. The alternatives were screened based on effectiveness in reducing risk, implementability and cost. A preferred alternative of an on-site repository was selected. The EE/CA has been prepared in accordance with the criteria established under the CERCLA, and sections of the National Contingency Plan (NCP) applicable to removal actions (40 CFR 300.415 (b)(4)(i)). The EE/CA is also consistent with EPA guidance document, Guidance on Conducting Non-Time-Critical Removal Actions Under CERCLA. The EE/CA removal action objectives were:

- , Reduce or eliminate the release of arsenic, lead, and mercury from the Manning Canyon mill site via surface water during flood events.
- , Reduce or eliminate the release of arsenic, lead, and mercury from the Manning Canyon mill site via surface water to ground water pathways.
- , Reduce or eliminate the release of arsenic, lead, and mercury from the Manning Canyon mill site via soil to air pathways.

- , Reduce or eliminate the release of arsenic, lead, and mercury from the Manning Canyon mill site via soil to ground water pathways.
- , Reduce or eliminate the potential for exposure to humans and wildlife from direct contact, ingestion, or inhalation with contaminated surface soils.

Conceptual designs were developed for each of the four removal alternatives, and an opinion of probable cost was prepared for each.

Alternative 2 - On-Site Repository and Surface Water Diversion (Selected)

The final EE/CA Alternative 2 is the recommended alternative. This alternative involves placing the tailings from the piles and ponds into an on-site repository near the tailings deposits. This represents a minor design change from the Draft Final EE/CA which conceptualized two repositories. Additional analyses demonstrated that a single repository is less expensive and reduces operation and maintenance requirements. The repository will be sited to keep the consolidated tailings out of the 500-year flood plain. The tailings that are contained near drainage courses will be relocated to reduce the potential for these tailings to be washed downstream during flood events. In addition, the channel will be restored and sized for the 500-year flood event, and run-on controls will be established around the repository. This alternative best met the screening criteria as most effective, implementable and cost-effective. The other alternatives evaluated are described below:

No Action Alternative (Not Selected)

This alternative, by definition, would involve taking no action at the site. The risks to human health and the environment at the site would remain unchanged. The cost associated with this alternative is zero, since nothing will be done to change the status or condition of the site.

Alternative 1 - Institutional Controls and Surface Water Diversion (Not Selected)

Alternative 1 involved developing measures that would reduce exposure to persons and reduce the transport of tailings from the Site downstream due to flood events. The measures that were considered include restricting access to the Site by instituting deed restrictions on the lands containing waste material, installing barriers to access, providing warning signs, and constructing diversion channels to route surface water flows away from the tailings and around the Site. The surface water flowing through the Site would be diverted to a constructed channel on the west side of the property that follows the existing drainage channel.

Alternative 3 - Off-Site Repositories and Drainage Channel Reconstruction (Not Selected)

Alternative 3 involved removing the tailings from the piles and ponds, transporting the waste material off-site, and consolidating it in off-site repository areas. The repositories would be located

out of drainage courses and isolated from ground water pathways. For the purposes of the EE/CA, the off-site repository area considered five abandoned clay pits that are southwest of the project site.

Alternative 4 - Waste Consolidation and Treatment (Not Selected)

Alternative 4 involved consolidating the tailings on-site and treating the surface of the waste pile to reduce the potential for release of arsenic, mercury and lead from the waste material. A comparison of the estimated present value cost for the alternatives is provided in Table 1 below.

Table 1. Summary of estimated present value costs for preliminary removal action alternatives

<u>Alternative</u>	<u>Description</u>	<u>Estimated Present Value Cost (\$)</u>
0	No Action Alternative	\$0
1	Institutional Controls and Surface Water Diversion	\$3,778,000-5,002,000
2	On-site Repository and Surface Water Diversion	\$7,225,000-9,211,000
3	Off-site Repositories and Drainage Channel Reconstruction	\$13,207,000
4	Waste Treatment and Consolidation	\$14,012,000

CONCLUSION

The present value cost includes initial response action capital costs, post-removal site-control costs, and long-term site maintenance and monitoring costs. These costs were estimated for a 30-year period and converted to year 2000 dollars.

ARARs are applicable or relevant and appropriate requirements contained in federal or more stringent state laws and regulations. ARARs are itemized and discussed in the EE/CA. State regulations concerning air and water quality will be attained by the selected remedy. Since the canyon is dry and groundwater is more than 100' below ground surface, no exceedance of water quality standards is anticipated provided best management practices for erosion control are complied with. Since there are no applicable state or federal soil standards, BLM risk management criteria for campers are to be considered ARARs for soil contamination. The repository will be sited in areas out of the 500 year flood plain and away from cultural or historical features, insofar as possible.

REFERENCES

- BLM, 2000, Final Engineering Evaluation/Cost Analysis, Manning Canyon Tailings. National Science and Technology Center, Denver, CO.
- Ford, 1996, Risk Management Criteria for Metals at BLM Mining Sites, Technical Note 390, National Science and Technology Center, Denver, CO.

DANGEROUS ATMOSPHERE CREATED BY STRIP MINE SPOIL

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ABSTRACT

Dangerous, low oxygen levels, commonly referred to as blackdamp, are often caused by carbon dioxide and nitrogen produced from abandoned underground coal mines. The blackdamp atmosphere from adjacent underground mine voids displaces normal air in homes through changes in air pressure. Three homes near and on a recently reclaimed strip mine are affected by blackdamp with no obvious association to deep underground mining. During periods of low barometric pressure, atmospheric levels of 12 to 25% carbon dioxide (CO₂) and near 10% oxygen (O₂) by volume entered the basements of these homes for periods exceeding 12 hours.

Drilling indicated that CO₂ was concentrated throughout the permeable mine spoil beneath one of the homes. The other two homes were adjacent to the strip mine but not undermined. The source of the CO₂ production in the strip mine was initially unknown. However, three potential sources were identified: 1) deep, open mine entries encountered during surface mining activities; 2) organic and landfill waste disposed in the mine pits; or 3) the dissolution of carbonate materials from reactive waters deep in the spoil. The source of the blackdamp needed to be identified to allow AML funding for abatement of the project.

Stable isotopic analysis (¹³C/¹²C) of the carbon dioxide identified that the gas was inorganic in origin, specifically, from dissolved carbonate material in the spoil. The water chemistry also supports a high capacity to dissolve carbonate material. The overburden analyses of the mine spoil showed a significant source of carbonate material in a glacial till at the site. The normally attractive neutralization potential of this glacial till combined with the waters from the adjacent abandoned mine to produce a detrimental source of CO₂.

BACKGROUND

On August 11, 2000, the Office of Surface Mining's (OSM) Federal Reclamation Program received a complaint from the office of State Representative LaGrotto regarding two of his constituents who reside in Washington Twp., Lawrence County, PA. They were Jason Parker, and Jack and Lisa Burk. These individuals were complaining about high concentrations of carbon dioxide and low oxygen levels in their homes. The symptoms were difficulty in breathing, anxiety, and one family went to the hospital with flu-like symptoms. An initial investigation by OSM on August 16, 2000, produced a third complainant, Larry Geiwitz, with similar problems.

The three properties of this project have similar symptoms, although the Geiwitz's problem seemed most severe. Each of the three properties has different site conditions and backgrounds. The Parker home is over 100 years old, recently remodeled and has a new addition. The older portion of the home had a stone foundation and an earthen basement floor. The gas appliances in the basement often extinguished before or during storms. The poor quality air often filled the basement, coming from the earthen floor and concrete block walls of the addition. High concentrations of CO₂ were measured in exterior pilasters located on the south side of the home. Little or no CO₂ was observed in the two water wells adjacent to the house.

The Geiwitz's home is a large, brick, ranch style home with a full basement about three years old. The basement is finished and their children have bedrooms in the basement. The home has no gas appliances, and is well built and tight. The home is located on a recently reclaimed strip mine. The residents complained of shortness of breath and anxiety often as storms approached. They would watch the barometer to anticipate the problem of low O₂ in their basement. These people worked extensively on their home to control the influx of poor quality atmosphere. First, they added vents to the French drain system around the foundation of the home. Second, they installed an air exchange system that replenished fresh air through the HVAC system. Finally, they installed a sub-slab ventilation system, similar to that used to control radon. Only small amounts of improvement were achieved with each modification. Measurements indicated that the gas was entering the basement through cracks and construction joints in the basement floor.

The Burk's home is a brick ranch home about two years old with a full basement. The basement foundation is partially exposed, with an on-grade, integral garage. The home has no gas appliances. The strip mine came to within 200 feet of the home and the site was used as a spoil stock pile. The residents went to the hospital one time when the air quality was very poor. However, by the time they arrived at the hospital most of their symptoms were gone. The homeowners did nothing to control the low O₂ but open windows when the atmosphere became stale. High concentrations of CO₂ were measured along the back basement wall at the deepest foundation on the north side of the home. High levels of CO₂ were also observed in the shallow hand-dug water well, located about 300 feet southwest of the house.

An Exploratory Investigation was initiated to install three recording gas meters, drill exploratory holes and obtain samples at the three sites. Gas meters have been in place since 11/9/2000 and are down loaded on a routine basis. The drilling was completed on 11/15/2000. Ten holes were drilled, TB-1 through 4 on Parker's property, TB-5 through 7 on Geiwitz's property, and TB-8 through 10 on Burk's property. The drilling investigation was intended to verify if underground mining existed at the site and to identify the source of the low O₂ and high levels of CO₂.

MINING HISTORY

The underground mining in the area was conducted around the turn of the century and abandoned in the 1940's. According to mine maps from the state permit records, the Oakes Mine, operated by Oakes Bros. and Pennsy Mine, operated by Pittsburgh & Erie Coal Company, mined the Brookville Coal Seam. Coal occurs from near the surface to depths of 190 feet.

The mapped underground mines did not extend under the problem sites, and the coal was estimated to be at least 80 feet in depth under the homes founded on bedrock. An abandoned slope entry of the Oakes Mine located about one mile northwest of the Parker site is discharging about 50 gallons per minute of mine drainage with high iron. The mine drainage is collected into a series of ponds then released into a large wetland area.

In 1985, a permit was approved to strip mine coal at the Leesburg No.1 Mine by Willowbrook Mining Co., Division of Adobe Mining Company in the project area. Around 1989 Amerikohl Mining Company took over operation of the bankrupt mine, and recovered the bond money by completing the reclamation of the site.

The large strip mine had pit cuts up to 5200 feet long and an average width of 140 feet

with a maximum highwall height of 198 feet. The area of the mine covered over 1800 acres. The overburden was excavated by a Marion 8050 dragline with a 325-foot boom and a 55-cubic-yard bucket, the largest dragline in western Pennsylvania at that time. The four coal seams from deepest to the most shallow that were mined are: Brookville, Clarion, Lower Kittanning, and remnants of the Middle Kittanning.

The initial cut of the mine was about 300 feet southeast of the Parker's residence. The mine plan had an irregular boundary adjacent to the underground mine identified on the northwest edge of the permit. The coal company drilled extensively to avoid the boundaries of the abandoned underground mine but reportedly still uncovered unmapped entries. In 1990 the coal company requested and was approved a variance in the permit allowing disposal of mine tippel waste in mine spoil.

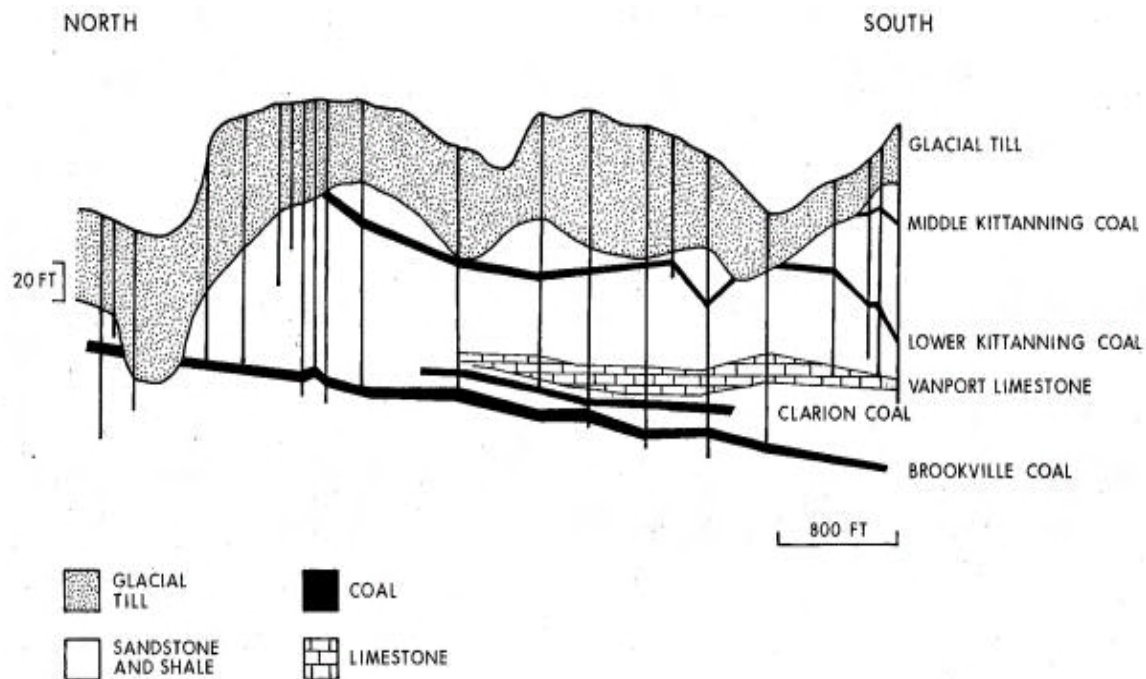


Figure 1 Geologic section across surface mine

The permit allowed the disposal of mine refuse from the company's prep plant. Rumor from local residents was that some land fill waste was also disposed at the site. The mine was designed to use neutralizing materials from the overburden in the backfill to minimize acid mine discharge. The surface mining continued to 1989 after exchanging ownerships. The site was reclaimed and final bond was released in December 2001.



Figure 2 Aerial Photo of Leesburg Mine

During operations, surface mine blasting damaged the Parker's property requiring repairs to the structure and drilling of a new water well. The Geiwitz and Burk homes were not built until mining operations were completed. The site of the Geiwitz home is over a thick section of backfill spoil and the site of the Burk's home is where a backfill stock pile was stripped to bedrock.

GEOLOGIC SETTING

The Parker Project is set in the northern extents of the Appalachian Bituminous Coal Region. The bedrock is composed of sandstone, shale, limestone, and coal of the Kittanning Formation of the Allegheny Group of the Pennsylvanian Period. The thickest coal seam is the Brookville coal averaging about 60-inches thick. The Vanport Limestone is a major marker bed in the region but is not present at the project site. The limestone was eroded away by a facies change or channel cut. The geologic structure of the area is simple. The bedrock dips about 1-2 degrees to the southwest. Most of the local changes in bedding are controlled by depositional patterns.

The surface is covered by a variable thickness of glacial till and outwash. The glacial till is from the Kent Stage of the Pleistocene Period. The glaciations deposited ground till, an end moraine and an outwash channel in the area forming gently rolling topography and an extensive

wetland area along an end moraine. The glacial till forms an excellent soil and provides a calcium carbonate for neutralizing materials in mine backfill. Much of the land impacted by the surface mine was characterized as prime farmland, so thick soil overburden was stock piled for reclamation.

Besides coal, gas and oil production have a history in the area. In the 1960's gas and oil exploration produced gas wells from the deeper formations. During mining most of the gas wells were abandoned and the gas wells left have been declining in production. A gas well served the Parker residence but has since been abandoned due to low production. Carbon dioxide is often produced in gas wells as they lose production.

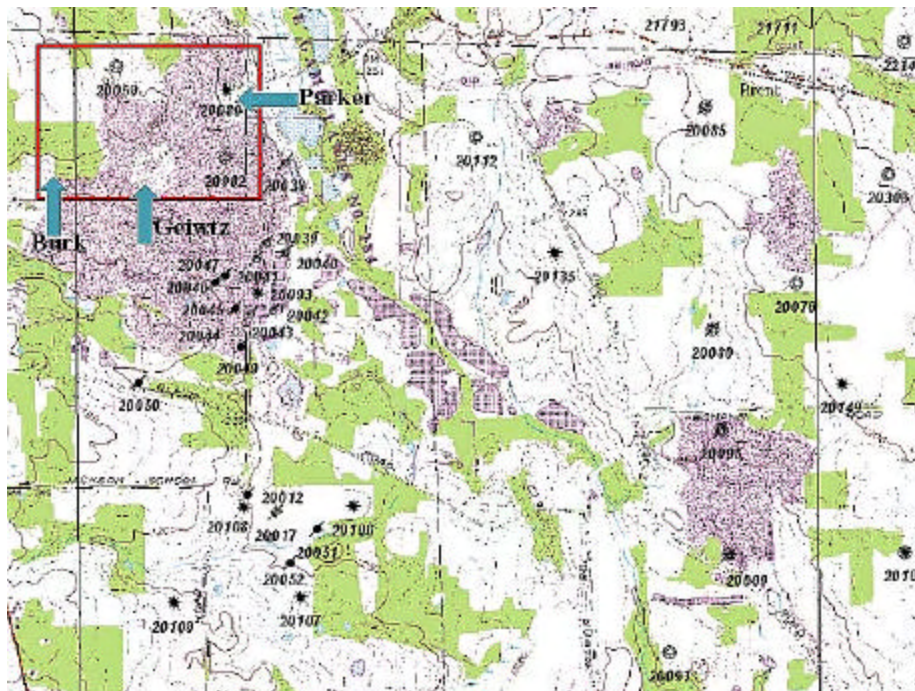


Figure 3 Location of project site and gas wells

Mining has impacted the surface and ground water conditions. The surface water was redirected by the surface mining activities with very little runoff or drainage observed coming from the reclaimed mine. In the unmined areas, a shallow surface aquifer exists in the glacial till. A deeper aquifer is associated with the Brookville coal seam. Fracturing created by mining and old fractures associated with glaciation, connect much of the ground water. This forms a complex system of connected water tables in the bedrock near the mining.

DRILLING DATA SUMMARY

The Brookville Coal is 80-120 feet below the surface, the Lower Clarion is about 40 feet above that seam. None of the drill holes encountered open mine voids. All four holes on the Parker property and two holes on the Burk property were drilled through solid Brookville Coal. One hole on the Burk Property was shallow to sample soil/till, and all three holes on the Geiwitz property went through mine spoil until solid rock was encountered at 120-122 feet depth. Water levels are near the bottom in the spoil holes and variable in the rock holes. The shallowest water level is 21.5 feet in TB-4.

The holes were installed with well screen to sample gases. Gas readings were taken directly after drilling and monthly from 12/2000 to 04/2001. Gas readings in the holes varied with depth and barometric pressure. In general, gas levels increased as barometer dropped and with depth in the hole. The lowest O₂ and highest CO₂ levels were measured in holes TB-2, TB-3, TB-5 and TB-6 directly following drilling: O₂= 3-9% and CO₂ >25%. During a falling barometer gas levels in TB-2, TB-5 and TB-8 were O₂ >10% and CO₂ 11-21% See Figures 4 and 5 for details on typical holes.

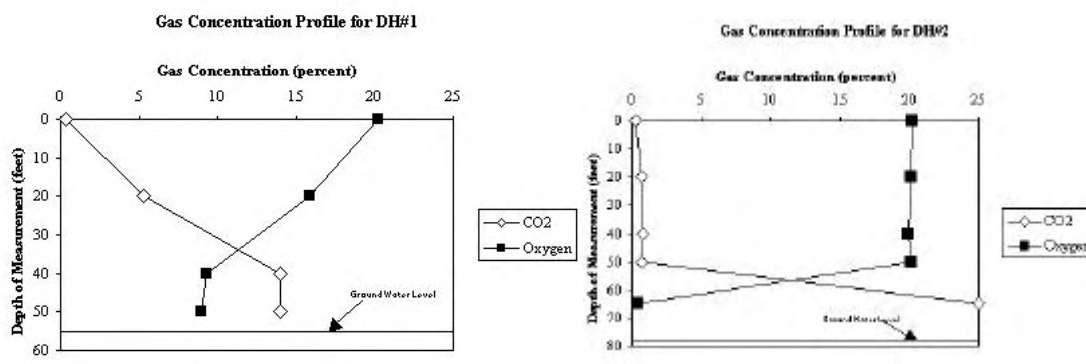


Figure 4 Gas and water levels in bedrock

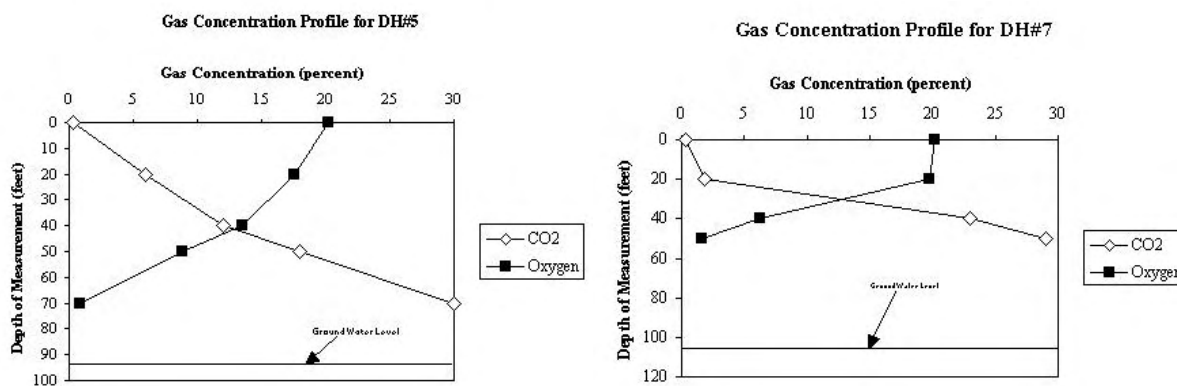


Figure 5 Gas and Water Levels in Spoil

An interesting phenomenon occurred while drilling TB-5 on Geiwitz property through the spoil. Air return was lost, shallow at 30 feet. Near the total depth at 105 feet, rough drilling and voids in the spoil stuck the drill bit. Shortly after air was lost, and a vacuum started in the borehole and continued until the hole was completed. The hole now responds to normal air pressure. Air was also lost in the other two holes in the mine spoil, TB-6 @100 feet and TB-7 @108 feet. No air loss was encountered in the other holes, drilled through solid rock.

GAS MONITORING SUMMARY

Three Draeger MultiWarn II (MWII) gas monitors were purchased and installed in each of the homes. These monitors measure O₂, CO₂, CO, CH₄ and will record 28 days at 10-minute

intervals. Each meter was installed in the basement of each property. The meters were located near the center of the basement, away from drafts but near areas that have shown anomalous gas measurements. The meters were raised on blocks at least six inches above the ground to reduce the layered gas effects. Gas meters were first installed on 11/8/2000 and downloaded monthly.

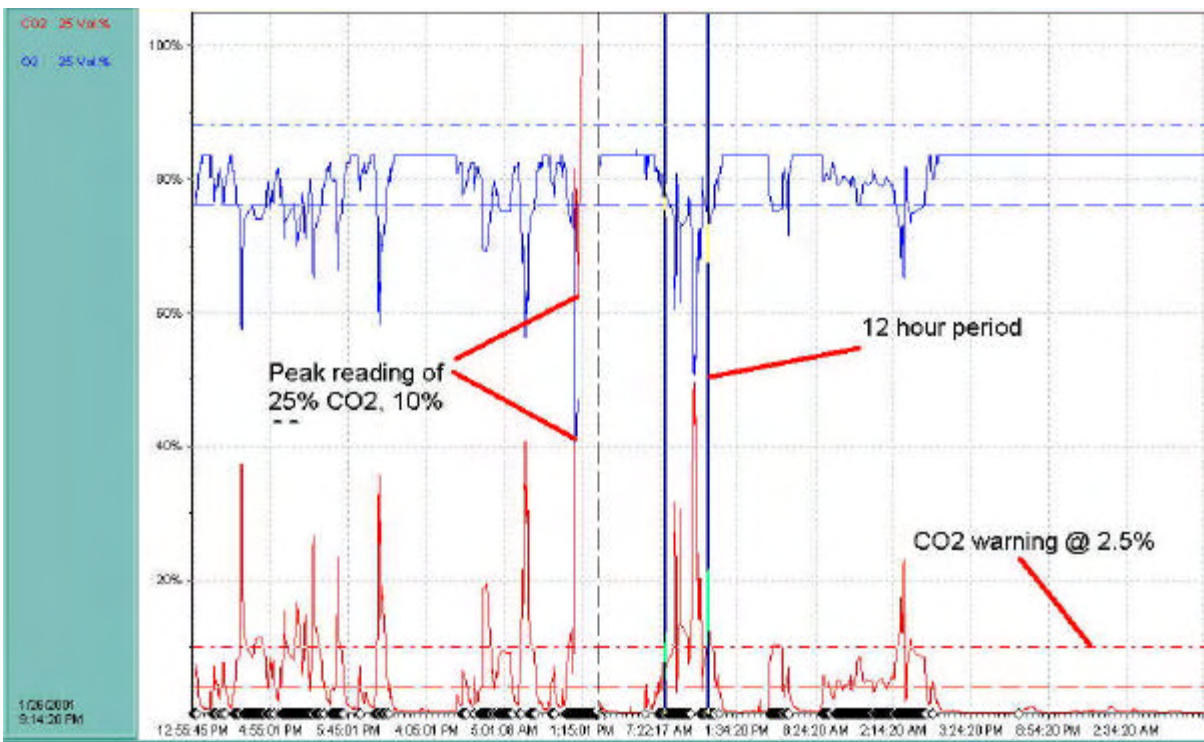


Figure 6 Gas measurements at Geiwitz

The monitor readings at the Geiwitz property showed the worst conditions of the three properties. The gas monitor data showed numerous events when the CO₂ levels were above 2.5% for more than 8 hours. Often the events had peak CO₂ levels above 25.0%. Corresponding oxygen levels peaked to lows of 10% with numerous, extended periods of 8-12 hours below 19.5%. During a rather low barometric pressure of 29.40 measured in Pittsburgh on Sunday morning 12/17/2000, the 12-hour average CO₂ level was 6.3% and the O₂ level was 16.6%. The residents were actively venting the basement during this period. The bad air at the Geiwitz property continued despite efforts by the homeowner to vent and exchange their basement air with fresh air. Since they moved into the property, they have been fighting the problems with the low oxygen and have become very well educated about the problem. They activate fans and open the doors at periods of low barometric pressure or when they feel the high levels of CO₂.

The monitoring of the Burk and Parker properties showed similar, although less severe, results than the Geiwitz property. The poor quality air occurred during periods of low barometric pressure. Some of the events were delayed by a few hours, due to the moving pressure front, or from delays as the gases moved from the source. Long term monitoring showed that the gas problems were worse in the early spring and late fall. These periods historically have more periods of very low barometric pressure, below 29.5 inches of mercury. The changes of the water table and frozen ground surface may also attribute to the gas problem.

HAZARDS

We should digress and discuss the hazards associated with low oxygen atmosphere. Blackdamp is the term commonly used for low oxygen conditions. Its hazard is asphyxiation. Blackdamp is the replacement of normal air, most commonly, with high levels of carbon dioxide and nitrogen. It is the product of adsorption by rock and coal, and microbial action in the mine atmosphere. Carbon Dioxide is also produced by chemical reaction of acidic waters on carbonate rocks and by microbial activity in water and soil. Similarly, oxygen is consumed by oxidation and microbial activity to produce an oxygen deficient atmosphere.

Oxygen meters and carbon dioxide meters commonly measure blackdamp. The gas is denser than air because of the typically large component of carbon dioxide. This gas will also produce an acid taste. Note that carbon dioxide, a principle component of blackdamp, is heavier than air with a Specific Gravity (sp.gr.) of 1.53 and will collect in low spots.

American Conference of Governmental Industrial Hygienists (ACGIH) and U.S. Department of Labor Occupation, Safety and Health Administration have set exposure limits and Threshold Limit Value (TLV's) for the basic components of blackdamp. Oxygen should not drop below 19.5% by volume and carbon dioxide should not exceed the TLV-Long-term-exposure limit of 0.05% by volume. Tables 2 and 3, respectively, show the typical effects of exposure of low levels of oxygen and high levels of carbon dioxide.¹

Table 1. Physiological Effects of Carbon Dioxide

Carbon Dioxide in Atmosphere (percent)	Increase in Respiration
0.05	Slight.
0.5	Maximum allowable for an 8-hour day.
2.0	50 percent.
3.0	100 percent.
5.0	300 percent and laborious breathing.
10.0	Cannot be endured for more than a few minutes.

Table 2. Effects of Oxygen Deficiency

Oxygen <u>Present</u>	<u>Effect</u>
21%	Breathing easiest
19.5%	Minimum requirement by law
19%	Flame safety lamp gives about one-third the light it gives in normal air (if the atmosphere is methane-free)
17%	Breathing becomes faster and deeper
16.25%	Pilot Lights extinguishes in a methane-free atmosphere
16-13%	Dizziness, buzzing noise, rapid pulse, headache, blurred vision

12.1%	Flame safety lamp extinguishes even if methane is present
9%	May faint or become unconscious
6%	Movement convulsive, breathing stops, shortly after heart stops

SOURCES OF BLACKDAMP

The source of the poor quality air at the Parker project was not apparent from the initial exploratory investigation. The gas monitoring showed changes in air quality as the barometric pressure changed, usually indicative of blackdamp from underground mine sources. Little or no methane was observed in the samples. This implies that the source is not likely from oil and gas wells, or landfills. It's important to determine the source of the gas to determine if a responsible party may aid in the abatement of the problem. If the problem was related to an abandoned mine source, federal or state AML funds can be expended to help abate the problem. However, no underground mines were discovered in the exploratory drilling. Other sources were postulated as possible sources of the very high concentrations of CO₂ as summarized below:

- Underground Mining
- Surface Mining
- Oil and Gas wells
- Septic systems
- Marsh Gas
- Landfill Gas
- Drift Gas
- Subsurface Geology
- Carbonate Dissolution

All of these possible sources could have potentially produced CO₂ at the Parker site. Drilling and gas monitoring identified the problem as more concentrated in the surface mine spoil than the surrounding bedrock. Other investigative tools were required to identify the source of the CO₂. Chemical and isotopic analyses of the blackdamp gas were used to help signature the gas and evaluate the postulated sources.

ISOTOPIC ANALYSIS

Carbon is one of the most abundant elements in nature, and the most important element in the Biosphere. The most common oxidized state of carbon is CO₂. Carbon Dioxide can produce a unique signature based on isotopic analysis of the various carbon isotopes of the gas. Carbon occurs in three common isotopes depending on how and when the carbon compound was formed. The plentiful and stable, natural isotopes of carbon are C¹² and C¹³. Normal carbon is 98.89 % C¹² and 1.11% C¹³. The isotopes are fractionated by a variety of natural processes, including photosynthesis, combustion and isotopic exchange among carbon compounds. This process tends to enrich C¹² in biologically synthesized organic compounds. On the other hand isotope exchange reactions between CO₂ gas and aqueous carbonate species enriches carbonates in C¹³. This can be used to evaluate sources that may be from biogenetic sources, thermogenic

sources, such as coal or natural gas, or from carbonate sources.

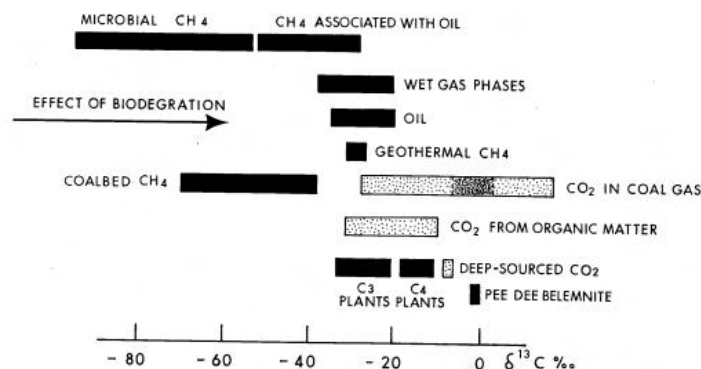


Figure 7 Sources from delta C¹³ Isotopic data

Another isotope of carbon, C¹⁴ is unstable and produced by interactions of cosmic rays neutrons with nitrogen (N¹⁴). This radioactive isotope has a relatively short half-life of 5,715 years, and often is used to date recent organic carbon material like plants and artifacts. The C¹⁴ isotope has been affected by various natural and industrial activities so it can be used as a marker compared to various sets of standards. For our work, the presence of C¹⁴ isotope identifies that the source is modern organic carbon found in landfills, septic systems, and other disposed organic material.

The ratio of the change in percent of C¹² to C¹³ presents distinct signatures for thermogenic gases that do not readily change in time. Isotopic ranges of natural gases such as methane and CO₂ are large in range, specific, predictable, and capable of providing diagnostic information on their source, see Figure 7. Differences in isotopic mass lead to subtle but significant differences in the behavior of an element during natural processes (*fractionation*).

$$\delta^{13}\text{C} = \frac{\left(\frac{^{13}\text{C}}{^{12}\text{C}} \right)_{\text{sample}} - \left(\frac{^{13}\text{C}}{^{12}\text{C}} \right)_{\text{standard}}}{\left(\frac{^{13}\text{C}}{^{12}\text{C}} \right)_{\text{standard}}} \times 1000 \text{ (permil)}$$

PARKER ISOTOPIC SAMPLES

Samples for isotopic testing were taken from five locations at the Parker project to help identify the source of CO₂. The samples were all taken on January 24, 2001. During this period, the barometric pressure had reached a low of 29.25 in.hg. and began to rise. Two samples from boreholes TB-5 and TB-7 were taken at 25 feet depth in the mine spoil material, with O₂ levels 9% to 8% and CO₂ levels at 15.6% and 17.5% respectively. Two other samples were taken from boreholes in the undisturbed bedrock TB-2 and TB-10 at the Parker and Burk properties, respectively. The fifth sample was gathered from the ambient atmosphere near the floor level of the basement of the Geiwitz's home. This sample had gas concentrations of 13% O₂ and 9% CO₂ in a 6-inch layer above the basement floor. The gas data is presented in Figure 8 below.

Four of the isotopic samples show a similar trend ranging from -2.64 to -7.01 Delta C^{13} per mil. One sample from boring TB-2 had a $+2.86$ Delta C^{13} per mil. All of the data is close to the PDB standard of zero. The reference standard is CO_2 gas obtained by reacting the belemnites of the Peedee Formation with a 100% solution of phosphoric acid, referred as the PDB standard of the University of Chicago.² Note that Figure 7, Plot of various Delta C^{13} Sources, shows that the range around zero is associated with CO_2 gas in coal or from inorganic sources. Organic sources tend to have a less rich or more negative values of Delta C^{13} .

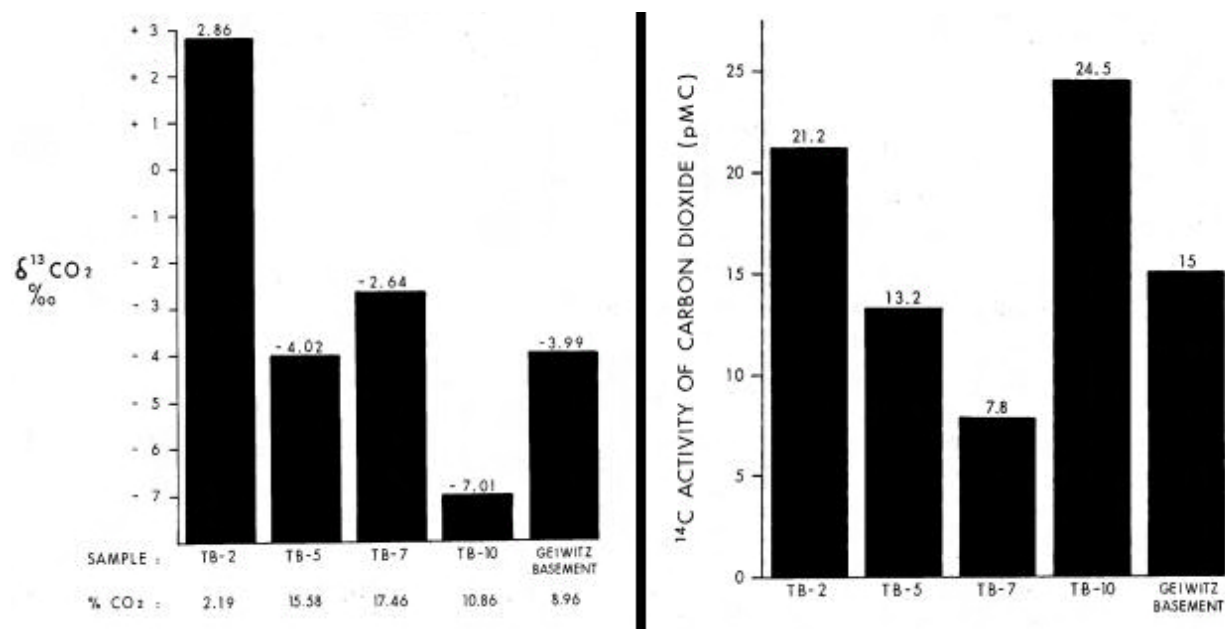


Figure 8 Isotopic data from Samples

Similarly, a thesis drafted by a geology student at Pennsylvania State University investigated the carbon isotope changes in the Vanport Limestone as a precursor for oil and gas exploration.³ He analyzed many samples of the carbonate and found that Delta C^{13} of the samples averaged -5.0 ‰ ^{13}C . The data again supports that the Delta C^{13} of the samples from the Parker sites is similar. This implies that the CO_2 gas is most likely derived from a carbonate source.

The other isotope of carbon, C^{14} is present in the analysis of samples from the Parker Project, ranging from concentrations of 24.5 to 7.8 parts modern carbon (pMC). The low percentage of C^{14} isotope is not from a modern source such as a landfill or buried organic mater. The slight increase of C^{14} isotope in the samples from the bedrock borings and the ambient atmosphere are related to modern carbon contamination of the samples from water and air.⁴ The sample from boring TB-7 most represents the atmosphere in the mine spoil.

CARBONATE SOURCES

The mine records showed that material for neutralization potential was abundant in the glacial till. Neutralization potential (NP) is defined as tons of Calcium Carbonate ($CaCO_3$) equivalent per thousand tons of material. The average neutralization potential of the overburden materials are tabulated below:

Table 3. Overburden Characteristics

<u>Overburden Material</u>	<u>%-Total Sulfur</u>	<u>Neutralization Potential</u>
Glacial till	0.22	54.5
Shale	0.17	17.1
Sandy Shale	0.12	21.7
Sandstone	0.24	13.9
Coal	3.14	2.45
Refuse		

The overburden material was not high in sulfur, therefore, mine tippie refuse was disposed at the mine in the vicinity of the Parker sites because of the neutralization potential of the overburden, especially the glacial till. The mine plan allowed the disposal of the acidic refuse placed in 2 feet lifts, separated from the high wall and mine floor by clean fill. This would theoretically reduce the production of acid mine drainage from the disposed refuse and place neutralizing material at the base of the mine.

Another source of carbonate material from the Vanport Limestone was not present at the site. The limestone is extensive in the region but was not deposited at the site due to a facies change or may have eroded away in the deposition of channel sands in the formation.

GROUNDWATER ANALYSIS

The theory that carbonate material was being affected from mine drainage, producing CO₂ was introduced by the isotopic analysis. If the theory was correct, ground water analysis should also provide information to support the theory. The ground water seeping from the abandoned underground mines should be highly acidic and low in pH. Water samples were collected from six sites at the Parker Project. Ground water samples and a sample from a drain in the abandoned Oakes Mine showed waters moderately high in alkalinity, ranging from 31.36 to 136.84, and only slightly low pH ranging from 5.82 to 6.55. One normally thinks of the acid-limestone reaction that produces a fizz and CO₂ gas. However, many alkaline waters also have large capacity to dissolve Calcium Carbonate (CaCO₃). The water quality data is summarized in the Table 4 below.

Table 4. Water Quality Data

Sample ID	Well #	Date	Time	Depth to water(ft)	pH	Field Sp. Conduct., Field	Temp C
P-1	Mine Drain	8/28/2001	1030	50gpm (flow)	6.31	675	12.2
P-2	TB-4	8/28/2001	1145	46.5	5.97	428	15.5
P-3	TB-7	8/28/2001	1255	106.7	5.82	1900	13.5
P-4	TB-8	8/28/2001	1420	72.7	6.55	120	12

P-5	TB-2	8/28/2001	1545	78.7	6.2	797	12.8
P-6	TB-3	8/28/2001	1615	113.7	6.2	330	14.1
No sample, field check only	TB-9	8/28/2001		43.8	6.48	175	11.8
1	TB-1	9/12/2001		55	6.36		14.1

The more important analysis of the ground water is its capacity to dissolve calcium carbonate as calcite, siderite, and dolomite to create carbon dioxide. This can be calculated as the partial pressure of CO₂ reported as PCO₂. The PCO₂ in the ground water was back calculated to be from 0.01 to 0.2 atmospheres in the ground water. The ground water and mine drain show that they are under saturated in carbonate minerals.

Table 4. Partial Pressure of CO₂ and solubility of Carbonate minerals.

Sample	pH (field)	Alkalinity (mg/L)	pCO ₂	si_CO2(g)	si_Calcite	si_Dolomit	si_Siderit
Mine Drain	6.31	113.64	0.054450	-1.264	-1.3352	-3.0419	-0.4581
TB-4	5.97	71.6	0.078650	-1.1043	-2.0199	-4.2497	-2.0108
TB-7	5.82	31.36	0.028431	-1.5462	-2.3601	-4.8631	-0.4786
TB_8	6.55	43.98	0.012551	-1.9013	-2.0002	-4.4499	-3.0787
TB-2	6.2	337.1	0.200955	-0.6969	-0.838	-2.0382	-0.1099
TB-3	6.2	136.84	0.088838	-1.0514	-1.4216	-3.2502	-1.4181
TB-1	6.36	110.7	0.048977	-1.31	-1.37	-3.17	0.06

Figure 9 shows the saturation of CO₂ at various pH and Alkalinity values. In general, as the pH drops in value and the Alkalinity rises, then more carbonate can be dissolved and CO₂ exsolved as atmospheric pressure changes.

Carbon Dioxide Concentrations at Varying pH and Alkalinity Values

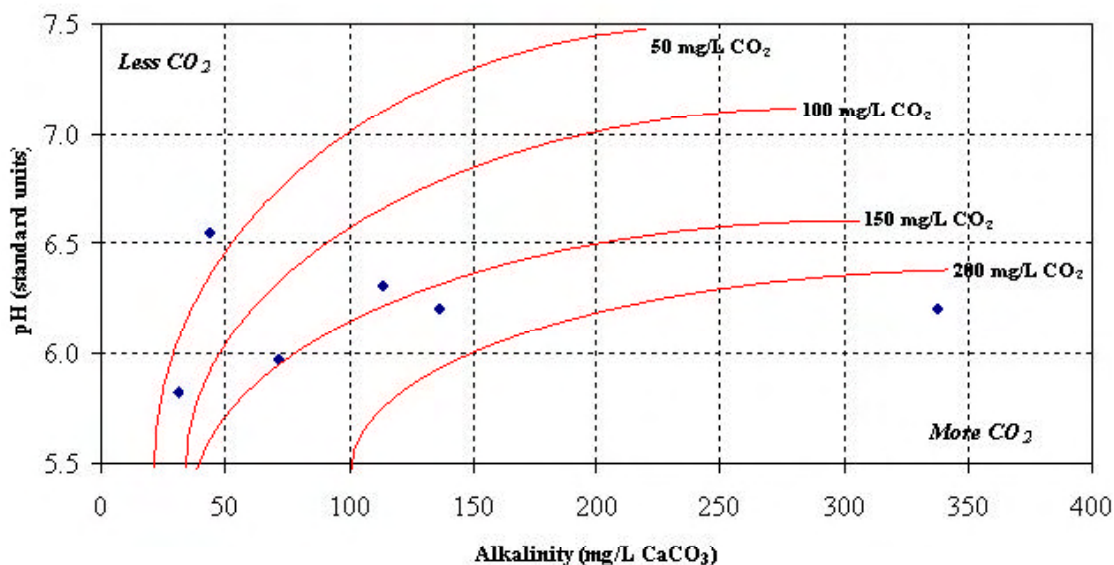


Figure 9 CO₂ and water quality

The on-going mechanism of seepage from the abandoned mine and saturation of the 'neutralizing' materials continues to be a source of CO₂ that is pumped into the deep coarse mine spoil. Mine tippable waste that was disposed in the area added material that would likely lower the pH of the water, further raising the PCO₂ of the ground water. The deep excavation of the surface mine is surrounded by relatively impermeable rock acting as a dam that would create a reservoir for the gas. A change in barometric pressure allows the gas to percolate to the surface first encountering fractures in the adjacent broken ground and eventually filtering into the basements of the homes. In the case of the Geiwitz property, the gas filtrates directly into the basement through the mine spoil and cracks in the foundation. The most likely source of the water for the chemical reaction is the abandoned mine. The recently permitted mine followed standard operating procedures and was no longer responsible. AML funds were approved to abate the problem.

ABATEMENT OF THE PROBLEM

In the case of the Parker Project, the source of CO₂ is large and relatively inexhaustible. Treating the CO₂ at the source would be impossible. Carbon Dioxide is heavier than air and does not easily drain from a structure. Drilling and grouting or installing an earthen barrier wall would not be practical and most likely would have only limited success.

Most current abatement methods act to seal the structure from the gas and provide ventilation to allow the gas to escape. Two of the buildings were recently constructed and appeared to have tight foundations. As mentioned above, the Geiwitz's had experimented with various ventilation techniques to no avail. Their radon system normally evacuated air from the gravel sub-base of the basement floor under negative pressure. In radon systems, the concentration of gas is very small and the supply is relatively slow. The gas can be easily evacuated from the sub-base and exhausted safely outdoors. In the case of our CO₂ problem, the

concentration of gas is quite large and the source is near endless. Drawing the gas under negative pressure provides a low-pressure sink to allow more gas to invade the property. The negative pressure often makes the problem worse.

We tried one last technique by modifying the radon system that was installed by the homeowner. This modification is termed a positive pressure radon system. Instead of evacuating the gas from the basement sub-base, fresh air is pumped into the gravel sub-base to displace the CO₂. The fresh air dilutes and creates a fresh air buffer around the property. Figure 10 shows the response of gas readings before and after the fans were reversed at the Geiwitz property. Over a 10-fold decrease in CO₂ levels was observed. Similarly, positive pressure sub-slab ventilation was constructed at the other properties with similar results. Extra work had to be performed at the Parker property to seal an earthen floor and the concrete block.

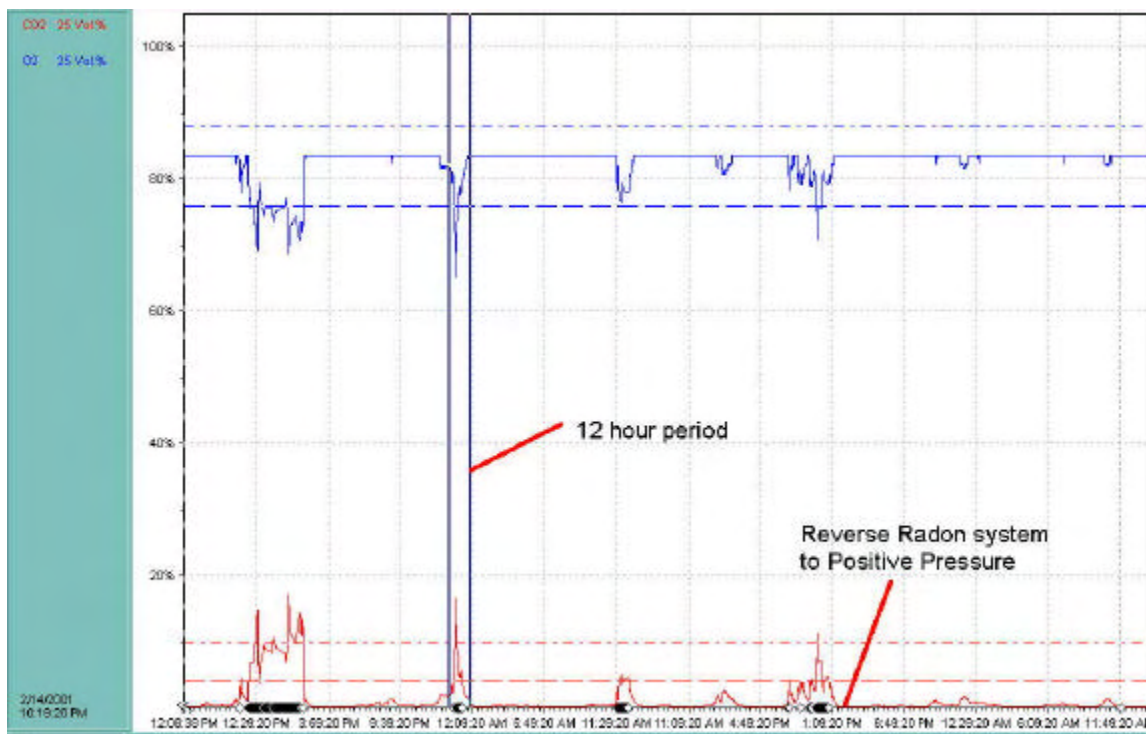


Figure 10. Gas readings after abatement.

SUMMARY

Blackdamp is a low oxygen atmosphere that can be produced by displacement of normal air by carbon dioxide. Blackdamp problems are typically associated with portals and shallow subsidence of abandoned underground mines. The hazard of low oxygen atmosphere is asphyxiation and can result in death. Common symptoms of a low oxygen atmosphere are gas appliances routinely extinguished for no apparent reason.

The source of blackdamp problems associated with surface mines was not clear and thought to be caused by buried organic matter, out-gassing of coal and carboniferous rock, or the interception of open underground mine entries. Data collected from isotopic analysis and supported by ground water analysis indicate that dissolution of carbonate materials can also produce very high CO₂ levels in mine spoil. The isotopic analyses with Delta C¹³ near zero per

mil indicate that the CO₂ is from a carbonate source. Groundwater high in alkalinity and with slightly low pH can easily dissolve carbonate material to produce the CO₂.

At least three projects in the northern bituminous coal fields of Pennsylvania and Ohio have had blackdamp problems associated with surface mines. The cause of the problems now appears to be related to ground water reacting with the spoil backfill material. Many surface mines are also designed to augment the backfill with carbonate materials to help reduce acid mine drainage (AMD). A simple by-product of AMD or waters with a high PCO₂ can produce dangerous levels of CO₂. Care in the design of backfill, drains and the post mine use of properties on or near surface mine spoil is required to prevent this type of problem in the future.

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DESIGNING FOR 1000-YEARS, EROSION PROTECTION

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ABSTRACT

Under requirements of the US Nuclear Regulatory Commission (NRC), Anderson was involved in the design and construction of a waste disposal facility that has a functional life similar to that of the great Egyptian Pyramids. Although this analogy seems extreme, the facility was required to have the design capacity to withstand the elements for a period of 1000 years. In the case of this uranium tailings facility, it was required to provide control release of radiological hazards for the term.

The Bluewater Uranium facility was the first non-government Title II site to be approved by the NRC for long-term custody. The accomplishment provided a model for others in the uranium industry to follow for final reclamation of uranium processing. The reclamation was a complex correlation of engineering design, regulatory compliance, environmental clean-up, and radiological health and safety.

Although many aspects of this project could be discussed including geotechnical stability, tailings impacted soils, relocation, and radiological source isolation, we focused on the engineering aspect of design and construction of erosion protection to satisfy the demands of the 1000-year term. This design included critical land shaping, runoff controls, erosion controls and overall watershed management to address the long-term stabilization of the radioactive wastes.

Approximately 3.2 million cubic yards of tailings impacted soils and evaporation pond residues were excavated, placed in repositories, and reclaimed. Around 2.0 million cubic yards of radon barrier cap material was placed and compacted over the graded features and over 1 million cubic yards of topsoil was hauled and prepared as seedbed for revegetation. Approximately 1,350 acres of former evaporation ponds and the soil borrow areas were revegetated. Approximately 500 cubic yards of rip rap and erosion protection rock was placed as well.

Erosion protective covers were constructed on the carefully shaped features that consisted of either topsoil with revegetation or rock armored. The entire repository surface was rock armored and large riprap relief spillways were designed and built for water handling and relief. All outslopes received a filter material and a larger rock size for the protective cap. The entire watershed was designed for extreme rainfall and runoff.

INTRODUCTION

Protection of public health and the environment from possible migration of hazardous materials has required the implementation of vigorous design methods. Current stabilization procedures include capping of wastes with various layers of earth and other synthetic materials to isolate wastes from erosion. Waste stabilization is a long-term concern which requires isolation of wastes in a controlled situation rather than mere implementation of a temporary solution.

The design of erosion-protection covers for various types of sites involve specific

requirements to address the waste type and potential hazards. One of the areas of specific design requirements is erosion protection for uranium mill tailings sites. The erosion protection designs prepared and implemented for the Bluewater Uranium Mill Tailings Facility Reclamation is the focus of this technical paper.

The Bluewater Facility is located in Northwest New Mexico and was a Title II site as defined by the Uranium Mill Tailings Radiation Control Act. The site was operated and reclaimed under license by the NRC. Atlantic Richfield Company (ARCO) owned Bluewater and discontinued milling operations in 1982. ARCO developed a reclamation plan that met the criteria for disposal and longevity as specified in 10 CFR Part 40, Appendix A, which was approved by the NRC in August 1990. Decommissioning of the mill and reclamation of the mill area and tailings were completed by December of 1995. ARCO received approval of its Alternate Concentration Limits (ACL) and implemented an approved Groundwater Corrective Action. The site has been successfully transferred to the United States Department of Energy for long-term care.

Erosion protection covers were designed and constructed for the tailings and are related features of the Bluewater site. These included the Main Tailings Impoundment, the Acid Tailings Facility, the Carbonate Tailings Facility, Ore Stockpile Area, and the area of the decommissioned millsite for a total of 540 acres of surface area watershed. A management plan was also prepared to control site run-on and run-off.

REGULATION REQUIREMENTS

REGULATION

Reclamation standards exist at the federal, state and local levels that require stabilization of mining wastes. The regulatory responsibility for the various types of mined material are with a large group of agencies. Regulation of Uranium Tailings is under the United States Nuclear Regulatory Commission (NRC). Criteria for minimizing dispersion of radioactive Uranium Tailings, with emphasis placed on isolation of tailings and protection against natural phenomena, are established in 40 CFR Part 192 and 10 CFR Part 40, Appendix A. Specifically, 40 CFR 192.02 and 10 CFR Part 40, Appendix A, Criterion 6, require that control methods be designed to limit radioactive tailings releases to specified levels.

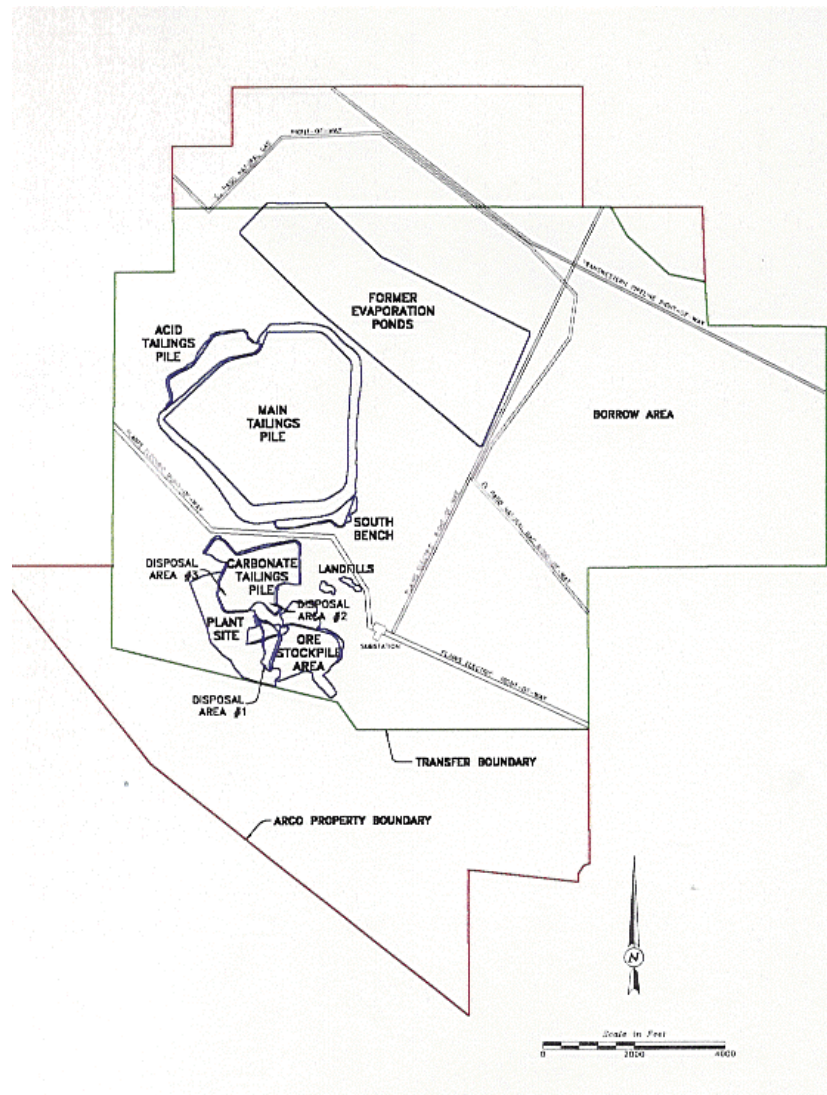


Figure 1 - Location of Tailings Facilities

LONG-TERM STABILIZATION

Several major design objectives for long-term stabilization of uranium mill tailings are established in 40 CFR Part 192 for Title I [government] sites and in 10 CFR Part 40, Appendix A, for Title II [private] sites. These can be summarized as follows: (1) prevent radioactive releases caused by wind and water erosion; (2) provide long-term stability; (3) require minimal maintenance to assure

performance; and (4) provide sufficient protection to limit radioactive releases. It is therefore critical to assess the forces associated with surface erosion, to design flood protection measures for appropriately severe flood conditions, and to minimize the potential for erosion and release of radioactive materials.

In order to control releases of Radon 222 from uranium tailings earthen covers are placed over the tailings materials. These covers range in depth dependent on the concentration of the source and cover type. The earthen caps are to be protected from erosional processes to maintain the cap integrity over time.

It is required by 40 CFR 192.02 and 10 CFR Part 40, Appendix A, Criterion 6, stabilization designs must provide reasonable assurance of control of radiological hazards for a 1000-year period, to the extent practicable, but in any case, for a minimum 200-year period. The NRC has concluded that the risks from tailings could be accommodated by a design standard that requires that there be reasonable assurance that the tailings remain stable for a period of 1000 (or at least 200) years. Erosion protection is to be passive control such as earth and rock covers rather than ongoing routine maintenance.

Regulations state that tailings should be disposed of in a manner such that no active maintenance is required to preserve conditions of the site. Criterion 12 states that: *“The final disposition of tailings or wastes at milling sites should be such that ongoing active maintenance is not necessary to preserve isolation.”* The NRC has defined active maintenance as any work that is needed to assure that the design will meet specified longevity periods. Such maintenance includes even minor maintenance, such as the addition of soil to small rills and gullies. The question that must be answered is whether longevity is dependent on the maintenance. If it is necessary to repair gullies, for example, to prevent their growth and ultimate erosion into tailings, then that maintenance is considered to be active maintenance.

DESIGN ALTERNATIVES

For design of erosion protection covers there are many options and design combinations that can be implemented. The design is to consider site specific conditions and erosional potential. Erosion protection designs generally fall into several categories. Taking into account the experience with erosion and reclamation design from mining and reclamation completed in the southwest United States the following are the design alternatives used for long-term stabilization:

- \$** Soil covers designed to be stable for 1000 years.
- \$** Combinations of soil covers on the top slopes and rock-protected soil covers on the side slopes, both designed to be stable for 1000 years.
- \$** Soil covers totally protected by a layer of rock riprap on both the top and side slopes.
- \$** Sacrificial soil covers designed to permit controlled erosion.

A combination of these design alternatives were utilized at the Bluewater Uranium Millsite. The size, geometry, layout and watershed impacts were evaluated for each millsite feature to be stabilized. Figure 1 shows the site layout and relative sizes of the features to be stabilized. A total of 540 areas were to be stabilized for long-term erosion. Approximately 320 acres of the evaporation ponds were removed and consolidated into the Main Tailings facility.

DESIGN STORM EVENTS

PRECIPITATION

The design precipitation event and resulting flood is that which would statistically not occur more than once in 1000 years. Such statistical analysis to estimate a 0.001 storm probability is not reliable. Therefore, the design approach used for the Bluewater project was based on site extreme meteorological and hydrological characteristics. The probable maximum precipitation (PMP) and the probable maximum flood (PMF) are events of very low likelihood to occur. NRC accepts the use of the PMP and PMF design events for erosion stabilization design. The PMF has been defined (COE, 1975) as the flood that may be expected from the most severe combination of critical meteorologic and hydrologic conditions that are reasonably possible in the region. The precipitation associated with the PMF is known as the PMP which is defined as the theoretically greatest depth of precipitation for a given duration that is physically possible over a particular drainage basin at a particular time of year, (AMS, 1959).

Analyses were performed utilizing a PMF based on the ratios between the 6-hour general storm and the 1-hour local storm PMF. (Hydrometeorological Report -HMR No. 55A). Maximum depths were adjusted by the 6/1 hour ratio recommended for the Bluewater area. (HMR No. 49). The estimated 6-hour depth for the local storm PMP is 13.47 inches. PMF discharges were computed by use of the computer program Army Corp of Engineers HEC1 model. Anticipated surface flows were evaluated by use of HEC2, calculations and computer programs designed for natural channel evaluation.

WIND EROSION

Prevailing winds at the site originate from the west and southwest of the Bluewater Site. These winds will have a direct impact on portions of the tailings embankments and on the top surface of the Reclaimed Tailings Facility. An estimate of wind erosion potential was made using the Wind Erosion Equation (Israelsen et. al., 1980).

Estimated losses using this methodology for reclaimed embankments at 5 horizontal to 1 vertical slope configuration for the tailings pond indicate the need for a rock-type, wind-erosion protection. Such slopes will receive rock-cover protection. Estimated wind erosion on the re-contoured tailings top surface for the same design period indicated some soil loss. Rock protection designed for water erosion would adequately protect against wind erosion. Minimal losses are projected for the adjacent reclaimed facilities surrounding the Main Tailings pond.

LAND SHAPING

The top surfaces and slopes of the various waste impoundments were shaped to comply with regulations and also to meet design objectives for erosion control. All out-slopes of the Main Tailings

Impoundment, Acid Tailings, and Carbonate Tailings were graded and shaped to a 5 to 1 geometry. This slope geometry is permitted in regulations when protected by rock covers.

Impoundments and other reclamation area top surfaces were graded to promote runoff from the feature surface. The land shaping also allows for flatter areas to be stabilized to meet the 1000 year requirement with soil covers and vegetation. The slopes on top surfaces must allow for drainage to eliminate standing water that can pose unwanted infiltration into the tailings and also not be excessively steep so as to cause water erosion from erosive flow velocities.

The final design surface grade of the Main Tailings was 3.8% over 252 acres and 2.8% over approximately 50 acres of the top surface. This slope shaping allowed for feasible volumes of cut and fill placement and also standing water on the surface.

The maximum slope length for the sand tailings area is 2250 feet. The maximum slope in the sands was used for the erosion protection calculations to maintain a safe, conservative design. Approximately mid-way across the impoundment, the grade becomes less than 0.5% and continues at this grade for an average of 2600 feet to the northern edge of the impoundment.

The maximum slope grade and slope length for the Carbonate Tailings are 3.0% and 1350 feet respectively. The surface of the Main Tailings and Carbonate Tailings required the placement of erosion-protection rock cover over the cap for long-term stabilization.

The Acid Tailings and South Tailings areas were graded to a stable slope design on the top surface. With the configuration of the surface less than 0.5%, soil covers were utilized with revegetation over these areas.

WATERSHED MANAGEMENT

The management of run-on from the upstream watershed was a critical design consideration for erosion stabilization of the impoundments at Bluewater. For the design of erosion protection, two different situations related to the watershed drainage must be considered. For an impoundment located in the flood plain of a major stream or wash, the PMF of concern would be that caused by an occurrence of the PMP over appropriate drainage areas upstream of the impoundment. The impact on the toe or face of the impoundment depends on the magnitude of the PMF and the location of the impoundment relative to the main drainage. Some sites are located on high ground beyond the influence of the PMF of a major drainage. For these cases, the PMF of concern is that corresponding to occurrence of the PMP on only the drainage area on and above the impoundment site.

A PMF occurring on the up-gradient watershed could influence surface erosion of the impoundment. These flows should be diverted around the reclaimed impoundment with diversion structures designed to withstand the calculated up-gradient PMF and any influence from the onsite PMF.

The upstream watershed drainage for the Bluewater Tailings Impoundment was estimated to be substantial for the PMF (7000 cfs). The stabilization of the 320 acre evaporation pond network within the watershed drainage path was extreme. To meet long-term stabilization needs and also to the extreme cost of rock cover the evaporation ponds were consolidated into the Main Tailings facility. The flow pattern of the upstream watershed could then be diverted away from the tailings impoundments and only the onsite precipitation considered for the out-slope erosion protection design. A 6300-ft long open channel was designed and constructed up watershed to divert flow

through the drainage area and direct flows downstream of the reclaimed facilities.

SOIL/VEGETATED EROSION PROTECTION COVER

Soil cover for erosion protection of the impoundment caps are only acceptable for flatter-top slopes. Soil covers are not recommended for side-slopes as the vegetation may not be able to resist gullies originating on the steep side-slopes. Vegetated soil covers also may have sufficient resistance to prevent advancing head-cutting from natural drainages surrounding the impoundment. The use of soil covers with vegetation must be shown to contain a self-sustaining plant community that will be sufficiently dense to reduce erosion potential. Soil covers alone likely will not be capable of providing long-term stability on slopes steeper than 1-2%. Soil covers with vegetation can be implemented when designed to be stable. Design is to account for precipitation conditions and stresses resulting from flow velocities of PMF events. If the shear stresses and flow velocities produced by concentrated runoff from design-basis flood events are less than the allowable stresses and velocities of the soils this cover method is acceptable to the NRC. These stresses are relative to the slope angle of the soil surface.

In addition to having a slope that is shown by analysis to be stable, the soil cover should be designed to be thick enough so that there is reasonable assurance that tailings will not be exposed and that radiological criteria will be met considering the combined effects of wind erosion, sheet erosion, and minor rill and gully erosion.

The existing slopes for the Acid and South Tailings Areas were very near flat on the top surface. The design of these areas were to comply with the following: (1) minimize the potential for development and growth of a gully over a long period of time, assuming that flow concentrations occur; and (2) prevent the erosion of tailings due to gullying.

The stability of soil-covered surfaces was determined by use of the Horton (NRC) method and the Permissible Velocity Method. The Horton method provides a direct solution of the value of the stable slope needed to prevent gully formation. Impacts for the determination included critical distance, runoff intensity, roughness factor, soil resistance, allowable shear and slope function. Permissible velocity determinations are evaluated from slope length, concentration factors, roughness, rainfall intensity, and stable slope impacts. The values are compared to published permissible velocities. The stable slopes for Bluewater were designed to be graded at 0.15 %. The calculated maximum velocity for the soil types placed was 1.05 fps which was less than the 1.5 fps acceptable maximum permissible velocity. The top slopes of these impoundments were constructed to the design specifications.

A vegetated cover consists of plants and soil, that have been selected to maximize transpiration and resistance to erosion. The soil and plants in a vegetated cover have specific performance objectives that must be met if the cover is to achieve its intended goal of controlling water, resisting erosion, and otherwise contributing to the long-term integrity of the stabilized pile. Soil types that have higher permissible velocities as defined in research are the types that should be used for cover if available.

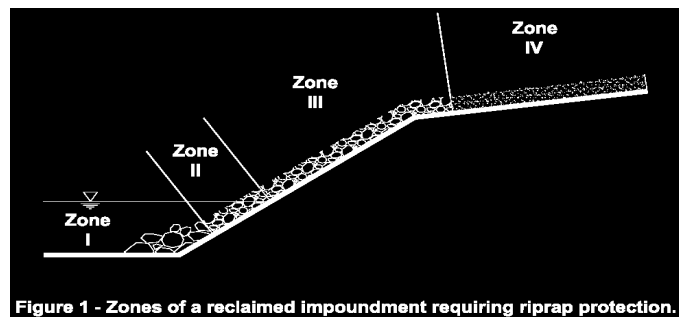
ROCK COVER

The design of stable covers and impoundment embankments requires that the surface be constructed on scour resisting material and be protected with some type of armor coating. When designing for long term periods, naturally occurring materials have well documented historic evidence of survival without significant degradation.

Several erosion protection types and methods of installation were compared while developing the Bluewater Reclamation Plan. With protection of the reclaimed features as the paramount consideration, cost of rock development and installation were also analyzed to find the most cost-effective best solution. At the time of the Bluewater Plan development, several agencies and groups had completed research on erosion protection methods for channels, however, there was limited research completed on surface protection methods where hydraulic properties are more akin to turbulent sheet flow. Despite the best intentions of the reclamation designer, over time this sheet flow action may create rills and localized settlement which can completely change the original design assumptions. To account for these long term varying conditions, covers design must incorporate significant factors of safety. No one method works for the various conditions encountered in designing cap protection systems.

ROCK DESIGN METHODS

Figure 2 illustrates the four design zones for a reclaimed cover. As described in the Long Term Stabilization design guide (Nelson, 1986).



- Zone I: Zone I is at the base of the impoundment slope and represents the area of greatest flow and hydraulic action. The riprap protecting the slope toe must be sized to stabilize the slope toe due to flood and dissipate the energy as flow transitions from the impoundment slope to the natural terrain. Zone I is considered a zone of frequent saturation.
- Zone II: This is the area along the side slope which remains in the major watershed flood plain. The rock protection must resist not only the flow down the impoundment slope, it must also resist movement from flows normal to the impoundment slope.

- Zone III: Riprap in this zone should be designed to protect the relatively steep slopes of the embankment. Zone III is considered a zone of seldom saturation.
- Zone IV: Rock protection in this area is designed for the mild slopes typical of the surface cover. Zone IV is usually characterized by sheet flow with shallow flow depths and low velocities. Zone IV is considered a zone of seldom saturation.

At Bluewater, rock sizes were designed for each zone. For purposes of constructability, in many cases the larger rock required was used for the entire slope. When using larger rock than required for momentum resistance, proper sizing of the filter is critically important to prevent erosion below the larger rock. Saturation applies primarily to the durability of the rock.

The Bluewater design team used various methods in the process of design development. Design method used for the Bluewater project used for sizing rock for long term were:

Corp of Engineers Method

The Corp of Engineers Method (BOR, 1984) was well suited for surface cover areas at Bluewater. Using equations to model the boundary shear created by the water movement to the shear the weight of the rock is capable of withstanding a d_{50} rock size is determined.

Stephenson Method

The Stephenson Method was found to be the best model for sizing rock on impoundment side slopes (Stephenson, 1979). The size of rock derived from this method is determined by input of the maximum flow velocity per unit width, the rockfill porosity, the acceleration of gravity, the relative density of the rock, the slope angle, the angle of friction and an empirical constant factor. The rock size derived is the d_{50} rock size at which rock movement is resisted for the given unit discharge.

United States Bureau of Reclamation

The USBOR method (BOR, 1984) was developed for high energy dissipation and protection of steep slopes. The characteristics corresponded with the protection requirements of the spillway section of Bluewater's Main Tailings Impoundment. The USBOR model estimates the d_{100} rock size as a function of the channel velocity.

SOIL/ROCK MATRIX DESIGN

Radon barrier and cap materials are commonly constructed from clays and silts for a number of reasons pertinent to the functionality of the design. These soil types are also fairly resistant to scour, especially when covered with grasses or other non-deep root species of vegetation. Combining the cohesive properties of the soil, the interlocking action of the root zone with the armor protection of rock in theory provides a very stable surface. Especially suited for surfaces with slopes of less than

1%, this surface also has the advantage of drawing water from the system to help reduce percolation through the waste body.

Design Process

The soil/rock matrix is practical for shallow slopes (typically less than 1%) that do not require large diameter rock. Rock is designed using standard equations as described above and graded in accordance with accepted methods (COE, 1970). The soil/rock design can typically be formulated in such a way that a filter is not required as a separate layer. The matrix depth should be a minimum of 6-inches and normally not exceed 12-inches. The maximum practical d_{50} rock size is half the depth of the matrix.

Implementation

The soil/rock matrix design was included in the original Reclamation Plan for the Bluewater Project. However, construction problems associated with homogeneous mixing of the soil and rock in the field resulted in the design team revising the design to a rock only cover on most of the project. Premixing, though higher in cost, provides a much more consistent product than field mixing.

Types of Cover - Rock

Rock only covers are well suited for the varying conditions associated with the reclamation of impoundment covers. At Bluewater, situated in the Mt. Taylor Malpais flow, good durable stone was economically available. Using the design methods discussed above, rock was designed for the varying slope conditions.

Design Process

Rock/filter covers are practical for impoundment surfaces and side slopes. Rock sizing should be designed using methods described above and graded in accordance with acceptable procedures. Filters should be a minimum of 6-inches deep. A design depth of 1.5 times the D_{100} provides sufficient depth to facilitate placement.

The rock size calculated for hydraulic conditions at the Main Impoundment was a d_{50} of **2**-inch. The size of the 350 area surface and the heterogenous composition of the tailings themselves made potential differential settlement or other future uncertainties a major concern for the long term stability of the radon barrier cap. Therefore a safety factor of 3 was used on the top surfaces for areas of mild slope and a factor of 4 was used on steeper slope areas. Gradations with a d_{50} rock size of 1-1/2-inches and 2-inches were used on the tops surface areas.

The side slopes of the Bluewater impoundments were constructed of engineered fill with significantly less chance of differential settlement. This fact associated with the less critical nature of the cover allowed the design team to use a much small factor of safety. The calculated d_{50} rock size on the Main Impoundment was 2-inches. The final design specified a d_{50} rock size of 2-1/2-inches.



Rock placement on asbestos disposal area

Implementation

Rock was produced at a near site quarry with an inpit crusher and screening plant. Rock was hauled to the site and placed using bottom dump tractor trailers. Rock was then spread using graders with laser guided blades to control depth.

Types of Cover - Spillway Rock

The Main Tailings Impoundment was designed to discharge all surface water off of the north embankment which was referred to in the reclamation plan as the spillway. The approximately 1600-ft. long spillway required a larger rock to both protect the underlying surface and disipate the hydraulic energy before the transition into the natural terrain.

Design Process

The potential high energy conditions of the spillway are similar to conditions for which the USBOR method was developed. Using this method a d_{50} rock size of 4.3-inches was calculated. A 5-inch d_{50} rock was used on the spillway embankment.

Implementation

The larger rock size could not be placed using the same bottom dump equipment. This rock was placed with off road end dump trucks and then spread with a small dozer and backhoe. The



View of Stabilized Impoundment Slope

backhoe was used primarily to restore the rock gradation where it had become segregated during dozing.

MATERIALS

Various cover systems were used at the site and required the selection of specific materials to best serve the erosion protection application. Soils and rock materials were obtained from local borrow areas and a near-by quarry. Plant materials were selected from local species and species that provide excellent stabilization characteristics.

SOILS

An inventory and analysis of the locally available borrow soils were conducted in which soil bore holes and test pits were completed to classify the soil materials. Grain size, permeability testing and volumetric analysis were done to understand the relative quantities of each type of soil that was tested. Locations of the various soils were mapped to complete haul designs and equipment optimization. Clayey sand and lean clay soils were used for radon cap and infiltration barrier. Alluvial soils generally of silty sand and clayey sand and silt classifications were used for soil covers and plant growth media. Very low organic mater levels existed in these soils. The soils did require fertilization to promote vegetation growth.

PLANT MATERIALS

A vegetated cover may be placed on the top-slopes of waste piles as an alternative to rock cover. Vegetated covers are generally not acceptable for side-slopes because the vegetation may not be able to resist erosion from high flow velocities.

The key to vegetated cover design is to use the proper combination of plants and soil to assure that some plants survive (even if dormant) during the dry periods so that adequate transpirational capacity will be available after precipitation events to prevent moisture from infiltrating into the contaminated materials.

The vegetation species used at Bluewater were a combination of grasses and forbs. The majority of the species are native and are drought tolerant and adapted to the semiarid southwest conditions. The introduced species are also adapted to dry conditions and provide excellent ground cover. The plant community will provide both ground cover and canopy cover protection of the soil through out the seasons of the year. Seeding rates and procedures were developed from USDA technical guides for critical area stabilization. The cover was prepared as a seed bed, fertilized and mulched.

ROCK

While history has demonstrated that rock has lasting value, not all types of stone weather the same over time. In assessing the long term durability of erosion materials, the NRC has relied on durability tests performed in the laboratory. Laboratory analysis included Specific Gravity, Absorption, Sulfate Soundness, LA Abrasion and Tensile Strength. A scoring system is used to determine the quality of the stone, if it is adequate or if over sizing is required. The Bluewater area had two types of rock available for use as erosion material. Existing quarries in the area produced a quality limestone or the Malpais Formation which was closer, potentially could be quarried for a high quality igneous rock.

The cost to open a pit and mine the Malpais was higher than obtaining locally produced limestone, however, the igneous rock scored higher, alleviating the need for over sizing. Transportation costs were also less because the malpais pit site was adjacent to the Bluewater project. Overall the igneous source was found to provide the best value to the project and was used. The pit produced over 500,000 cubic yards of erosion protection material for the Bluewater project.

QUALITY CONTROL

Quality control testing for erosion protection rock was completed with a quality assurance program that monitored rock physical properties, gradation and placement. Testing for gradation and strength began at the rock quarry as soon as the product was produced. Testing was completed by the quarry contractor. All testing was reviewed and documented by the construction management team. Products not meeting the specifications were returned to the raw material stockpile for reprocessing. It was found that gradations having a wide band of rock sizes were the most difficult to produce and to place. Calculations for alternate erosion protection gradations were made and a request for a gradation adjustment was submitted to the NRC. NRC's quick response and subsequent approval of the recommended revision made both production and placement of the rock more feasible while providing for the same protection on the surface.

Quality assurance during placement consisted of visual inspection during placement followed up by depth of cover testing and insitu gradation analysis. Depth of cover testing was completed on a grid pattern and field measurements photographed to show compliance with specifications. Tracking

sheets and mapping were maintained which logged all testing. Non-complying areas were reworked and retested as described above.

EFFECTIVENESS

The effectiveness of the erosion protection covers has been successful to date. The covers have been in place for 5 to 7 years and no head-cutting, gully or rill erosion has been experienced on the rock corners. Minor flow concentration has been observed where water is flowing around the base of large plants. However these minor water paths are healing with deposition of plant organics and windblown soil accumulation.

It is considered at this point in the erosion protection period that the designs are effective. The test of 995 years is yet to come.

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ZORTMAN AND LANDUSKY WITH 20/20 HINDSIGHT

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ABSTRACT

The Good, The Bad, and The Ugly. Is this the name of an old western or the historical account of the Zortman and Landusky gold mines in north-central Montana? These two mines played an industry-leading role in the development of cyanide heap leach operations of low-grade gold deposits. They have also been in the news for “state-of-the-art” reclamation efforts. **The Good** this mine did for a depressed part of Montana is not in question. Where else could 300 people make a good living for 20 years on 1200 acres? **The Bad** is a blotchy past, starting over a hundred years ago with the “white man’s” dealings with the Fort Belknap Indian Reservation. **The Ugly** is a present-day bankrupt gold mining company with a bond shortfall and numerous site problems.

This paper will provide you with insights into the political/economic climate leading to the development of Pegasus Gold as the golden employer having several Montana gold mines (including Zortman Mining Inc.’s Zortman and Landusky Mines) with the State singing their praises and their subsequent fall from grace. A brief history is necessary to understand how things happened followed by a discussion of some of the lessons learned along the way.

HISTORICAL BACKGROUND

Chris Keyes is supposed to have found signs of paying placers somewhere in the Little Rockies region in 1864, but he was killed before his partner could join him. Twenty years later on July 3rd, 1884, Frank Aldridge found gold in his sluice box on Alder Creek. It was averaging over \$0.12 per pan. “Dutch” Lewis Meyers and Pike Landusky were there and before a week had passed a new gold rush stampede had started and within a month a mining district had been formed. It is thought that as many as 2,000 men may have been involved. The area lay within the major Indian Territory for the northern tribes, and federal troops were sent to investigate the placer activity and keep order at the peak of the rush. A mere two months would pass before a bustling, rowdy, lawless mining camp with tent saloons, dugouts, hastily constructed log cabins, and a dance hall and grocery store sprang from nowhere. This first “strike” did not pan out and soon thereafter only a handful of prospectors remained. It took another 10 years before Pike Landusky, for whom the Landusky town and mine were named, would strike it rich on the August claim on the Landusky side of the mountain in 1893. Pete Zortman, for whom the Zortman town and mine were names, came into the picture shortly thereafter. He and his partner constructed a mill on Ruby Gulch in 1904. This mill had a 120-ton per day capacity and was further enlarged in 1907 to 300 tons per day capacity. Fire destroyed it in 1912 and it was replaced with a 600-ton mill in 1914. World War I idled the mine in 1918. It reopened in 1922 and was plagued with problems. In 1923, a fire destroyed the second mill, forcing the mine to closed until the early 1930’s. Still a third mill was constructed with the remnants still standing today on the north side of the Zortman 89 Leach Pad. All three mills used cyanide leach tanks to extract the gold. A third disastrous fire swept through in 1936, closing the Ruby Gulch and Little Ben mines. The mines restarted and continued sporadically until 1942, when the World

War II's war production boards order L-208 caused the mines to close again. Another attempt at starting in 1946 failed and in 1954 all the property was sold in a sheriff's sale for \$60,000.

The low-grade ore associated with Zortman and Landusky lie buried deep in the earth for another 40 years from the mid-1930's, waiting for the next generation of prospectors. In 1977 a group formed Pegasus Exploration. They drilled 400 test holes on both sides of the mountain with samples taken every 10 feet. Following an Environmental Impact Statement by the Montana Department of State Lands, mining was allowed to start, once again, in 1979 as the modern day Zortman and Landusky Mines were approved.

Was there a silver lining or golden parachute for those early pioneers? Not hardly, the two key figures in the early development of the area did not die wealthy or famous. Pete Zortman died penniless at the age of 65, having been a county charge for three and half months prior to his death and was buried in the paupers corner of the county cemetery. Pike Landusky met his death in 1894, when he was shot in a bar fight by Kid Curry during one of his frequent visits to the Landusky town saloon with his gang (the "Wild Bunch" and The Sundance Kid).

The Good

Fast-forward to today and we find Montana is a very depressed state, ranking 46th in personal income. Mining jobs and the associated trickle-down effect of mining related purchases of goods and services had been pursued very aggressively by the state and the governor's office. Labor salaries often are 4 times the states average per capita income of \$15,360 (for 1998). With agriculture requiring 300 acres to feed one cow, the attractiveness of providing a good standard of living for 300 people on 1200 acres is a given. Phillips County had the lowest unemployment rate in the state during mining at around 3.5% compared to the state average of 6.5%. Since mine closure, Phillips County has soared to around 8% unemployment and now has the 10th highest unemployment figures in the state. Pegasus Gold had several gold mines running in Montana and the Company was viewed very favorably by everyone but the environmentalists.

The Bad

The bad is a blotchy past, starting over a hundred years ago with the "white man's" dealings with the Fort Belknap Indian Reservation. The early placer strikes in 1884 brought a huge influx of white men to Indian country. It took three years to work out an initial agreement with the Indians. By the time the Agreement of January 21, 1887 defined a new boundary for the southern end of the tribal land (Gros Ventre and Assiniboine Tribes), placer activity was pretty well over. Life could have gone on with the land fairly untouched if it had not been for mans persistence and Pike Landusky's new strike in 1893 on his August claim. It was located within the boundary of the Tribal lands and the miners worked the claim at night, getting down 65 feet of shaft, and removing ore that brought in \$32,000 from an Illinois smelter. As word leaked out, Montana politicians secured the appointment of commissioners to negotiate a further land cession by the Indians. Headed by George Bird Grinnell, the commission secured the services of Walter Weed, a geologist, to assist in identifying the mineral lands that were to be bought. With his recommendations, the commission on October 9th, 1895 concluded an agreement changing the Reservation boundary so as to exclude the mineral lands. The "Grinnell" land, as it has become known, was purchased from the Reservation in 1895 and again repurchased in recent

years as part of a BLM settlement with the Tribe. The BLM is currently engaged in another lawsuit with the Tribe, where they are requesting the land be returned to the Tribe.

Protests regarding water degradation date way back in the history of the mining. The Montana State Board of Health, at the request of the Sanitary Engineer with the U.S. Public Health Service inspected King Creek and the Little Ben Mining Company properties on 9/26/1933. Accompanying him were the Forest Examiner for the Fort Belknap Indian Reservation, Mr. Kirkaldie, field clerk for the Indian service, and John Buckman, Thomas Mann and Russell Young representing the Tribal Business Committee. The Report of Investigation indicated that “no tailings had as yet been discharged into King Creek”, but “further observation and analysis following the discharge of tailings” would be necessary. Those tailings eventually found their way down King Creek and in 2000 the Corps of Engineers, through their contractor IT, removed approximately 78,000 cubic yards of tailings for a cost of over \$3.4 million (over \$43/cy). These tailings found their way back up the mountain and were used as a six-inch subsoil layer on the lower Landusky leach pads. In tribal meetings over the past three years, many people have spoken out on how the mines ruined the water and caused their health problems including diabetes and cancer. EPA has conducted public meetings regarding the disconnect between the mine and the Tribal waters to no avail. Land and water have always been hotly debated issues worth fighting over in the west. It is certainly true for this small piece of the Little Rockies.

The Tribe has ongoing lawsuits pending right now to force the BLM and DEQ to implement the preferred alternatives selected in the Final Supplemental EIS published in December 2001. The federal and state agencies chose alternatives that exceeded the available bond funds with the caveat that should additional funding not become available; two lesser alternatives would be implemented. The Tribe has repeatedly requested that the “Grinnell” lands be returned and that Spectrum Engineering and all white men be removed from the reclamation effort and water treatment on the site.

The Ugly

The ugly is a present-day bankrupt gold mining company with a bond shortfall and numerous site problems. Large-scale mining started in 1979. Pegasus was a modern day pioneer, not in looking for gold, but in cyanide heap leaching practices. There were able to take a very low-grade deposit and make it profitable. The production from the two mines is summarized in the following table:

**ZORTMAN MINING INC.
HISTORICAL PRODUCTION REPORT**

ZORTMAN MINE

YEAR	ORE (TONS)	GOLD (OZ/TON)	SILVER (OZ/TON)	WASTE (TONS)	TOTAL MOVED (TONS)	STRIP RATIO
1979	218,000	0.057	0.39		218,000	
1980	675,000	0.031	0.29	620,000	1,295,000	0.92
1981	1,023,000	0.025	0.25	418,000	1,441,000	0.41
1982	1,889,000	0.035	0.25	968,000	2,857,000	0.51
1983	2,008,000	0.034	0.15	2,217,000	4,225,000	1.10
1984	2,373,000	0.022	0.07	1,491,000	3,864,000	0.63
1985	5,334,000	0.026	0.20	2,356,000	7,690,000	0.44
1986	1,654,000	0.027	0.14	993,000	2,647,000	0.60
1988	1,043,000	0.024	0.04	1,493,000	2,536,000	1.43
1989	3,683,000	0.019	0.05	2,939,000	6,622,000	0.80
TOTAL	19,900,000	0.026	0.15	13,495,000	33,395,000	0.68

517,400 ounces

LANDUSKY MINE

YEAR	ORE (TONS)	GOLD (OZ/TON)	SILVER (OZ/TON)	WASTE (TONS)	TOTAL MOVED (TONS)	STRIP RATIO
1979	458,000	0.038	0.12	11,000	469,000	0.02
1980	616,000	0.030	0.15	603,000	1,219,000	0.98
1981	1,084,000	0.025	0.18	1,024,000	2,108,000	0.94
1982	1,994,000	0.031	0.30	1,740,000	3,734,000	0.87
1983	2,021,000	0.033	0.25	1,452,000	3,473,000	0.72
1984	3,301,000	0.022	0.11	1,658,000	4,959,000	0.50
1986	4,865,000	0.021	0.19	4,910,000	9,775,000	1.01
1987	9,663,000	0.019	0.07	5,805,000	15,468,000	0.60
1988	10,379,000	0.019	0.09	4,567,000	14,946,000	0.44
1989	6,369,000	0.019	0.08	2,559,000	8,928,000	0.40
1990	12,895,000	0.016	0.31	4,558,000	17,453,000	0.35
1991	14,236,000	0.018	0.35	6,045,000	20,281,000	0.42
1992	12,974,058	0.015	0.08	5,852,745	18,826,803	0.45
1993	12,510,178	0.018	0.12	8,324,062	20,834,240	0.67
1994	14,842,721	0.017	0.13	10,964,957	25,807,678	0.74
1995	10,020,394			7,700,861	17,721,255	0.77
1996	138,945	0.015		207,942	346,887	1.50
TOTAL	118,367,296	0.017	0.15	67,982,567	186,349,863	0.57

2,012,244 ounces

TOTAL MODERN DAY PRODUCTION FROM ZORTMAN AND LANDUSKY MINES

TOTAL:	138,267,296	0.018	0.15	81,477,567	219,744,863	0.59
TOTAL	OUNCES	2,529,644	20,740,094			

Production is good and gold in the process solution is even better. It helps keep profits up. But when a permit expansion is delayed, gold prices drop dramatically, and your parent company gets involved in an overseas project gone bad, it spells disaster for all the subsidiary companies. Zortman Mining Inc., one of Pegasus's more profitable subsidiaries, had to follow its parent into bankruptcy. Like the early prospectors, the State of Montana now has to pioneer new ground in its quest for securing the bonds and starting the reclamation implementation phase. After negotiating through the bankruptcy court system and come out the end with far less than needed to complete the work, the State of Montana was forced with taking a very hard look at what could realistically be done with the money available.

The state solicited statements of interest from qualified engineering firms to assist them in the reclamation process. The present-day engineering and reclamation design phase started in June of 1999 with the hiring of Spectrum Engineering out of Billings, Montana. This led to many changes and modifications of the BLM and Montana DEQ pre-selected reclamation plans. This was necessitated, in part, by a large reclamation bond shortfall for Zortman and Landusky. The resulting reclamation designs have been implemented with the majority of the two mines already backfilled, regraded, topsoiled, and revegetated.

One of the first steps involved a detailed engineering evaluation of existing proposed alternatives and any and all other potential alternatives, both within the bond funding and those costing more than the available bonds. The engineering evaluation was completed within the framework of a multiple accounts analysis with the EPA, BLM, Fort Belknap Tribe, and the Montana DEQ all being stakeholders as well as reviewers of everything produced. What came out of this process were a set of alternatives with many common elements, which everyone agreed could be implemented immediately and a set of distinct tasks requiring more study. These additional tasks eventually were analyzed in a full-blown Supplemental EIS. While the EIS was being developed, much of the reclamation was ongoing and taken to final completion. The engineering evaluation identified a few areas with major bond deficiencies. These included process water management and acid mine drainage treatment via the two water treatment plants. The water treatment shortfall had already been identified, but the reason for the shortfall was unknown. In the next two sections is a brief discussion of the two major bond shortfall problems:

PROCESS WATER MANAGEMENT

The heap leach operation consumed 295 acres at the Landusky Mine on seven different leach pads. One pad completely blocked an entire large drainage. At the Zortman Mine, the ore was leached on six different leach pads covering 121 acres. The dikes of each of these leach pads are at the angle of repose (typically 1.7H:1V) and the revegetation success has been problematic at best with erosional rills being an ongoing problem. Handling the process water was the largest single bust in the bonding calculations done by the State of Montana. The then unprecedented high bonds already posted for Zortman (\$10 million) and Landusky (\$19.6 million) for reclamation and handling of leach pad process water seemed to be plenty to handle anything to come up. However, the state had been led to believe that a two pore water flush of the leach pads and then puncturing the liners would be the solution for the leach pad solution water. The estimated bond cost for this was \$120,000 with another \$40,000 for leach pad sump sampling for 3 years. Nothing could be further from the truth.

A table on the following page shows the yearly LAD costs:

ZORTMAN AND LANDUSKY MINE SITES

YEARLY PROCESS WATER MANAGEMENT AND SAFETY

Cost Category	Quantity	Monthly Units	Rate/ Unit	Number of Months	Total Estimate	Total By Category
LAD and General Operations & Maintenance Labor						
Zortman Operators	1	176	22.88	7.0	\$28,188	
Landusky Operators	1	176	22.88	7.0	\$28,188	
Mechanic/Electrician	1	176	28.84	7.0	\$35,531	
Technician	0.5	176	28.32	12.0	\$29,906	
Bookkeeping	0.5	176	30.00	12.0	\$31,680	
Clerk	1	176	21.04	12.0	\$44,436	
Project Eng. Manager	0.6	176	78.00	12.0	\$98,842	
Lab Manager	0.9	176	37.42	12.0	\$71,128	
General Superintendent	0.9	176	63.58	12.0	\$120,853	
Operator Overtime	1	12	31.72	12.0	\$4,568	\$493,320
LAD/General Mine/Safety Expenses						
Lab/Analysis Costs	1	1	1400.00	12.0	\$16,800	
Mine Office Lease/Water	1	1	1555.00	12.0	\$18,660	
Repairs/Maintenance	1	1	8350.00	12.0	\$100,200	
Fuel/Propane	1	1	1950.00	12.0	\$23,400	
Chemical Tank Lease	1	1	400.00	12.0	\$4,800	
Biological Treatment Plant Oper.	12	8	500.00	1.0	\$48,000	
MSHA Training Course	1	1	2000.00	1.0	\$2,000	
General Office/Phone/Ins./Misc.	1	1	1700.00	12.0	\$20,400	
Assett Purchases	1	1	62000.00	1.0	\$62,000	\$296,260
Power Cost						
Zortman 82 Pond	1	1	620.00	12.0	\$7,440	
Zortman 83 Leach Pad	1	1	680.00	12.0	\$8,160	
Zortman 85 Leach Pad	1	1	380.00	12.0	\$4,560	
Zortman 89 Leach Pad	1	1	1220.00	12.0	\$14,640	
Landusky 83 Leach Pad	1	1	330.00	12.0	\$3,960	
Landusky 87 Leach Pad	1	1	3900.00	12.0	\$46,800	
Landusky 87 Pad Dike	1	1	1000.00	12.0	\$12,000	
Landusky 91 Leach Pad	1	1	9600.00	12.0	\$115,200	
Landusky Barren Pond	1	1	1620.00	12.0	\$19,440	
Landusky Mine Maint. Shop	1	1	390.00	12.0	\$4,680	
Zortman Gate-Pit Security	1	1	60.00	12.0	\$720	
Landusky Gate-Pit Security	1	1	100.00	12.0	\$1,200	
Mine Office	1	1	500.00	12.0	\$6,000	
Zortman Generator	1	1	200.00	12.0	\$2,400	
Landusky Generator	1	1	320.00	12.0	\$3,840	
Capital Credit Repayment	1	1	300.00	12.0	\$3,600	\$254,640
TOTAL LAD/GENERAL COSTS FOR 2002						\$1,044,220

All of the leach pads have elevated nitrates (averaging around 250 ppm) and residual amounts of cyanide. At the end of June 1999, there were 253 million gallons of process water in solution. By the end of June 2002, this total had been dropped to 123 million gallons. To pump down the existing water and all new rainfall, it requires yearly LAD disposal of 80 to 100 million gallons of water. This was happening on less than 100 acres prior to expansion to almost 400 acres. The yearly costs for direct land application disposal, safety, and general site operations have been averaging around \$1 million per year to send 80-100 million gallon per year to the LAD.

Contrary to popular opinion, these costs are NOT based on a per gallon formula from an estimating guidebook. Many of these costs are fixed costs and do not go down when you place covers over the leach pads. For example, the monthly power costs are based on \$1/Kva of transformer size plus power consumption. While most of the leach pads sit much of the year without being pumped, they may be running \$750 to \$3000 per month in power due to the transformers. The previous table shows power to be 25% of the total yearly costs. The mines were over 75% of the total base load for the small electric cooperative servicing the mines and general area while operating. When the mines closed, Big Flat Electric was forced to increase rates significantly. Therefore, even with engineering revisions and redesign to drop the power demand, it has not had a dramatic effect on the bottom line as rates go up.

The largest leach pad complex (87/91 at Landusky) contains the largest volume of water and has the added bonus of containing selenium in the process water. This water chemistry was assessed and a decision was made to pre-treat this water before land application. A biological treatment system, developed by Applied Biosciences from Salt Lake City, was selected as the system of choice. A total of \$3.03 million has been expended to date with the plant test results looking promising. Full-scale implementation is scheduled for late August 2002.

Adding the biological pretreatment plant construction (\$3M), ongoing pumping, treatment with hydrogen peroxide to kill the cyanide, and subsequent land application (\$1M/yr x 3 years) together gives a staggering \$6 million expenditure for which there was \$160,000 worth of bonding available. Ouch.

WATER TREATMENT

If the creek isn't running red from a claim jumper shot in the back (or the State's red ink) yet, then let's continue with a discussion of water treatment. Having never bonded anything but drill holes, exploration roads and some simple mine reclamation earthwork now the State was tasked with figuring out the real costs for running two water treatment plants mandated by a Consent Decree resulting from a massive lawsuit by the environmentalists, EPA, BLM, DEQ, and Fort Belknap Reservation against the mining company. They enlisted the EPA's help and ended up with a series of line items with costs for each (labor, maintenance labor, direct costs, indirect costs, general and administrative, administrative, monitoring and analysis, sludge removal, and engineering). The sureties bonded these 9 line items individually. If the state exceeds a line item, they eat the cost. If the state underruns a line item, the sureties keep the money. Direct costs were funded at just over \$62,000 per year to include all hydrated lime, ferric sulfate, power, fuel, and other direct costs. This line item requires closer to \$250,000 to \$300,000 per year. Another shortfall and more red ink in the creek sours the states outlook on mining. The state no longer can see the gold glitter in the pan.

ZORTMAN AND LANDUSKY WATER TREATMENT PLANT COSTS YEAR 2001 TO YEAR 2000 COMPARISON

----- YEAR 2001 -----					----- YEAR 2000 -----			
Cost Category	Cost By Category	Total Gallons	Cost Per 1000 Gallons	Total Cost	Cost By Category	Total Gallons	Cost Per 1000 Gallons	Total Cost
Zortman WTP Water Treated		51,325,290				52,591,030		
Landusky WTP Water Treated		266,250,000				273,710,324		
Entire Year		317,575,290	\$2.770	\$879,727.73		326,301,354	\$2.585	\$843,387.18
COST BREAKDOWN								
POWER AND FUEL								
Zortman Power								
Water Treatment Plant	\$40,950.48	51,325,290	\$0.798		\$36,465.95	52,591,030	\$0.693	
Alder Spur Capture System	\$11,019.85	5,260,811	\$2.095		\$9,958.49	4,798,611	\$2.075	
Carter Gulch Capture System	\$14,266.05	7,212,980	\$1.978		\$12,888.38	6,340,760	\$2.033	
Ruby Gulch Capture System	\$35,793.44	28,902,900	\$1.238		\$35,344.46	24,527,000	\$1.441	
Zortman Fuel (Propane)	\$6,225.30	51,325,290	\$0.121		\$4,779.44	52,591,030	\$0.091	
Landusky Power								
Water Treatment Plant	\$53,247.28	266,250,000	\$0.200		\$52,175.85	273,710,324	\$0.191	
Lower MT Capture System	\$22,845.47	923,060	\$24.750		\$17,496.94	51,631,570	\$0.339	
Upper MT Capture System	\$13,952.99	143,041,040	\$0.098		\$14,332.02	115,062,990	\$0.125	
Mill Gulch Capture System	\$5,181.08	15,119,070	\$0.343		\$6,539.70	13,441,700	\$0.487	
Sullivan Park Capture System	\$4,173.67	2,936,150	\$1.421		\$3,580.56	2,553,470	\$1.402	
Landusky Fuel (Propane)	\$6,374.10	266,250,000	\$0.024		\$5,860.80	273,710,324	\$0.021	
ZMI Capital Credit	\$390.00				\$88.45			
Lab	\$2,962.36				\$3,123.64			
Zortman Backup Generator	\$1,290.57				\$1,268.50			
Landusky Backup Generator	\$1,958.99				\$1,714.36			
SUBTOTAL POWER COSTS	25.08%	317,575,290	\$0.695	\$220,631.62	24.38%	326,301,354	\$0.630	\$205,617.55
LABOR								
Operations	\$232,436.70				\$232,436.70			
Maintenance	\$115,357.60				\$115,357.60			
Sludge Removal	\$26,344.30				\$26,344.30			
SUBTOTAL LABOR COSTS	42.53%	317,575,290	\$1.178	\$374,138.60	44.36%	326,301,354	\$1.147	\$374,138.60
MONITORING AND ANALYSES								
SUBTOTAL LAB ANALYSES	7.56%	317,575,290	\$0.209	\$66,522.60	7.82%	326,301,354	\$0.202	\$65,949.39
GENERAL, INDIRECT, PARTS, ENG.								
SUBTOTAL PUMPS, SUPPLIES	15.43%	317,575,290	\$0.427	\$135,744.07	16.59%	326,301,354	\$0.429	\$139,911.66
REAGENTS								
Hydrated Lime								
Landusky Water Treatment Plant	\$8,412.62	266,250,000	\$0.032		\$6,881.71	273,710,324	\$0.025	
Zortman Water Treatment Plant	\$36,240.94	51,325,290	\$0.706		\$19,203.35	52,591,030	\$0.365	
Ferric Sulfate - Zortman WTP	\$38,037.28	51,325,290	\$0.741		\$31,684.92	52,591,030	\$0.602	
SUBTOTAL REAGENTS	9.40%	317,575,290	\$0.260	\$82,690.84	6.85%	326,301,354	\$0.177	\$57,769.98
SUMMARY BY CATEGORY								
POWER AND FUEL COSTS	25.08%	317,575,290	\$0.695	\$220,631.62	24.38%	326,301,354	\$0.630	\$205,617.55
LABOR COSTS	42.53%	317,575,290	\$1.178	\$374,138.60	44.36%	326,301,354	\$1.147	\$374,138.60
LAB ANALYSES	7.56%	317,575,290	\$0.209	\$66,522.60	7.82%	326,301,354	\$0.202	\$65,949.39
PUMPS, SUPPLIES	15.43%	317,575,290	\$0.427	\$135,744.07	16.59%	326,301,354	\$0.429	\$139,911.66

The table on the previous page provides two years of actual operating cost data for the Zortman and Landusky water treatment plants. Power, once again, is a significant part of the total at 25%.

Another misconception comes to light in the quest for cost savings measures on the two water treatment plants. Those darn fixed costs! About half of the operating costs are fixed, regardless of the quantity of water processed. It takes one operator per shift to process 10 million gallons per month through Landusky or 25 million. Price per gallon cost estimating on water treatment does NOT work. The prime example is the Landusky WTP. This plant processes around 480 gpm on a 24-hours per day, 7-days per week basis (around 20-25 million gallons per month). The input feed is made up of 145 gpm of 5.5 pH water from the old underground workings of Pike Landusky, 39 gpm from the Mill Gulch Capture System at 4.75 pH, 11 gpm from the Sullivan Capture System at 4 pH and a new source. The reclamation alternative selected for the August-Little Ben Pit required opening up an artesian well to prevent water from ponding in the pit complex (as opposed to cutting a \$6 million dollar notch through fresh sulfides to make the pit free-draining). The artesian well and upper Montana Gulch provides 283 gpm at 6.5-7 pH water to the mix. The addition of this 283 gpm did NOT double the cost of water treatment, as you would predict by using a cost per gallon estimating guide. Instead, the cost went down. The higher pH water lowered the lime requirements. The Landusky plant currently processes almost twice the quantity of water for less money than originally spent. It is seldom in life that you get more for less.

The Zortman water treatment plant processes from 2-15 million gallons per month, running around 6 days per month and averaging 160 gpm. This plant consumes \$70,000 more per year in chemicals than the Landusky WTP. Again, cost per gallon costing is dangerous.

RECLAMATION

Reclamation earthwork started in 1999 and is still ongoing. Virtually all of the earthwork affordable within the bond should be completed by mid-2003. Spectrum Engineering is operating an equipment spread consisting of eight Cat D400 haul trucks, one Cat 345 excavator, one Linkbelt excavator, one Cat D9 dozer, one Cat D10 dozer, a Cat 16 G grader and support equipment. Mungas Company, an earthwork contractor is operating a Cat 375 excavator and two Cat 777 haul trucks with support equipment. Approximately \$9 in reclamation has been completed to date.

SUMMARY

The reclamation process has been a learning experience for everyone involved. The State of Montana went from a bonding and review agency to an operator, owning their own heavy equipment with a new appreciation of how to bond other sites. The Fort Belknap Reservation has seen pits backfilled and the prospect of future mining diminish. The BLM has been requested to fund water treatment shortfalls from their operating budgets and has been requested by the Tribe to submit to a public caning for allowing this mine to ever exist. The EPA saw a tremendous amount of work accomplished for minimal expense, including moving tailings on the Zortman side for less than \$2/cubic yard versus the Corps cost of moving tailings a similar distance for over \$40/cubic yard. Spectrum Engineering has learned that satisfying four masters simultaneously is a daunting, thankless, task.

TECHNICAL PAPER SESSION 13 WATERSHED SYSTEMS

Title: [Abandoned Mine Site Restoration in Pine Creek, Coeur d'Alene Basin, Northern Idaho](#)

Authors: [David Fortier](#)*, P.E., Environmental Protection Specialist, USDI, Bureau of Land Management, Coeur d'Alene Field Office and **Steven W. Moore**, Bureau of Land Management, Idaho State Office

Title: **Mercury Contamination of Water, Sediment, and Biota in Watersheds Affected by Historic Hydraulic Gold Mining in California**

Authors: [David Lawler](#)*, Abandoned Mine Lands Coordinator, BLM – California State Office; **Janine Clayton**, U.S. Forest Service, Resources Division; **Charles N. Alpers**, U.S. Geological Survey, Water Resources Division; **Michael P. Hunerlach**, U.S. Geological Survey, Water Resources Division; **Roger L. Hothem**, U.S. Geological Survey, Biological Resources Division; and **Jason T. May**, California State University Sacramento Foundation

Title: [High Ore Creek Watershed Restoration](#)

Authors: [Mike Browne](#)*, Abandoned Mine Land and Hazardous Materials Program Leader, Bureau of Land Management, Butte Field Office; **Ben Quinones**, Montana Department of Environmental Quality, Mine Waste Cleanup Bureau; and **James Madison**, Assistant Research Professor, Montana Bureau of Mines and Geology

ABANDONED MINE SITE RESTORATION ON PINE CREEK, COEUR D'ALENE BASIN, NORTHERN IDAHO

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ABSTRACT

Following severe flooding in northern Idaho in 1996, the Bureau of Land Management (BLM) and partners began implementing a systematic restoration of the Pine Creek watershed to reduce the impacts of past mining and milling. This work is continuing to progress as part of the Idaho's Abandoned Mine Lands (AML) program and the Coeur d'Alene Basin cleanup activities with the Environmental Protection Agency and the State of Idaho. This ongoing, multi-year effort includes a variety of sites in a mountainous 79 square-mile watershed. Actions to date include streamside tailings removals, mill site cleanups, stabilization of waste rock dumps, and stream restoration. This paper will focus on the mine waste removals and waste rock dump stabilization aspects of the restoration effort.

Contaminants of concern are primarily lead, zinc, cadmium and arsenic. Site characterization methods included: site surveys, historic information reviews, field sampling with a portable X-Ray Fluorescence (XRF) unit, transect sampling of soils with XRF and laboratory analysis and periodic water quality monitoring. Limitations and benefits of various characterization and sampling methods are briefly discussed and compared.

Interpretation of sampling data, specific-site characteristics, and cost/benefit limitations, were all considered in design of projects. Project design plans, contract administration, on-the-ground implementation, and preliminary results are also presented as examples of factors involved in conducting AML projects.

BACKGROUND

Pine Creek is located just south of Pinehurst in Northern Idaho's historic Silver Valley. Most of the sites are located along the East Fork of Pine Creek within the Pine Creek watershed. This watershed encompasses an area of approximately 79 square miles and includes the area commonly referred to as the Pine Creek Mining District, a subdivision of the larger Coeur d'Alene Mining District known as the "Silver Valley". The Coeur d'Alene Mining District has been one of the largest metal producing areas of the United States and the largest silver-producing district in the world. The Pine Creek District covers a lead-zinc area which from the early 1900s to the late 1970s, ore was processed at nine flotation mill sites. Seven abandoned or inactive mill sites are located either partially or entirely on BLM administered lands (public lands) within the Pine Creek watershed.

During the winter of 1995-96, several old mine and mill sites and stream segments in the Pine Creek drainage were severely damaged by flooding. BLM received flood repair and protection funding to remove tailings that were in imminent danger of flood erosion and to rehabilitate stream channels. The flood and other cleanup funding provided the opportunity to further investigate and

begin cleanup actions at many sites within the basin. Preliminary investigations had indicated that areas in and adjacent to the mill and mine sites were contaminated with heavy metals. Lead, zinc, cadmium, and arsenic are the contaminants of concern in Pine Creek. The widespread distribution and toxic properties of these metals has the potential of adverse effects to fish, wildlife, and humans.

This paper will focus on the Pine Creek mine waste removals and waste rock dump stabilization aspects of the watershed restoration effort. A general synopsis of issues and methods used in the process of AML site characterization and cleanup, and lessons learned are presented here.

In the conference presentation, more detail on specific AML sites will be provided as illustrations of the effort. An accompanying paper (Stevenson and others, 2002, in this volume) covers stream-restoration aspects of the Pine Creek projects.

SITE CHARACTERIZATION

Site characterization for BLM's AML and Hazardous Materials efforts are done using the process of the National Contingency Plan (NCP) (NCP, 40 CFR, Part 300). Site characterization is an iterative process in assessing problems at the site, and determining if, and how to best cleanup the site. The general NCP process is as follows:

1. site identification;
2. preliminary assessment (PA);
3. site investigation (SI);
4. removal site evaluations (Engineering Evaluation/Cost Analysis - EECA) or remedial investigations/feasibility study (RI/FS);
5. removal cleanup decision or remedial Record of Decision (ROD);
6. project design; and
7. project implementation.

After a site has been identified as having potential problems, the preliminary assessment and site investigation collect the information to determine if a release has occurred and whether a cleanup action is warranted. If a cleanup action is needed, the next stage of characterization is to collect the information to determine how to best cleanup the site. The extent of investigation is determined by the project funding source and the documentation required to implement the project. The removal process under the authority of a lead agency can be every effective with AML sites with normal problems and needed actions. The remedial process, usually done by the Environmental Protection Agency, is for more complex or controversial sites. The remedial investigations and process can easily cost 10 times the cost of a removal investigations and process for the same site.

Initial field investigations are to inventory the basic features at a site and for the preliminary assessment. The potential pathways are examined and initial sampling is done to confirm if releases and problems are actually located at the site. From the preliminary site assessments, the site investigation needs for further site information are identified to determine whether a cleanup action is warranted. The site investigation normally includes checking surface and ground water quality and collecting soil samples to determine the relative magnitude and the aerial extent of the soil contamination. More detailed AML removal site assessments factors are discussed in the following sections based on our Pine Creek and Coeur d'Alene basin removals and investigations. The basic plan for many of our removal sites and their characterization can be found in our EECA for Pine

Creek Millsites (CCJM, 1998).

Once an AML site is targeted for investigation, a literature search is useful in determining the type of mining and milling processes, extent of the mining and ore production, and types of contaminants and physical hazards that are likely to be found. US Geological Survey (USGS) reports, Bureau of Mines reports and State mining bureau reports, which cover the local area, are usually good starting points. Other places to collect historic site information include mining databases, mineral claim and patent survey documents, courthouse records, Sanborn fire insurance maps and checking local historic maps, books, papers and museums.

The initial site surveys have been field visits to map out site features to develop initial site sketches from field observations. The field information can be added to geographic information systems (GIS) with USGS topographic maps and orthophotos to develop initial site maps. Now global position system (GPS) units are also being used to locate and map site points and features which then can be added into GIS maps. For the site investigations and project designs site base maps are expanded with site topographic surveys and low-level aerial photography.

Soil sampling of the waste materials can be a major task with the variety of materials and concentrations that can be found at mines and mill sites. The use of a field portable X-Ray Fluorescence (XRF) unit is a particularly helpful tool in identifying heavy metal contamination in mining related site investigations. The XRF is also excellent at doing transects and checking test borings/pits to quickly determine the extent and magnitude of the contamination. During and after the removals, the XRF can check, confirm and monitor the cleanup levels. The XRF unit is quite cost effective to screen and select which confirmation samples should be sent to the laboratory for analysis.

Water quality sampling is a part of AML investigations from beginning to the end of the project and beyond. Initial investigations collect basic water quality for contaminants or indicator parameters from the surface water streams above and below the sites, any mine drainage and local seeps that might indicate ground water characteristics. If there is significant ground water contamination, monitoring wells are added and included in the site investigations and monitoring. Periodic water sampling of points within the Pine Creek watershed is being done to determine seasonal variations and to identify priority action needs. Periodic water quality monitoring of points within a watershed and at specific sites is necessary to assess the success of clean up efforts and to monitor the long-term water quality.

TAILINGS REMOVALS

The Pine Creek tailings removals have consisted of two types: (1) mill site tailings piles; and (2) deposited floodplain tailings. The removal of the floodplain mill site tailings piles that were being eroded by the streams, was the first priority to be removed. The mill site tailings usually have tailings dams or dikes around and below the tailings that define the boundaries and control the height of the tailings. At several of the sites the streams had eroded away the dikes or flowed over the impoundments, eroding the tailings into the streams.

The characteristics of mill tailings vary with how the site was operated. At many of the older mill sites, the tailings were dumped on the original floodplain to flow to and be carried off by the stream. When the stream did not have the capacity to transport them away, impoundments would be formed with dikes. During the removals we often were working around or removing old tree stumps

and floodplain debris while removing the tailings. The tailings impoundments are generally layered, reflecting a progression in milling practices, or a variation in ore mineralogy. The deeper layers usually contain higher concentrations of metals, since older milling practices were not as effective in beneficiating the metals. Also the upper layers are usually leached and oxidized. The digging of test pits and XRF analyses were usually used to confirm the extent of the tailings.

While the tailings in the impoundments were easy to locate and characterize, the floodplain tailings were widely distributed and presented significant challenges. The major deposits of floodplain tailings are located at variable distances below the mill sites and occur where floodplain widening and stream-gradient reductions cause the bedload to readily drop out of suspension and become deposited. The past dumping of tailings during low flows increased bedload filling in the stream channels and greatly contributed to destabilizing the streams (Kondolf and Matthews, 1996). High flows and over bank flows carry the tails further through the system and deposit them on the upper banks of the floodplains. These higher flows scour the channels and rework floodplain deposits, mixing the tails with the other sediments carried and eroded by the streams. With a destabilized stream, large flood events enable further mixing of tailings and sediments as the channels shift and erode the upper bank areas and redistribute the deposits.

To locate stream deposited tailings, it is very important to understand the stream dynamics and geomorphology of the stream. Local visual indicators, such as silt- and clay-sized material, lack of vegetation, and rusty oxide colors, are useful in identifying tailings. Old tree stumps, debris, and original organic soil layers are useful for determining depth. In areas particularly of old milling operations or reaches with extensive flood activity, the tailings can be concealed beneath clean sediments that support generous vegetation. The revegetation makes these areas hard to recognize and characterize. Estimating volumes for removals are extremely difficult due to the reworking of the deposits by the stream. During the excavation of the deposits, additional volumes of tailings are often discovered that have been obscured by newer stream deposits.

Decisions for removals of streamside tailings can be complicated by the complexity of the deposits. Priorities used for the removal areas were: (a) highest concentrated deposits; (b) areas nearest the stream or in old floodways that are susceptible to erosion; (c) leachable deposits in the zone between high and low ground water levels; and (d) areas that are used by recreational users (for protection of human health). During the removal work, keep focused on the priority removal areas and track the progress versus the budget available. Since the volume of the removal is directly proportional to costs, careful monitoring of the excavation (e.g., with an XRF unit) is necessary to conserve costs.

Often a difficult decision is whether tailings buried by newer sediments with established vegetative cover are to be removed. The decision can be made by weighing the thickness and hazard level of the tailings level versus the amount of overburden and vegetation. The onsite XRF analysis of the layers and sediments during the removals have been key to many of the field decisions. Often visual indicators cannot alone distinguish clean soil from tailings, especially when they are buried below the water table and the tails have not been oxidized. In some areas with tailings beneath clean sediments and established vegetation, it may be more prudent to leave undisturbed.

MILLSITE REMOVALS

Removals were undertaken at the mill sites on public lands by cleaning and removing wastes materials

from and around the mill building locations. Mill sites can have widely varying conditions depending on the type of processing that was done at the site; the location from the mine and how ore was brought to the mill; the means of mine and mill waste disposal; and if the mill has been demolished and/or burned. At some of the sites, found were past generations of mills below or beside the current mill features. The older mills used stamp mills and jigs that depended upon gravity separation, thus not as efficient as newer flotation mills. The tailings from these mills contain relatively high concentrations of remnant metals and the flattened particles can be more readily leachable than other tailings. The improved grinding methods associated with the newer flotation mills resulted in very fine particles that are easily transported by wind and water. Process chemicals used in the flotation mills may also add another component of the contamination problems.

The location of the mill in relation to the mine makes the transport route of the ore important to identify, since increased levels of contamination may exist along that route. Sites examined have had varied ore transport systems ranging from the mine cars on rails to aerial bucket trams to large railroad and truck transports.

The mine and mill waste handling at the mill site are usually important to identify, since these waste piles are usually the most pressing cleanup needs. The tailings piles were discussed above and the mine rock dumps will follow. We have found extensive wastes around, in and below the mill buildings. The highest metal concentrations found were associated with spilled concentrates in loading and storage areas. Other high level contamination exists in chemical storage areas and around and below the flotation units and the ball mills. Milling dust and the waste tailings are extensively found all around mill sites. The waste disposal pathways are important to track, since contamination is usually elevated there.

In the case of mills that have been demolished or burned, concentrated metal wastes are mixed with, and/or concealed by the debris and ash. Usually the old concrete foundations for the large milling and floatation machinery can be found and the knowledge of the basic processing flow can give one a general layout of areas needing to be cleaned up. Old fire insurance maps can be a very helpful source of the layout of buildings at a site and may also give one a time history of the facilities. Cleaning up demolished and burned sites are also made more difficult due to the physical hazards that need to be worked around in the characterization efforts and during the actual cleanup work.

Before the cleanups were started, the mill sites were documented and recorded by cultural specialists. Part of the cleanup plans was to leave the large concrete foundations or other historic features, where possible, to leave part of the history of the local area. During the mill cleanups we found that much of the work in the building areas and around the old foundations needed to be done by hand or with bobcats or mini-hoes. Also with the hand labor, small crews worked better because they worked together better and the larger crews seemed always to have some workers waiting for directions. After the concrete foundations and slabs had the materials removed from them, the areas were flushed using hoses from water trucks.

WASTE ROCK DUMPS

While removals of heavy metal contaminated tailings decreases potential for water quality problems, waste dump stabilization has been done primarily for reduction of sediment input into the watershed. Waste dumps in direct contact with streams have caused increased bedload, which has been hypothesized (Kondolf and Matthews, 1996) to be a major cause to the channel instability in the Pine

Creek reaches. At most all of the major producing mines, the extensive amounts of waste rock generated has created dumps that either completely fill over the steep walled canyon draws or severely encroach on the streams floodplains. Since most of the streamside dumps are at least at the angle of repose, the dump is significant long-term sediment source. With the large volumes of waste rock, an excavated removal is usually not practical or economical, so stabilization consisting of pulling back from and armoring the stream, reduction of slope, terracing, and revegetation has been pursued.

A good topographical survey using a total station survey unit which imports data into a computer aided drafting (CAD) system expedites designing regrading options and volume estimates. The topographic survey should include all of the mine related features and the areas where the materials might be moved to. Stream features and dump erosion areas need to be well identified since they are the key removal action areas.

The rock dump projects have been onsite regrading, but in the case of highly contaminated waste rock, moving to another site may be needed. The rock dumps are usually a mixture of rock, ranging from clean parent rock to low-grade ore rock. The sites have been in steep draws, which cannot be regraded to where the stream originally flowed. During spring runoff periods, subsurface flow through the pile in the original stream areas are often seen. These flows are not a concern if they do not create significant erosion or water quality issues, or dewater a fishery stream segment.

STREAM STABILIZATION

As part of the mine related removal work, the sites are being revegetated and the stream channels stabilized. The tailings impoundment removals in the floodplains generally require subsequent restoration of the stream and the floodplain. The floodplain tailings removals usually resulted in the need to backfill areas next to the streams or the reconstruction of the stream zone and floodplain. More details on the issues dealing with stream restoration in Pine Creek are presented in a companion paper in this volume (Stevenson and others, 2002).

MINE WATER TREATMENT

Seeps and mine adit discharges are often a major source of water quality degradation. Treatment of these sources often is the only reasonable option to address these sources. Mine water characteristics and potential treatment options vary considerably with mine characteristics, climatic factors, and geochemistry. In other words, what works in one area may not work in another. Design procedures are not well established to design mine water treatment systems because systematic research of the systems has been very limited.

Due to the regional mine site variations, pilot systems usually are needed to evaluate system effectiveness and gather the additional characterization information. Mine discharge rate and seasonal water quality variations need to be considered in system design. Abandoned mine site systems in our mountainous region require very limited operation and maintenance needs because the sites are remote, without power and inaccessible for most of the winter and spring. In the Coeur d'Alene basin, we have started experimenting with several pilot treatment systems trying small tank units with bioreactors and zeolites. We are installing further pilot bioreactor cells (subsurface flow wetland concepts) and a tank system using biochelators. These pilot systems are being tried to investigate

what may work with our regional mine characteristics and weather conditions. From the first winter of operation, we found that our units that are buried flush with the ground did not appear to have any freezing problems during the winter with a good snow cover. There appears to be no easy answers. This is a significant area of experimentation and a future area of applied research.

SOME OTHER LESSONS LEARNED

Time and materials (T&M) contracts with capped limits have provided flexibility in AML cleanup work. With T&M contracts, one needs to keep focus on the removal priority needs. On-site oversight of the contractors is essential to: keep priority work on track; track overall progress and expenditures; and to assure work is done properly. If possible do not work during extended adverse weather conditions, which make efficiently decline or threaten to compromise the environmental protection controls. T&M contracts shift the risk of work not working correctly or taking much longer than planned from the contractor to the one paying for the contract. The contractors will get paid for the work they are directed to do, and the contractors know that well, so under a T&M contract one needs to know what they are doing.

Abandoned mines and mill sites can be very expensive to extensively characterize and can cost more than the cleanup needs in the end. If contracting the characterizations, carefully define what is to be investigated and what data needs to be collected. A contractor can always find more questions that they would like you to pay to answer. With flexible cleanup contracts, a good contractor, past experience at similar sites, and tools like the XRF, cleanups can be done very cost effectively with limited general characterization. A portable XRF unit can pay for itself during a large removal in the savings gained during the site characterization and by determining what needs, and does not need, to be removed.

A good topographic site survey with a total station is needed for a mill site cleanup or rock dump regarding project base maps. For streamside tailings and stream stabilization efforts, low-level aerial photos enlarged to a scale of 1 inch = 100 feet have been very effective as project base maps. Project base maps are important to be able to estimate the removal volumes, to map the planned removal areas and to locate the stream stabilization needs for the project planning, contract documents and project documentation.

Working with AML sites is challenging because of the widely varying conditions encountered at the sites. We need to share our findings - what works, and what doesn't - so we can improve solutions of water quality and safety on our public lands. From BLM's Characterization of Abandoned Mine Lands course, Mike Browne's ending slide in the approach session struck a true note: **"Good judgment comes from experience, and a lot of that comes from bad judgment."** (BLM, 2002). We often learn more from our mistakes than our successes, so one should not be afraid to try to do what one believes is reasonable to do.

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HIGH ORE CREEK WATERSHED RESTORATION

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ABSTRACT

A cooperative effort by the state of Montana, Bureau of Land Management, twenty private landowners, and several contractors resulted in the restoration of four miles of stream channel on High Ore Creek and the reclamation of the Comet, Golconda, King Cole, and Silver Hill mines in the High Ore Creek watershed. High Ore Creek, located east of the town of Basin in Jefferson County, Montana, flows through the abandoned Comet Mine and Mill site and into the Boulder River.

Mill tailings and waste rock, from about 400,000 tons of ore milled at the Comet Mine, filled a large area of the High Ore Creek Valley and were retained behind a dam. Failure of the dam allowed mine wastes to erode and be transported downstream to the Boulder River. The Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (MWCB) completed the first phase of reclamation at the Comet mine site in the 1997 and 1998. Approximately 430,000 cubic yards of mine wastes were excavated and placed into the pit area. The Bureau of Land Management, in 1999 and 2000, and the MWCB, in 2001, removed streamside tailings material, a significant source of metal and sediment contamination in the High Ore Creek and Boulder River watersheds. Reclamation included the removal of approximately 62,000 cubic yards of streamside tailings and waste-rock over a 4-mile length of stream channel, stream channel and floodplain reconstruction, and re-vegetation with native plant species.

The Montana Bureau of Mines and Geology (MBMG) has been monitoring water quality in the High Ore Creek and Boulder River watersheds since 1997. The MBMG compared post-reclamation analytical results with pre-reclamation water-quality data to determine the success of the Comet Mine and High Ore Creek reclamation projects. Analytical results indicate trace-element concentrations are substantially lower than pre-reclamation conditions.

INTRODUCTION

High Ore Creek is located northwest of Boulder, Montana in Jefferson County, Montana. High Ore Creek flows through the Comet Mine site and into the Boulder River approximately 3-miles northeast of the town of Basin.

The Comet Mine and Millsite is one of the oldest abandoned hardrock mine sites in the Basin/Cataract Mining District. The site was first mined in about 1880 by the Alta-Montana Mining Company. The majority of the production from the Comet occurred from 1883 to 1893 while owned by the Helena Mine and Reduction Company. Initially, ore was rope trammed to a milling and smelting facility in the nearby town of Wickes, about 5 miles northeast of the mine. In

1889, a mill was built at the mine site to process ore from the Comet Mine; the mill tailings were placed in an impoundment located in the High Ore Creek flood plain. Unlike most mines that shut down in 1893 due to the silver panic, the Comet Mine continued operation through 1897. Between 1900 and 1926, the mine was worked by several different operators; a 3-compartment shaft was sunk to a depth of 975 feet, and levels were driven at 100-ft intervals down to the 800 level; and most of the ore was removed from the 100 and 200 levels. The mine consists of 9 drifts at levels comprising 20,000 feet of lineal workings. The Basin Montana Tunnel Company acquired the Comet in 1926 and constructed a new 200-tons per day flotation mill in 1931 to treat ore from the Comet and Grey Eagle mines. Interestingly, the mill tailings from the previous operations were reprocessed through the new mill and \$1.4 million of metals recovered.

The Comet Mine is credited with production valued at \$13,000,000 prior to 1911. From 1934 through 1940, production from the Comet Mine averaged about 58,000 tons per year. The Comet and the Grey Eagle mines closed in 1941. Reported production for the Comet Mine from 1904 to 1950 is 493,444 tons of ore, which yielded 41,754 ounces of gold, 3,152,896 ounces of silver, 28,222,300 pounds of lead, 23,835,847 pounds of zinc, and 2,234,353 pounds of copper.

ABANDONED MINE LAND RECLAMATION, MONTANA

Cooperating state and federal agencies using a collaborative “watershed approach” identified the Boulder River as a priority watershed to begin reclamation of AML sites impacting water quality in 1997. The Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (DEQ), administers the abandoned mine land (AML) program for the state of Montana using funds from the Office of Surface Mining to reclaim private lands impacted by historic mining. The U.S. Bureau of Land Management, Butte Field Office, (BLM) is responsible for the reclamation/remediation of all AML sites on BLM administered lands in Montana. The BLM identified the Boulder River as one of the two pilot watersheds that would be used to implement a watershed approach for reclamation of AML sites impacting water quality. Funding for restoration of High Ore Creek, a tributary of the Boulder River, was provided as part of the Clinton administration’s Clean Water Action Plan.

The Comet Mine and High Ore Creek Stream Side Tailings Reclamation projects were considered non-time critical removal actions under the National Oil and Hazardous Substances Pollution Contingency Plan (NCP). In accordance with the NCP, an Expanded Engineering Evaluation/Cost Analysis (EEE/CA) for the Comet Mine and High Ore Creek Stream Side Tailings Reclamation Projects were completed and used to present the detailed analysis of reclamation alternatives. The detailed analysis of alternatives and additional background information provided in each EEE/CA was used to determine the preferred alternative for reclamation at the Comet Mine and High Ore Creek.

The Montana Department of Environmental Quality inventoried the Comet Mine in 1993 for inclusion on the Abandoned Hardrock Mine Priority List (DEQ/MWCB-Pioneer Technical Services, Inc., 1995). The Comet scored 10th out of 276 sites using the Abandoned and Inactive Mines Scoring System (AIMSS). The Montana Bureau of Mines and Geology (MBMG) inventoried abandoned mines in the High Ore Creek watershed in cooperation with the Bureau of Land Management (MBMG, 1995). Most of the sites inventoried consisted of caved adits with

small unvegetated waste dumps. Environmental problems associated with these sites were mostly due to waste material being entrained in storm water and transported to High Ore Creek. Mine waste and mill tailings at the Comet Mine and Mill, and stream side tailings along the lower 4-mile reach of High Ore Creek were identified as the most significant environmental problem affecting Bureau of Land Management administered land in the High Ore Creek drainage

WATERSHED RESTORATION

Initial reclamation work began at the mine and mill site in 1990 when the Montana Department of Fish, Wildlife, and Parks (FW&P) reconstructed a pre-existing creek diversion around the tailings impoundment. The Montana FW&P also reconstructed an existing sedimentation pond to capture storm water running off from the tailings and control the release of mine waste sediments into High Ore Creek.

The MWCB conducted interim reclamation activities at the mill site in 1995 and 1996 to improve erosion and sediment control from the tailings in preparation for full-scale reclamation of the site (DEQ/MWCB-Pioneer Technical Services, Inc., 1996). The MWCB initiated Phase I of the Comet Mine and Mill Site reclamation in 1997. Phase I of the Comet Mine and Mill Site reclamation required the construction of a mine waste repository at the location of the abandoned glory hole. Approximately 300,000 cubic yards of waste rock and tailings were removed from the flood plain and placed in a constructed repository at the Comet Mine site.

The Bureau of Land Management's High Ore Creek stream side tailings reclamation portion of the watershed restoration began in 1999 and was completed in 2000. The stream side tailings reclamation began below the Comet Mine site and continued to the creek's confluence with the Boulder River. The stream side tailings reclamation included approximately 32,000 cubic yards of stream side tailings and 5,800 cubic yards of waste rock that was distributed throughout the 4-mile High Ore Creek flood plain below the Comet Mine.

The MWCB completed Phase II of the Comet Mine reclamation in 2001. This reclamation involved removal of approximately 39,000 cubic yards of tailings and waste-rock material beneath the High Ore Creek diversion channel and placement of these materials into the BLM repository located 1-mile SE of the Comet Mine. The diversion channel installed in 1990 was removed and the High Ore Creek stream channel was reconstructed and returned to its original location in the bottom of the valley. The Comet Mine and BLM repositories were capped with soil and seeded.

OBJECTIVE

The objective of the Comet Mine and Millsite Phase I and Phase II Reclamation Projects were to protect human health and the environment in accordance with the guidelines set forth by the NCP. Specifically, the remedy was selected to limit human and environmental exposure to the contaminants of concern and reduce the mobility of those contaminants in the local surface water and groundwater resources, and to reduce the safety hazards associated with an open shaft at the site.

The objective of reclamation in the High Ore Creek watershed was to reduce the detrimental impacts to water quality and riparian vegetation as well as the impacts to human

health and the environment. Reclamation was expected to restore riparian vegetation; allow High Ore Creek to function properly; improve water quality; and potentially establish a healthy, diverse biotic community and fisheries. The High Ore Creek reclamation is expected to bring the BLM into compliance with the requirements of the NCP, the Butte Field Office's RMP/EIS, and the Clean Water Act.

COMET MINE AND MILL SITE RECLAMATION

The Comet Mine and Millsite is located in the northeastern part of the Basin/Cataract Mining District. The legal description of the site is South 1/2 of Section 36, Township 7 North, Range 5 West. The Comet site is located adjacent to High Ore Creek on privately owned land, and is bordered by BLM-administered land. The altitude ranges between 6,100 and 6,400 feet above mean sea level. The terrain surrounding the site is generally rugged and consists of relatively steep south and north facing slopes. The climate of the area, typical of southwest Montana, is cool and dry. Average annual precipitation at Basin is about 14 inches; temperature records for Boulder, 5 miles to the southeast, indicate average maximum high temperatures of about 80°F in July and August, and average minimum temperature of 9°F in January (Western Region Climate Center, 2001).

The Comet Mine site encompasses an area of approximately 35 acres, and includes two tailings impoundments located in the High Ore Creek flood plain, three waste rock piles (two of which are in the flood plain), five waste-rock dumps on Silver Hill, a large glory hole or open pit mine area, and numerous abandoned buildings and structures associated with the mine and the town of Comet. The mill-tailings deposits have been eroding into the creek for many years.

General problems at the Comet Mine site that could impact human health included high concentrations of metals and arsenic in waste materials (mill tailings and waste rock), and elevated concentrations of metals and arsenic in surface water, and stream sediments downgradient from the site. The easily accessible waste materials may result in significant health-related consequences to the human population. At the Comet site, mill tailings, underlying soils, waste rock piles, surface water, and stream sediments had arsenic, silver, cadmium, copper, iron, mercury, lead, antimony, and zinc present at concentrations significantly above background levels.

INTERIM RECLAMATION ACTION

During the spring of 1996, the DEQ conducted the Comet Mine Interim Reclamation Project. The objective of this interim project was twofold: first, the sediment control capabilities of the existing sediment pond needed to be returned to a functional condition; and second, construction of a lower sediment pond to improve the sediment trapping capabilities and serve as the first phase of the overall site-reclamation strategy. As part of this interim action, a new sedimentation pond was constructed; approximately 2,500 cubic yards of sediment were removed from the existing sedimentation pond constructed in 1990; a temporary fence was erected around the sedimentation ponds; and temporary erosion controls were installed within the tailings impoundment areas.

Under contract with the DEQ's AML program, Pioneer Technical Services, Inc., was assigned the responsibility of engineering and preparing the interim reclamation specifications prior to contractor selection, and conducted on-site quality assurance inspections during construction. Smith Contracting, Inc, from Whitehall, Montana, performed the work for the Comet Interim Construction Project. Total construction cost for the interim reclamation action was \$46,905. The total engineering cost for this project was \$45,701. The Work Plan, Field Sampling Plan and Reclamation Investigation cost \$21,156 to prepare. Construction engineering and preparation of plans and specifications cost \$12,893. Construction management including engineering administration and inspection cost \$11,651.

PHASE I RECLAMATION ACTION

The Phase I reclamation activities at the Comet Mine and Millsite took place during the 1997 construction season (September through December) and the 1998 construction season (May through July). Pioneer Technical Services, Inc. (under contract with the DEQ/MWCB), was responsible for preparing the final design and engineering specifications for the project, and for overseeing construction. Ten qualified bidders responded with bids ranging from \$903,580 to \$1,989,639. The Engineer's estimate was \$1,943,650 for the project. The contract was awarded to the lowest qualified bidder, Shumaker Trucking and Excavating Contractors, Inc. Shumaker performed all of the on-site construction work.

The project involved consolidating the solid media waste sources which represented the greatest risks to human health and the environment (two tailing impoundments located in the High Ore Creek flood plain and several waste rock dumps) into an open pit located at the site. The pit was divided into an upper and lower section. The lower pit contained most of the coarse waste rock and was constructed as a buttress to contain the wetter, finer-grained tailings that were placed in the upper pit. Most of the excavated areas were graded to blend into the native contours. After the specified wastes were placed into the open pit, the entire contents of a larger waste-rock dump material were placed over the wastes to act as an interim cover until the final cap was installed.

The purpose of the Phase I Comet Mine Reclamation project was to excavate two tailings ponds and three waste rock dumps and disposed of them in the open pit located on the east side of the site. The wet tailings were to be disposed within the deepest portion of the pit, and the dry tailings and waste rock were disposed of in the open section of pit and the benched area within the pit. Sediments contained in the upper settling pond were completely excavated and disposed of in the open pit. A portion of the High Ore Creek diversion embankment was also excavated and disposed of in the pit.

Phase I of the project was completed over two construction seasons. The most significant items completed during Phase I construction included the excavation and consolidation of 300,000 cubic yards of tailings and waste rock materials; and revegetation of 15 acres of reclaimed land. The construction cost for the Comet Mine and Millsite Phase I project was \$1,268,624. Shumaker's original bid of \$903,580 was increased by \$365,043 due to quantity increases and change orders. The total engineering costs associated with the project were \$296,967.

During Phase I of the Comet Mine Reclamation Project most of the contaminant sources, responsible for impacting the High Ore Creek drainage were removed from the site. The largest waste rock dump was removed and the area recontoured to its slope; compost, fertilizer, seed, and erosion control mat were added to the slope.

After the Comet Mine and Millsite Phase I Reclamation Project was completed, the Comet Mine repository was monitored for a year due to several large cracks and seeps which had developed over and along the repository face. The monitoring indicated that the repository was settling, rather than failing. It was also determined that the Comet repository was filled to capacity, and that an alternative repository site was necessary to dispose of the remaining mine wastes. Prior to Phase II reclamation, the BLM and the DEQ entered into a cooperative agreement allowing the DEQ to place the remaining mine wastes into an engineered, multi-layered repository situated on BLM administered land. In addition, the BLM provided approximately 35,000 cubic yards of borrow material to be used as cover soil/topsoil for the Comet Mine site.

PHASE II RECLAMATION ACTION

The purpose of the Comet Mine and Millsite Phase II Reclamation Project was to remove the remaining mine waste from the site, restore the High Ore Creek valley through the Comet Minesite, cap the Comet and High Ore Creek repositories with engineered, multi-layered caps, revegetate the Comet Mine site, and to fence the reclaimed areas to allow for vegetative growth to become established. All construction activities for the Comet Mine and Millsite Phase II Reclamation Project occurred during the 2001 construction season. The reclaimed mine site was completely fenced during the spring of 2002. Olympus Technical Services, Inc. (Helena, Montana) was assigned the responsibility of engineering and preparing the reclamation specifications for the Comet Mine Site. Olympus was also responsible for construction engineering and quality control inspection for the Comet Mine Site. Pioneer Technical Services, Inc. was responsible for the engineering, preparation of the reclamation specifications, and the construction engineering and quality control inspection for the BLM repository site. Two qualified bidders responded with bids ranging from \$1,317,417 to \$1,638,597, with an average of \$1,478,007. The Engineer's estimate was \$967,717. Mobilization was unintentionally left blank on Shumaker's original bid submittal. One subcontractor was used for fence installation on the project.

Phase II reclamation involved the removal of residual tailings from the High Ore Creek flood plain area, and the removal, replacement, and grading of 23,196 cubic yards of non-tailings overburden soil to access tailings for excavation and disposal in an engineered repository designed and constructed by the BLM and U.S. Army Corps of Engineers. The work involved construction of 1,491 lineal feet of High Ore Creek stream channel through the former Comet Mine tailings and waste rock pile area. The majority of the 39,206 cubic yards of tailings were placed and compacted in the BLM repository. The remaining tailings were placed on top of the Comet Mine repository. A temporary bridge was installed to cross the stream reconstruction area and provide access to the Comet repository, BLM repository and cover soil stockpile. The stream channel construction involved excavation of the streambed and banks, placement of streambed backfill material, and the installation of erosion control mat and willow cuttings on the

streambanks. A drop structure was constructed to convey High Ore Creek into the constructed stream channel. The existing High Ore Creek riprap-lined diversion channel and gabion drop structure (constructed in 1990 by the Montana Department of Fish, Wildlife, and Parks) were removed. Waste rock piles, slopes and depressions in the vicinity of the Comet Millsite and the Silver Hill area were graded, contoured, amended with fertilizer and compost, and revegetated.

An open shaft on the Comet Mine repository buttress slope, as well as a shaft near the Silver Hill area that was discovered during construction, were backfilled. Approximately 35,000 cubic yards of cover soil was applied and graded on the repository buttress slope and the slope was graded with dozer basins for erosion control. The repository buttress slope, graded flood plain, and graded waste rock areas were amended with 1,258 tons of organic compost and revegetated with native plant species. The Comet and BLM repositories were capped with geocomposite clay liners and organic amended cover soil. Other work items included removal and on-site disposal of debris, construction of a runoff control ditches, repair and grading of a slump area, and reclaiming the access road through the site. The project site was fenced off with a 4-strand barbed wire fence to control access in order to establish vegetation.

Shumaker Trucking and Excavating Contractors was awarded the contract and the construction cost for the Comet Mine and Millsite Phase II project was \$1,581,899.75. The original bid was \$1,317,430.00 for the Comet Mine and Millsite Phase II project, with three change orders issued. The major cost items were tailings excavation, hauling, placement, grading and compaction (11.9%), organic amendment (8.65%), mobilization (6.88%). The total engineering cost for this project was \$161,572.04. The total project cost was \$1,743,471.79.

HIGH ORE CREEK STREAM SIDE TAILINGS RECLAMATION

The High Ore Creek watershed consist of an 8.5-square mile area. Forty-three percent of the lands on High Ore Creek are Public Lands administered BLM and 57% of the land is private property belonging to 20 landowners with 34 patented mining claims. Nine County, State, and Federal Agencies along with numerous consultants, contractors and interested parties worked together to investigate, characterize, design, and mitigate environmental impacts on High Ore Creek.

Stream side tailings deposits from the Comet Mine and mill site (Figure 1) eroded into High Ore Creek for many years. Stream side tailings from the tailings impoundment located in the bottom of the drainage were released during large runoff events. Tailings were transported

downstream where they were deposited in the Creek and along the flood plane or flowed into the Boulder River. The most significant event occurred when the tailings-impoundment dam was breached by flood waters. This and subsequent events easily scoured the tailings and transported them downstream. In some downstream areas, tailings accumulations were several feet thick and spanned the width of the valley, typically a few hundred feet wide. In most of the areas along High Ore Creek, the tailings were less than 1 foot thick



Figure 1-Comet Mine prior to Phase I reclamation.

These tailings were the largest mine waste source of concern because they are one of the highest contributors of metals and sediment to the surface water. These tailings severely affected the vegetation in the flood plain of High Ore Creek.

The Montana Bureau of Mines and Geology (MBMG, 1995) and the BLM (BLM, 1999) measured concentrations of antimony, arsenic, cadmium, copper, iron, lead, manganese, silver, and zinc that were significantly elevated above background concentrations ($>3X$) in soil and water samples in the flood plain and surrounding area. Preliminary findings by the U.S. Geological Survey also indicate that sediments, fluvial tailings and water from High Ore Creek are significant contributors to water quality degradation of the Boulder River below Basin, Montana (USGS, 1999). In 1998 the BLM initiated the reclamation of High Ore Creek with the development of the Expanded Engineering Evaluation/Cost Analysis (EEE/CA) to evaluate reclamation alternatives.

SITE ASSESSMENT

Site assessment began with the initiation of the EEE/CA in February 1998. Site assessment, in addition to the EEE/CA, included: 1) Owner/Operator History Report, 2) Community Relations Plan, 3) Quality Assurance Project Plan, 4) Laboratory Analytical Protocol, 5) Health and Safety Plan, 6) Cultural Inventory Report, and 7) Engineering Design/Construction Bid Specification Package.

The stream side tailings were the largest mine-waste source of concern because of high contributions of metals and sediment to the surface water. Reclamation first required the identification of mine waste types, location, volumes, and impacts to human health and the environment. The BLM conducted a stream inventory on High Ore Creek in 1998 to identify stream reach segments that required reclamation. Twenty-one reaches with 45 sub-reaches were identified that required reclamation as a result of mining impacts or poorly functioning riparian areas. The stream side tailings were separated into three types of tailings impacted areas. Areas

with no vegetation growing on the tailings (approximately 21 acres) were classified as High Impact Areas (Figure 2). Areas where tailings were visible with some vegetation were classified as Medium Impact Areas (Figure 3). All remaining areas of the High Ore Creek flood plain were considered Low Impact Areas. Vegetation was prominent in these areas with little or no effect from the tailings. Some Low Impact Areas required stream bank reconstruction to return riparian areas to a functioning condition. Discrete and composite samples, from separate sampling events, in the High Ore Creek flood plain were collected by Pioneer Technical Services Inc., the MBMG, and the BLM. Thirty-seven discrete samples and one composite sample were collected for X-ray Fluorescence Spectrometer (XRF) analysis, while three composite samples were collected for analysis of total metals, Acid Base Accounting (ABA), agronomic and Toxicity Characteristic Leaching Procedure.



Figure2 - High Impact Areas.



Figure 3 - Medium Impact Areas.

Risk Assessment

Stream side tailings were separated into three types of tailings impacted areas to assist with the analysis of alternatives based on the following criteria: 1) the relative protectiveness of human health and the environment provided by the alternatives; 2) the long-term effectiveness provided by the alternatives; and 3) the estimated attainment of ARARs for each alternative. An alternative screening summary, Table 1, was used to determine alternatives retained for detailed analysis. Table 2 is a summary of overall cost comparisons between the Alternatives based on the amount of Human Health (HH) and Ecological Risk Reduction (E).

Table 1. Alternatives Screening Summary (BLM, 1999).

ALTERNATIVE DESCRIPTION	EFFECTIVE- NESS	IMPLEMENT- ABLE	EST. COST	RETAINED FOR DETAILED ANALYSIS
Alt. 1: No Action	NA	NA	\$0	Yes
Alt. 2: Institutional Controls	Low	Yes	\$390,000	No
Alt. 3: In-Place Containment of Wastes With Cover soil	Low-Medium	Yes	\$674,298	No
Alt. 4a: Partial Removal/Disposal in Constructed Repository and Partial In-Place Containment (bottom liner and drainage layer)	High	Yes	\$1,139,602	Yes
Alt. 4b: Partial Removal/Disposal in Constructed Repository and Partial In-Place Containment (no bottom liner)	High	Yes	\$1,020,211	Yes
Alt. 5a: Removal/Disposal of all Solid Waste Material in a Constructed Repository (bottom liner and drainage layer)	High	Yes	\$1,529,393	Yes
Alt. 5b: Removal/Disposal of all Solid Waste Material in a Constructed Repository (no bottom liner)	High	Yes	\$1,343,786	Yes

Table 2. Alternative Cost-Effectiveness Comparison Summary (BLM, 1999)

ALTERNATIVE	Ecologic Risk Reduction (E)	Human Health Risk Reduction (HH)	Total Present Worth Value	Cost per 1% Reduction in Risk (\$)
Alternative 1	0%	0%	\$1.14 Million	NA
Alternative 4a	72%	94%	\$1.02 Million	\$15,833 (E) \$12,128 (EH)
Alternative 4b	72%	94%	\$1.02 Million	\$14,167 (E) \$10,851 (HH)
Alternative 5a	76%	100%	\$1. 53 Million	\$20,132 (E) \$15,300 (HH)
Alternative 5b	76%	100%	\$1.53 Million	\$17,632 (E) \$13,400 (HH)

Alternative 4b was selected as the preferred alternative for the reclamation of High Ore Creek. This alternative should protect human health and the environment by removing the highest risk mine wastes in the High Ore Creek watershed. This alternative consists of excavating selected solid waste material from the High Ore Creek flood plain and disposing of it in a modified RCRA repository constructed about 1 mile southeast of the Comet Mine site. The repository design includes a multi-layered cap with no bottom liner. This alternative is expected to reduce risks to human health by 94% and ecological risks by 72%. The long-term effectiveness of this alternative is expected to improve the water quality protect human health and the environment.

RECLAMATION

The construction bid package for reclamation was administered for the BLM by the U.S. Army Corp of Engineers (USACE) and contained the reclamation engineering design, project plans and specifications prepared by Pioneer Technical Services, Inc.. Schumaker Trucking and Excavating Contractors, Inc., from Great Falls, MT, was awarded the construction contract and issued a Notice to Proceed by the USACE in September 1999. Shumaker Trucking and Excavating Contractors, Inc. began construction in September, 1999 and completed construction in June, 2000.

The reclamation of High Ore Creek included: areas with complete tailings removal, channel, and flood plain reconstruction; areas with partial tailings removal and flood plain reconstruction; areas with only stream bank reconstruction ; and areas with no tailings removal or stream bank reconstruction. The construction contract involved removing waste adjacent to High Ore Creek and disposing of these materials in a constructed repository located approximately 1 mile southeast of the Comet Mine and Mill site.

Reclamation included:

- Clearing, grubbing, and constructing a six acre borrow area/repository and improving the existing access road to the repository,
- Stockpiling 34,000 cubic yards of cover soil to be used by the MWCB for Phase 2 of the Comet Mine reclamation,
- Excavating and hauling 31,913 cubic yards of stream side tailings and mine wastes to the BLM repository,
- Installing 4,127 lineal feet of stream protection structures,
- Installing 12,246 lineal feet of silt fence,
- Reconstructing 3,459 lineal feet of High Ore Creek stream channel,
- Reconstructing flood plain with 14,276 cubic yards of clean cover soil,
- Backfilling flood plain with 18,103 cubic yards of clean, organically amended cover soil (topsoil) following waste removal,
- Constructing streambed including steps, pools, and grade control structures,
- Installing 4,612 square yards of Type A bank stabilization fabric,
- Installing 8,442 square yards of Type B erosion control mat,
- Installing willow cuttings and 833 lineal feet of willow fascines on stream banks, and

- Seeding and mulching reconstructed and stabilized streambanks.
- Construction of the repository cap:
 1. Installation of 17,531 square yards of a geotextile cushion over the uppermost lift of compacted mine wastes,
 2. Installation of 18,051 square yards of Geosynthetic Clay Liner,
 3. Installation of 17,811 square yards of a Geonoet and filter fabric geocomposite,
 4. Apply and grade 12,934 cubic yards of organically amended cover soil,
 5. Apply and grade 7.2 acres of salvaged topsoil, and
 6. Seed and mulch 7.2 acres.
- Construction of repository run-on/runoff control ditches,
- Replace and install four properly sized culverts on High Ore Creek,
- Obliterating and reseeded temporary haul roads and the existing access road between the Comet repository and the new BLM repository.

WATER QUALITY INFORMATION

Base flow in High Ore Creek at a monitoring station about 1-mile upstream from the confluence with the Boulder river is about 0.5 cfs. Peak flow measured in April 2002 at the same station was about 6 cfs. During the 2001 field season, peak storm flows caused by summer thunderstorms and fall rain and snowmelt runoff did not exceed 2 cfs.

Mineralization at the Comet is hosted by quartz monzonite and andesite. The zone of mineralization is nearly 150 feet wide, strikes almost east-west, and dips steeply south to vertical. The ore consist of galena, sphalerite, and pyrite with some arsenopyrite, chalcopyrite, and tetrahedrite in a gangue of quartz, carbonate minerals, and altered wallrock. Average ore concentration include 0.084 ounces gold and 6.4 ounces silver per ton, 3.2 % lead, 3.9 % zinc, and 2.2 % copper (Roby et al., 1960; Becraft et al., 1963).

Laboratory analyses for water samples collected at 8 stations along High Ore Creek and tributaries as part of the initial abandoned-mine inventory and two diurnal sampling events at one station were used for the pre-reclamation basis. These pre-reclamation samples were collected during low stream flow when storm water was not flowing into the creek. For the post-reclamation monitoring, water samples were collected at selected sites as a way to assess the effectiveness of reclamation; as a way to assess the three different reclamation approaches; and as a way to identify any stream reaches or sites that may require additional work. Current monitoring includes collecting water samples for laboratory analyses and/or field parameters at 8 stations during low-flow; and diurnal sampling at the same station that was sampled during the pre-reclamation monitoring (Figure 4).

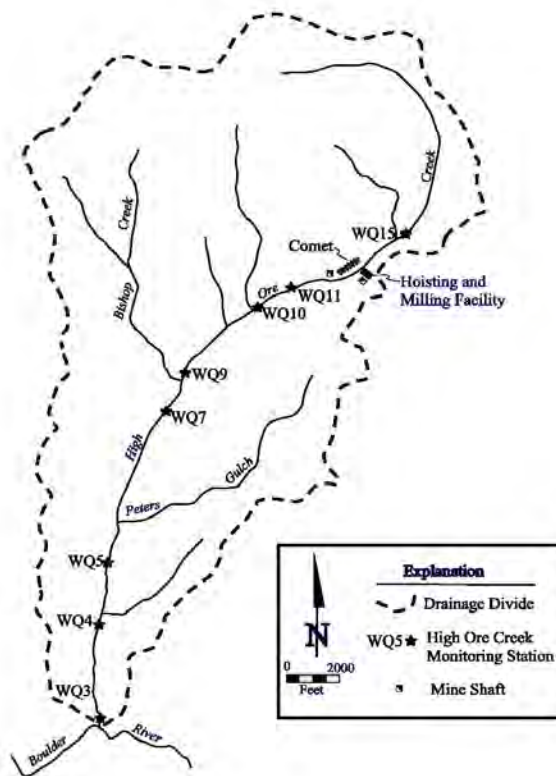


Figure 4. High Ore miles east of Basin,

are monitored along High Ore Creek and its tributaries for field parameters and/or major ions and trace element constituents.

Creek is located about 4-Montana. About 8 stations

At each monitoring station, stream flow was measured with a current meter, parshall flume, or pipe-bucket-stopwatch; and field parameters including pH, dissolved oxygen, specific conductance, and temperature were measured with field instruments. During low-flow, samples were collected for dissolved analyses of major anions, major cations, trace element and for total-recoverable analyses of major cations and trace elements.

RESULTS

Most pre- and post-reclamation field parameters values were similar. High Ore Creek field parameters were monitored continuously with a data sonde. The most significant and important change in field parameters was pH. Prior to reclamation, pH in High Ore Creek was about 7.7 and varied by a few tenths of a pH unit due to diurnal fluctuations caused by photosynthesis and respiration of aquatic organisms. Post reclamation monitoring indicates that pH is now about 8.7 and also varies diurnally. Typically, pH is highest in late afternoon, and lowest in early morning. Dissolved oxygen fluctuates diurnally, but is at or near saturation---about

9.5 mg/L---during daylight hours. Temperature can vary significantly in a 24-hour period; during July and August, early morning water temperature is about 10EC, and late afternoon temperature is about 20EC. Pre-reclamation and post-reclamation specific conductance values of High Ore Creek were about 360 mS/cm.

Low-Flow Sampling. Table 3 compares pre-and post-reclamation concentrations of selected trace element constituents at monitoring station WQ3, just upstream from the mouth of High Ore Creek. With the exception of arsenic, post reclamation concentrations of most trace elements were below pre-reclamation concentrations; the post-reclamation concentration of arsenic was higher than the pre-reclamation levels.

Table 3. Pre- and post-reclamation dissolved concentrations of selected trace elements at WQ3, near the mouth of High Ore Creek.

	Date	Fe (mg/L)	Mn (mg/L)	Ag (ug/L)	As (ug/L)	Cd (ug/L)	Cu (ug/L)	Pb (ug/L)	Zn (ug/L)
Pre	9/28/1993	0.107	0.814	<1	18.9	5.6	5.1	<2	1970
Post	10/17/2000	<0.024	0.199	<1	21.5	<2	2.51	<2	807

Figures 5a through 5e compare pre- and post-reclamation loading rates for dissolved cadmium, iron, manganese, and zinc collected in October 2000, and in September 1993 at monitoring stations along High Ore Creek. Loading was calculated by multiplying flow rates by concentrations, and is reported in units of g/day (Tupling, 2001).

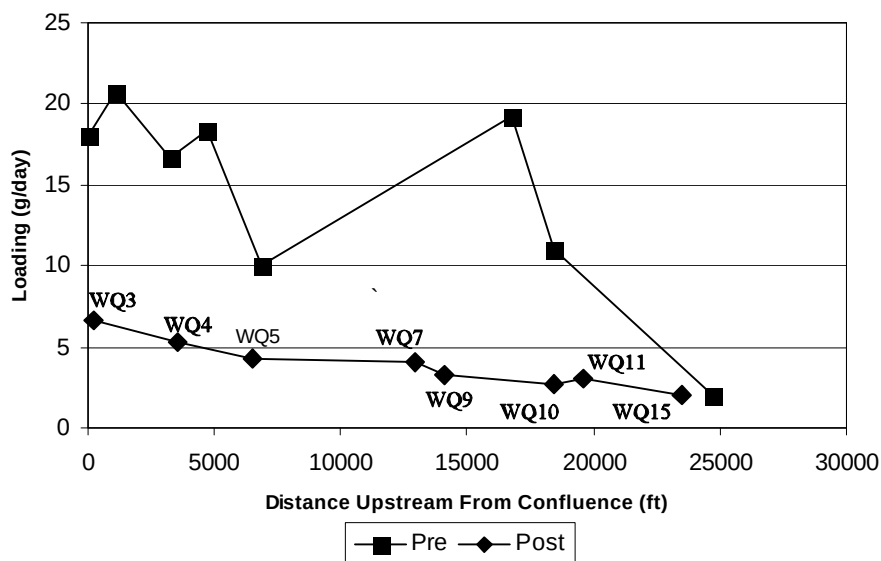


Figure 5a - Cadmium

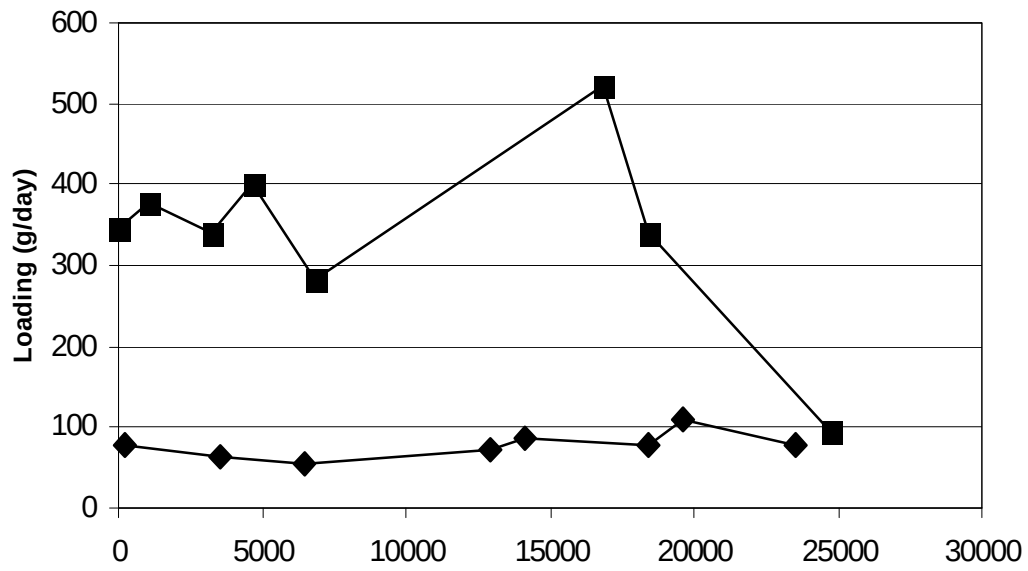


Figure 5b - Iron

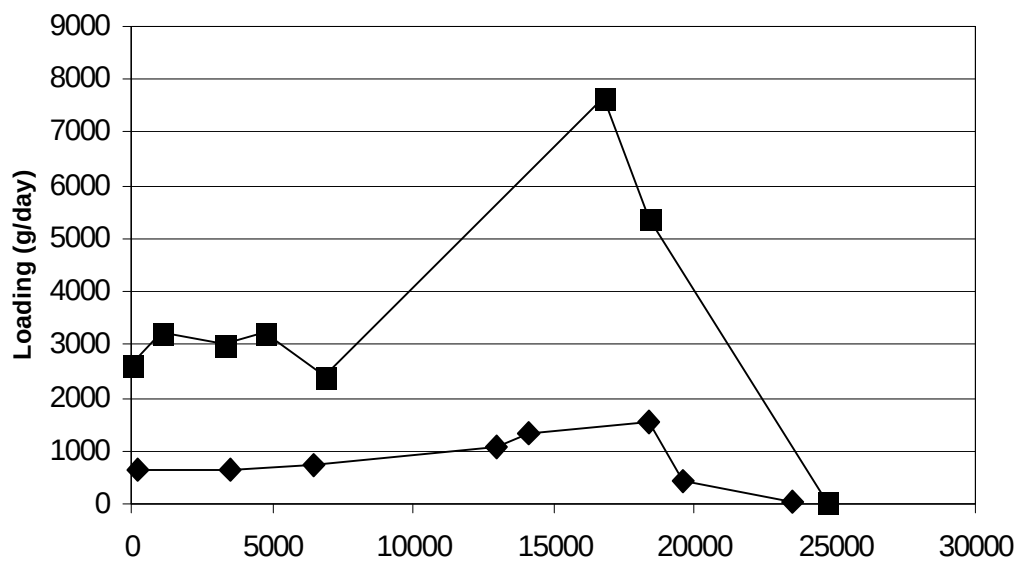


Figure 5c - Manganese

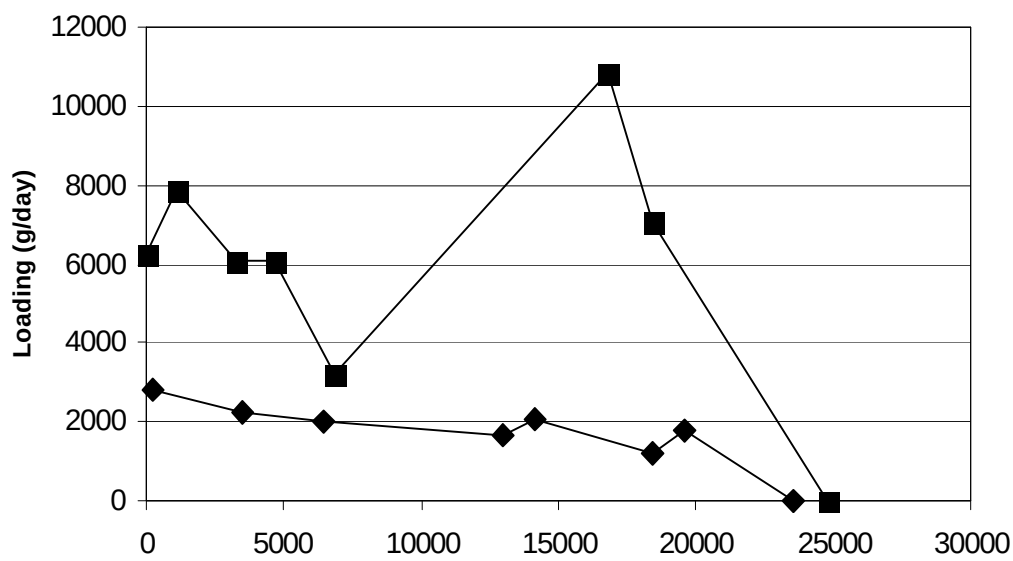


Figure 5d - Zinc

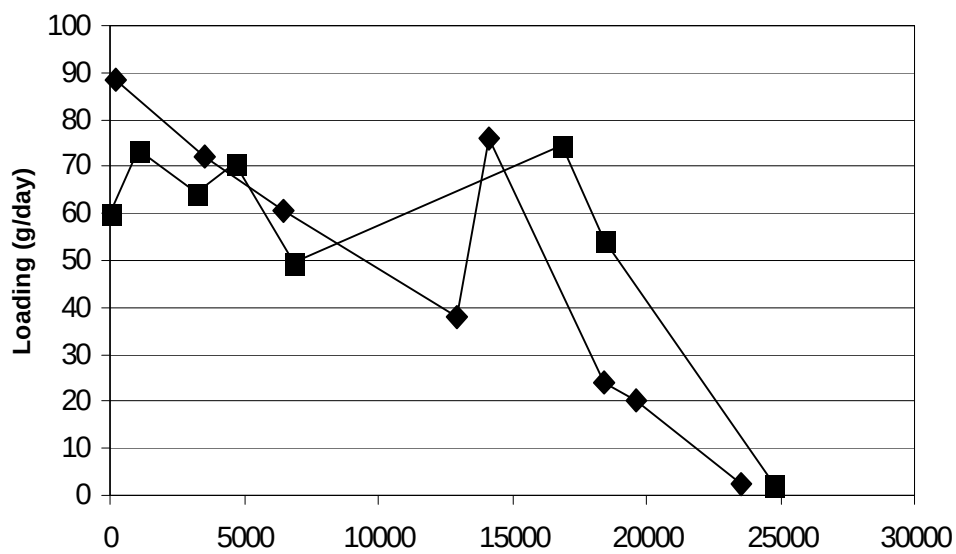


Figure 5e - Arsenic

Figure 5a-e. Post reclamation loading at the mouth of High Ore Creek (WQ3) has decreased significantly for cadmium, iron, manganese, and zinc. Post reclamation loading of arsenic has increased slightly.

Data presented in Figures 5a through 5d clearly show that dissolved loading for cadmium, iron, manganese, and zinc have significantly decreased. During low flow, dissolved and total recoverable concentrations were essentially the same. At the mouth of High Ore Creek, the loadings from these constituents were approximately one third of the pre-reclamation values. In addition, removal of large quantities of mine waste from the flood plain has resulted in flatter loading profiles.

Figure 5e shows that post reclamation arsenic loading has increased between 1993 and 2000. Removing the stream side tailing along the flood plain of High Ore Creek undoubtedly decreased the acid generation and acid contribution to High Ore Creek, which may explain why the post-reclamation pH is almost a log unit greater than pre-reclamation pH. Increased pH in High Ore Creek would tend to increase instream arsenate mobility. Because phosphate is more selective than arsenate for exchange sites, phosphate in the fertilizer may have replaced arsenate on adsorption sites, thus mobilizing arsenate (Darland and InsKeep, 1997).

Diurnal Cycling of Trace Elements. Pre-reclamation water samples for dissolved analyses of major cation, major anions, and trace elements were collected at station WQ4 at two-hour intervals from 12:25pm on the 26th August 1997 to 12:00pm on the 27th August 1997. Post reclamation water samples for dissolved analyses of major cations, major anions, and trace elements were collected at station WQ4 at two-hour intervals from 11:30am on the 24th July 2000 to 11:45am on the 25th July 2002. During both diurnal sampling events, trace elements that showed diurnal variations in concentration include Cd, Cu, Fe, Mn, Pb, Ti and Zn.

During the 2000 diurnal sampling event the changes in concentrations of the following trace elements were noted: Cd (max 2.8 Fg/L, min 2.1 Fg/L), Cu (max 2.9 Fg/L, min 2.0 Fg/L), Fe (max 216 Fg/L, min 88 Fg/L) Mn (max 113 Fg/L, min 60 Fg/L) Pb (max 7.5 Fg/L, min 2.9 Fg/L), Ti (max 8.3 Fg/L, min 2.8 Fg/L) and Zn (max 618 Fg/L, min 332 Fg/L). Maximum concentrations, for elements exhibiting diurnal cycling, occurred around the mid morning hours (06:00-10:00) with minimum concentrations occurring during the early evening hours (14:00-18:00).

Prior to reclamation, the concentration of zinc at station WQ4 would vary by as much as a factor of 5; maximum concentration of Zn during the diurnal sampling event in 1997 was 2570 Fg/L, and minimum concentration was 509 Fg/L. Figure 6 shows pre- and post-reclamation diurnal cycling of zinc in High Ore Creek.

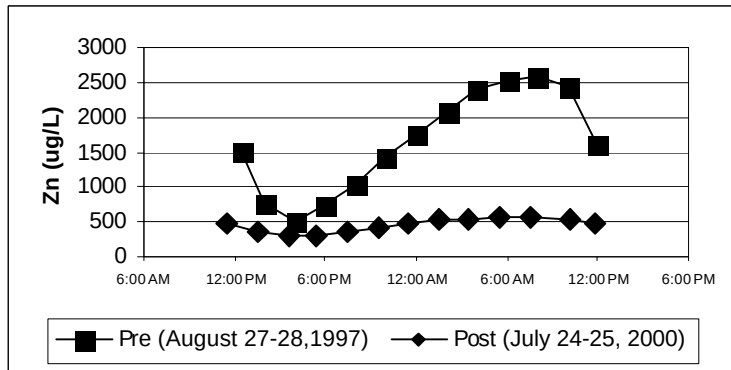


Figure 6. Dissolved zinc concentration in High Ore Creek fluctuates diurnally, but the fluctuations were more pronounced prior to reclamation with the concentrations varying by as much as a factor of five within a 24-hour period. Post-reclamation zinc concentrations fluctuate by a factor of about 1.5 within a 24-hour period; post reclamation zinc concentration is significantly lower than pre-reclamation values. Data from monitoring station WQ4.

SUMMARY

The areas targeted for reclamation at the Comet Mine and Millsite have been reclaimed and the hazards associated with the site have been mitigated. Total costs to reclaim the Comet Mine and Millsite were \$3,401,669. Of these expenses, \$2,897,429 was for construction, while \$504,240.45 was for engineering activities. The total construction contract, excluding engineering activities, for the High Ore Creek stream side tailings reclamation was \$1,520,837.

The necessity to completely remove all tailings rather than partial removal of tailings can not be adequately assessed until post reclamation monitoring results have been assessed as a part of the water quality monitoring program for this watershed. Pre and post reclamation changes in vegetation (Figures 7-8) and preliminary water quality results indicate reclamation of the Comet Mine and High Ore Creek watershed has been successful. Water quality and re-establishment of vegetation will be closely monitored for the next 3-5 years to determine the success of this reclamation project.



Figure 7-Pre-reclamation, 1997.



Figure 8- Post-reclamation 2000.

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**TECHNICAL PAPER SESSION 14
POLITICS**

Title: **[The EPA Rocky Mountain Regional Hazardous Substance Research Center \(RMRHSRC\)](#)**

Authors: **[Thomas Wildeman](#)***, Professor of Chemistry and Geochemistry and **D. L. Macalady**, Department of Chemistry and Geochemistry, Colorado School of Mines; **C. D. Shackelford** and **S. L. Woods**, Department of Civil Engineering, Colorado State University

Title: **[Recent Court Rulings on Takings and the Possible Impact on the AML Program](#)**

Author: **[Vaughn P. Girol](#)***, Realty Specialist, Office of Surface Mining Reclamation and Enforcement, Appalachian Regional Coordinating Center

Title: **The Politics of a Mega-Project: Institutional Resistance to Innovative Ideas**

Author: **[Andrew S. Voros](#)***, Executive Director, NY/NJ Clean Ocean And Shore Trust

THE EPA ROCKY MOUNTAIN REGIONAL HAZARDOUS SUBSTANCE RESEARCH CENTER

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ABSTRACT

The Rocky Mountain Regional Hazardous Substance Research Center (RMRHSRC) for remediation of mine waste sites has recently been formed. The RMRHSRC is funded by the U. S. Environmental Protection Agency (EPA), represents EPA Region 8 states, and consists of a consortium of participants from Colorado State University, Colorado School of Mines, and several academic and non-academic participants from other regions of the U. S and Canada. The research goal of the RMRHSRC is to develop new and improve existing methods or technologies for remediation of mine waste sites that are cost effective and lead to clean ups that are protective of human health and the environment. Also, the activities of the RMRHSRC include training, technology transfer and outreach programs that will focus on the development of new technologies. A number of issues were considered in establishing an action plan and in choosing the research projects to fund. Some of these issues, such as cost, apply to every possible method of treatment. Others such as whether to concentrate on abandoned or active operations are somewhat mutually exclusive. The issues that were considered, the conclusions that were made, and how these conclusions affected the decision of which research projects to fund is the subject of this paper.

INTRODUCTION

The Hazardous Substance Research Center (HSRC) Program of the US EPA was established in 1989 and is the longest-running competitive research program within the agency. Five centers are funded for five year periods, and these centers are geographically distributed throughout the ten regions of the EPA. In the recent renewal competition, the EPA directed that there be one center in Region VIII that focuses on the treatment of mining wastes. This paper describes the establishment of this Rocky Mountain Region Hazardous Substance Research Center (RMRHSRC) and the initial direction of its research and outreach activities.

Six states comprise the U. S. Environmental Protection Agency (EPA) Region 8: Colorado, Montana, North Dakota, South Dakota, Utah, and Wyoming. Mining has played a critical role in the socio-economic history of all of these states, and all of these states have environmental problems associated with historic or current mining operations. Of particular concern in this regard is the threat to the environment resulting from inactive or abandoned mine lands (AMLs). In the Region 8 states, 26 of the 45 active National Priority List sites are associated with AMLs.

In general, these AMLs represent hardrock and non-coal mines located on private, state, and federal lands that were actively mined over the past century and a half, but subsequently

abandoned prior to the promulgation of the modern environmental regulations (e.g., Clean Water Act, RCRA, CERCLA) enacted since the 1970s.

In response to this concern, the RMRHSRC for remediation of mine waste sites recently has been established at Colorado State University (CSU), and consists of a consortium of participants from CSU, the Colorado School of Mines (CSM), and several academic and non-academic participants from other regions of the U. S and Canada. The Center is funded by the EPA in the amount of \$4 million for an initial period of 5 years, with an additional \$1 million in funding contributed by CSU and CSM.

CENTER ORGANIZATION

The organizational structure for the RMRHRC is illustrated in Figure 1. The Center consists of two main activities related to research and outreach programs that pertain to remediation of mine waste sites, and a third activity related to quality assurance/quality control (QA/QC) for these programs. The research activities are separated almost equally between the two main participating universities (i.e., CSU and CSM), and the outreach activities include three main components, that is technical transfer, technical outreach to communities, and technical outreach to communities with brownfield activities. The research activities are overseen by a Science Advisory Committee (SAC), and the outreach activities are overseen by a Training and Technology Advisory Committee (TTAC).

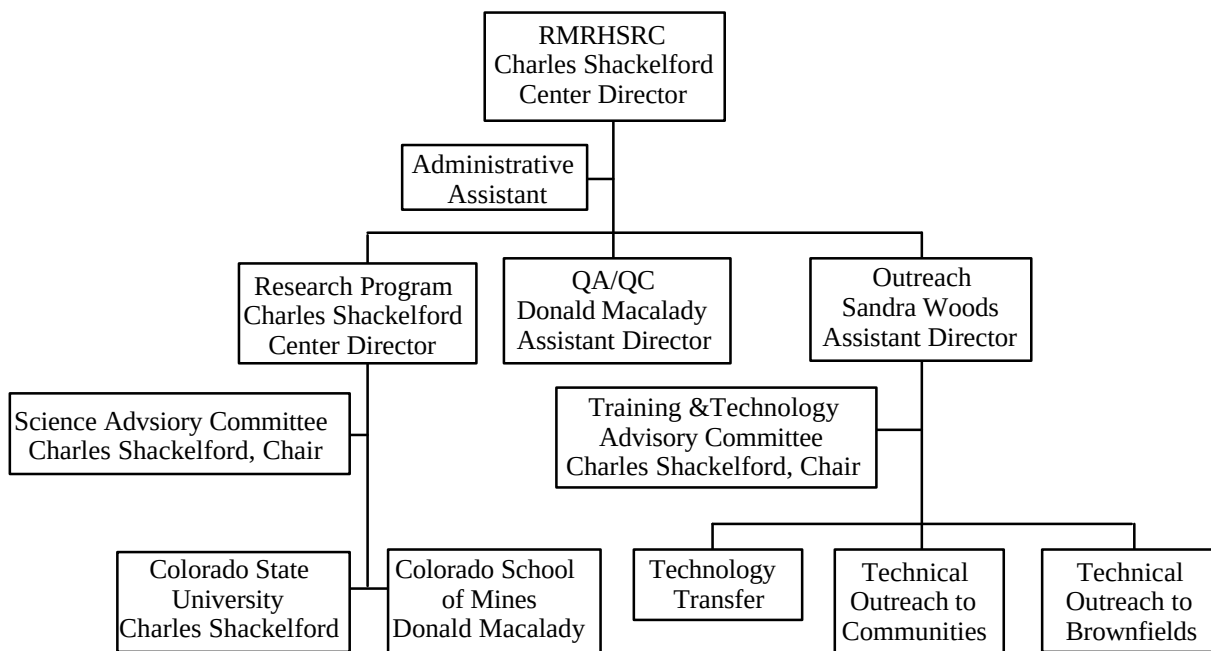


Figure 1. Organizational structure for the Rocky Mountain Regional Hazardous Substance Research Center (RMRHSRC) for remediation of mine waste sites.

The membership of the SAC consists of 6-9 technical peers drawn from the public and private sectors and academia. At least one-third of the SAC membership must consist of appropriate personnel from EPA's Regional Offices and Laboratories, and at least another one-third of the membership must be drawn from the academic community. The remaining members

may come from industry or other Federal, State, or local governmental units. Appointments to this committee are subject to approval by the EPA project officer. Duties include reviewing the RMRHSRC's research plan, annual development of a list of relevant research topics, preparing recommendations regarding the relevance and technical merit of project proposals, and reviewing ongoing projects. Meetings are held twice a year. Members must be chosen from outside the institutions comprising the HSRC.

Membership of the TTAC includes representatives from relevant EPA Regional Offices, EPA's Office of Emergency Response, academia, and states or localities. Others may be added by the Center Director with approval by the EPA project officer. Duties include annual meetings to recommend outreach activity plans for the next year, review progress, and recommend changes to current year programs.

ENVIRONMENTAL ISSUES AFFECTING MINING

Because of the proposal competition and subsequent award of funding from the EPA for a major research Center, we have had to assess those issues that concern mining and the environment and decide which ones will control the initial research and outreach activities of the Center. Certainly, our decisions on which areas of mining and the environment deserve our concentrated efforts can be modified or changed. However, at this time it is necessary to make decisions so that our projects have an appropriate focus. In the case of the outreach and community service efforts of the Center, all hazardous substances will be addressed. However, the EPA specifically requested that this Center, located in Region 8 of the 10 national EPA regions, concentrate on the environmental problems related to mining wastes. We have decided which issues are important and how they impact on the goals and operation of the RMRHSRC.

The Issues Affecting the Center

Cost is a dominant issue particularly because of the physical size of some mining wastes. Because many of the sites that have been impacted by organic wastes are U. S. Department of Defense and Department of Energy sites, development of innovative and low cost methods of treatment at these sites has been supported by significant Federal funding initiatives. However, the Federal government is not involved in any of the priority pollutant mining sites found in Colorado, Utah, Montana, Wyoming, South Dakota, and North Dakota, the states that make up Region 8. So, state and local governments are going to be required to some extent to initiate treatment efforts, and these entities demand a low-cost solution. Also, the record so far shows that high costs paralyze most current attempts at remediation. Consequently, cost limits both the scientific questions that can be answered with respect to a given problem as well as the level of technology that can be implemented to solve the problem. In other words, cost drives feasibility.

Although this is a regional center, treatment of environmental problems related to mining is obviously a global issue. Also, some academic, governmental, and private agencies beyond this region and nation have a great track record on working on the treatment of mining wastes. The MEND Program of Canada and the Acid Drainage Technology Institute of the University of West Virginia are two examples. Also, political restrictions, such as the Good Samaritan problem within Colorado, sometimes create hurdles that must be overcome when attempting pilot-scale and full-scale treatment projects within the region. Consequently, in preparing our proposal and now in carrying out the objectives of the RMRHSRC, our approach has to be

beyond Region VIII. At least two of the four research projects have investigators outside of the region and the University of Waterloo in Canada is a participant. The EPA dictates that outreach activities be coordinated across the EPA Regions. However, for the technology transfer and outreach of this Center to be successful, the Center also must conduct research with other entities outside of Colorado and Region 8 that have already been concentrating on the treatment of mining wastes.

In the case of mining wastes, social and political issues will eventually drive most treatment efforts. However, this Center will concentrate research on the scientific and engineering aspects of the problem. The objective will be to make the answers to all the scientific and engineering questions to be clear and complete enough that the social and political questions can be played out on a well-defined scientific and engineering field.

With respect to concentrating on active versus abandoned mining operations, the plan will be to start studies on abandoned operations and then work with the mining industry to transfer solutions developed through the research activities to active operations. Since the Summitville disaster of December 1992, the permitting procedures for all states appear to be so extensive that all contingencies are taken into consideration. In particular, a complete closure plan has to be included in any new mining permit, and companies understand that their liability extends through the closure of the operation. Currently, opening and operating a mine depends on environmental regulations that are based on reasonably good science and engineering. Thus, the Center will begin operations concentrating on AMLs. There are some issues related to current operations that certainly deserve study, such as whether the models used to predict pit water chemistry are accurate, and how to bring a continuing operation that was started in the 1970's or 80's into compliance with the current regulations that relate to new operations. However, AMLs comprise the majority of the problems in Region 8 and appear to be a more fruitful area for the application of science and engineering for developing inexpensive and innovative treatment strategies. Also, bringing a current operation into compliance with more modern regulations means that treatment is done after contamination has occurred. Consequently, this can be considered to be similar to the treatment of an abandoned operation.

When considering whether the most important problem is contamination of the air, water, or earth, the water and the earth command the most attention. The question of what to do with abandoned tailings and waste rock piles represents the largest physical problem in any of the national priority pollutant sites that are on the EPA list. The problem of acid mine drainage (AMD) contaminates more miles of surface streams than any other type of contamination by hazardous substances. Consequently, these materials will command the research attention of the RMRHSRC.

Research Activities

Applying the focus issues to research activities uncovers the following problems concerning the remediation of AMLs: (1) an inadequate ability to rapidly and cost effectively characterize the extent and impacts of the effects of contamination resulting from mining activities; (2) an inadequate ability to accurately characterize the fate and transport of metals and other toxic chemicals from mining sites; (3) a paucity of cost-effective technologies that can clean up mine waste sites; and (4) a need to develop less costly and more rational clean-up strategies. Based on these problems, the goal of RMRHSRC research activities will be to extend our knowledge of the geochemical, biological, hydrological/ mineralogical and engineering

aspects of environmental questions associated with mining and mine wastes and, based on this knowledge, develop new or improved methods or technologies that are cost effective and lead to clean ups that protect human health and the environment. The specific research objectives that will be addressed to accomplish the goal of the Center are:

(1) to more rapidly and effectively characterize the extent and impacts of the effects of contamination resulting from mining activities;

(2) to more accurately characterize the fate and transport of metals and other toxic chemicals from mining activities;

(3) to develop cost-effective treatment processes and associated technologies that can effectively clean up mine waste sites; and

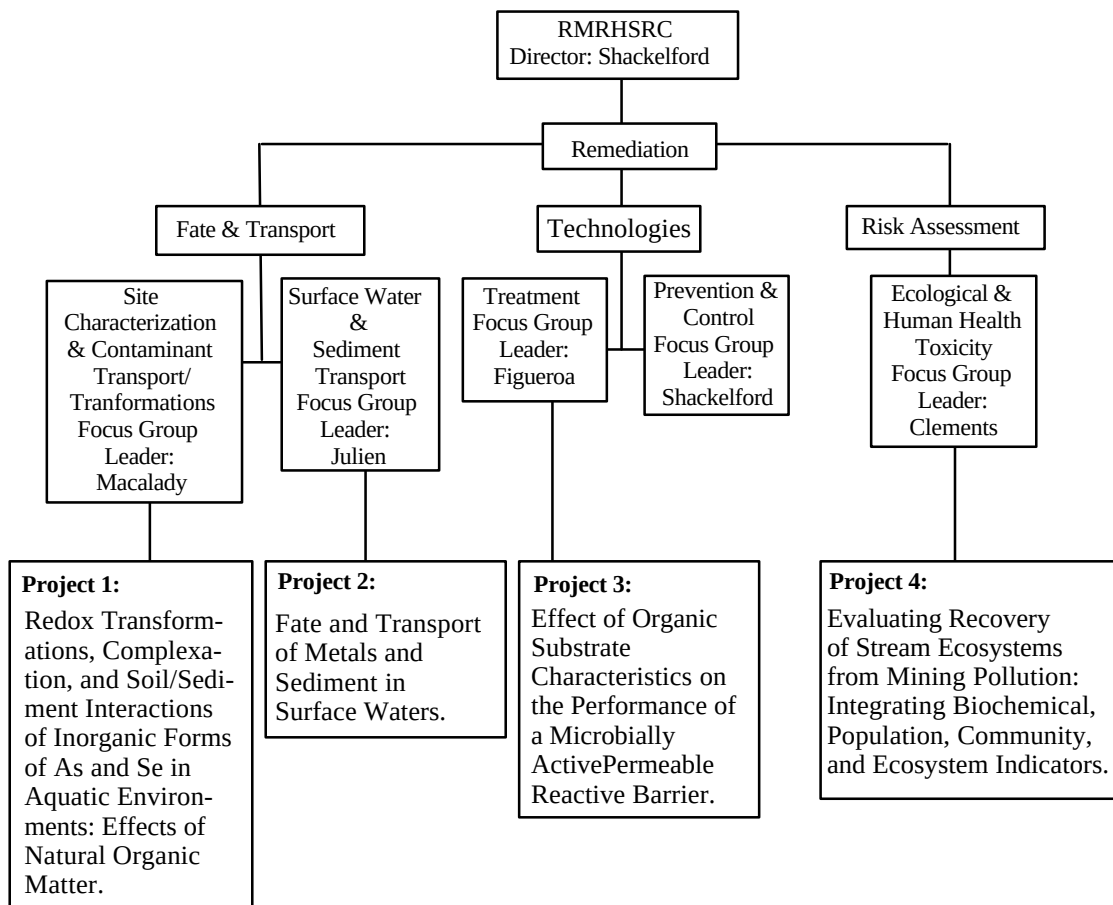
(4) to improve our ability to evaluate risk assessments for developing rational clean-up strategies.

To achieve these objectives, Center research will address three main areas of activity with respect to the remediation of mine waste sites: (1) fate and transport; (2) treatment and technologies; and (3) risk assessment. Each of these research activities represents an essential component of the remediation process. For example, fate-and-transport analyses using an appropriate modeling approach typically are required as an integral part of a risk assessment in order to estimate exposure-point concentrations of a given contaminant. Based on these concentrations, a toxicity and risk assessment is performed to determine the cleanup goals that ultimately affect the technology that is implemented for the remediation. Within each of these three research activity areas, both basic and applied research will be included. Mathematical and physical models will be used to better understand the processes being studied and to help extend the results of the basic research to field demonstrations.

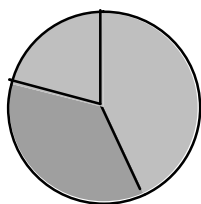
Research focus areas and approach

In order to address the three main areas of research activity, the Center research program is divided into five research focus areas, each with a focus group leader, as shown in Figure 2. The focus areas include: (1) site characterization and contaminant transport/transformation; (2) surface water and sediment transport; (3) treatment processes; (4) technologies; and (5) ecological and human health toxicity. The types of contaminant problems and the specific processes to address these problems are identified within this structure. Mathematical and physical modeling will be key components of each of the focus areas. In addition to the research focus areas of the Center, the first-year research projects of the Center also are identified in Figure 2.

To meet the goals of the Center, a multidisciplinary group of researchers has been assembled, as shown in Table 1. These people have a history of working on complex environmental processes, and taking these processes from the "laboratory to the field". Also shown in Table 1 are the principal investigators (PIs) and Co-PIs for the first year projects. A broad range of multidisciplinary expertise and experience is represented in this group and in their research proposals. A particular strength of this research group is the excellent distribution of Center investigators among the three categories, with 12 investigators from CSU, 11 investigators from CSM, and 11 participating investigators from other states within Region 8 and other EPA Regions, and Canada. Also, two of the first year projects (Projects 3 and 4) have investigators from both partnering universities (CSU & CSM) as PIs/Co-PIs.



**Percent of Research Budget
(1st Yr, Total Costs) within
Research Activity Area**



**Percent of Research Budget
(1st Yr, Total Costs) within
Research Focus Area**

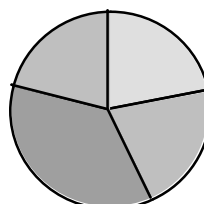


Figure 2. Research focus areas of the Rocky Mountain Regional Hazardous Substance Research Center (RMRHSRC), and first-year research projects.

Table 1. Investigators and participants of the Rocky Mountain Regional Hazardous Substance Research Center.

Investigator/Participant	Discipline and/or Expertise Areas
Colorado State University:	
Rajiv Bhadra	Chemical & Bioresource Engineering
Brian Bledsoe (Co-PI)	Sediment transport
Kenneth Carlson (Co-PI)	Environmental Engineering
William Clements (PI)	Fish and Wildlife Biology
Nancy DuTeau (Co-PI)	Microbiology
Pierre Julien (PI)	Sediment transport
Kenneth Reardon (Co-PI)	Chemical & Bioresource Engineering
Elizabeth Pilon-Smits	Biology
Charles Shackelford (Co-PI)	Geoenvironmental Engineering
Chester Watson (Co-PI)	Sediment transport
Sandra Woods (Co-PI)	Environmental Engineering, outreach
Ray Yang	Environmental Health Sciences
Colorado School of Mines:	
Dianne Ahmann (Co-PI)	Environmental microbiology, arsenic geochemistry
Ronald Cohen	Treatment of oxyanions in AMD
Linda Figueroa (PI)	Environmental engineering microbiology
Bruce Honeyman	Environmental geochemistry, surface interactions
Tissa Illagansekare	Meso-scale environmental testing, remediation
Junko Munkata Marr	Environmental microbiological engineering
Donald Macalady (PI)	Aquatic chemistry, metal/organic interactions, AMD
Harold Olsen	Geotechnical Engineering
James Ranville (Co-PI)	Particle size effects, AMD, surface chemistry
Robert Siegrist	Environmental Engineering, remediation technology
Thomas Wildeman (Co-PI)	Constructed wetlands for AMD, outreach
Other Investigators/Participants:	
George Aiken (USGS)	Natural organic matter, analytical geochemistry
Katherine Banks (Purdue U.)	Phytoremediation, bioremediation, wastewater treatment
Craig Benson (U. of Wisconsin)	Geoenvironmental Engineering
David Blowes (U. of Waterloo (Co-PI))	Geochemistry, permeable reactive barriers
John Garbarino (USGS) (Co-PI)	Analytical chemistry
Joe Meyer (U. of Wyoming) (Co-PI)	Environmental toxicology, zoology
Danny Reible (Louisiana State U.)	Environmental transport and mechanics, turbulence
Paul Schwab (Purdue U.)	Chemistry of heavy metals in soil
Otto Stein (Montana State U.)	Environmental Engineering (wetlands)
Richard Wanty (USGS)	Environmental geochemistry, AMD remediation
John Westall (Oregon State U. (Co-PI))	Geochemical models, inorganic and redox chemistry

Relation of the Issues to the Research Projects

In the initial year of the Center, four research projects shown in Figure 2 were chosen for funding. How do these research projects relate to the examination of the issues presented above? All the projects concentrate on science and engineering rather than politics and sociology. Also, none of the projects are tied to a particular mining site, so the results could be transferred to any specific project. In the respect that the transfer of the technology can be to any other site, the issue of focusing on abandoned sites is not obvious. However, all of the projects deal with questions that have to be answered at any abandoned site-or also any active mining site. An examination of how other issues are involved in each specific project follows.

The first research project deals with the availability and transformations of arsenic and selenium in natural environments where organic matter is an important component. At first glance, this project seems unrelated to mining problems. However, this is a key area where the science is lacking to make the proper decisions on how treatment should proceed. For the heavy metals such as Cu, Zn, Pb, and Cd, principles of geochemistry and microbiology can be applied to treatment situations with a good degree of certainty. For the most part, the metals remain in one positive oxidation state and the precipitation sequence for carbonates, hydroxides, and sulfides is well known. However, for As and Se there are multiple oxidation states. In some of these oxidation states, removal is quite difficult. Furthermore, both these elements can occur in volatile compounds and their fate and transport in a removal system confuse the issue. So, for these two contaminants, fundamental scientific questions about speciation, transformation, and fate in biogeochemical systems have to be answered. Currently, we are designing treatment systems for arsenic and selenium. However, if pressed, we cannot answer questions about the ultimate fate of arsenic and selenium in these systems. This project hopes to answer those questions.

There are thousands of tailings and waste rock piles throughout the Western United States that are the relics of earlier mining operations. The questions that even the casual observer asks are: How are all those piles going to be treated, does every one of those piles have to be treated, and are there really contaminants moving from those piles into the surface and ground water? At present, the answers to the questions of which piles are contributing the most to the contaminant load in a watershed and which contaminants are coming from which pile are not known. In addition, material may move from the pile only during severe storms, and the material that moves may not dissolve but rather travel to a stream as suspended solids. However, upon reaching and entering the stream, the continuous contact of the material with the water may result in dissolution and thereby contribute to the contaminant load in a watershed. The answers to these questions are also unknown. Project 2 on the fate and transport of metals and sediment in surface water addresses these questions. The objective of the project is to develop and test a model that will provide meaningful estimates of the transport of particulates from a mine waste pile. Estimates for severe storm events will be included. Ultimately, because the cost is so great, treatment of waste piles will only be accomplished when there is a sufficient scientific basis to justify the cost. That basis can only be developed when good models for the fate and transport of contaminants in waste pile are developed.

Over the past decade, passive treatment is one method for the removal of contaminants from AMD that has been extensively investigated. Passive treatment meets the criteria of being an innovative and low-cost solution. Because they require no utilities and do not need constant attention, passive treatment systems are especially attractive for treating contaminants in mine

drainage at abandoned sites. Because the objective in treatment is to fix the problems at the lowest possible cost, the criteria that are used in the design of these systems have never been thoroughly investigated. Because designs are made using incomplete criteria, failure sometimes occurs and the reasons for failure are not understood. However, enough is understood so that the weak points in the design are known. These areas need to be investigated so that passive treatment systems can be made more reliable and efficient. These systems rely on the activity of microbes to produce products such as sulfide and carbonate that form precipitates with the metal contaminants. A key question is just what can be added to the system to increase the activity of the microbes? Another key question is whether some of the contaminants are toxic to the microbes? Also, there is a nagging question of whether the organic material that is used in these systems causes the dissolution of the contaminants through complexation. In Project 3, these and other questions concerning passive bioreactor systems will be answered so that this promising method of water treatment can be made to be more reliable and efficient. Initially, laboratory studies will use batch tests to attempt to answer the question of how much contaminant can be removed. Then column experiments will be conducted to maximize the microbial kinetics. Then hopefully armed with new insights into how to improve passive treatment systems, bench-scale reactors will be tested in the field.

Finally, there are the skeptics on both sides of a mine treatment project. One side says, "How do you know that you really have to carry out this expensive remediation?" This side especially focuses on waste rock piles, and sometimes argues that removal means destruction of part of our mining heritage. The other side says that, if you don't remove all the piles and clean all the sediment from the stream, then achieving a natural ecological condition is impossible. Obviously, a middle ground exists and both parties need a good scientific basis for achieving a common decision on which mine waste piles require priority treatment. Project 4 addresses these issues concerning sediment particles in a stream originating from a mine waste pile. The objective of the study is to decide whether a contaminant in a stream is really toxic to the aquatic ecosystem and then determine under what conditions that toxicity is more or less severe. If these questions can be answered, then using these results along with the fate and transport modeling program developed in Project 2, waste rock piles that should be removed to provide the greatest benefit to watershed restoration can be designated.

OUTREACH PROGRAMS

Technology Transfer

The primary goal of the RMRHSRC Training and Technology Transfer Program is to provide effective training and technology transfer resulting in the progression of ideas from the laboratory to application.

The purpose of the Training and Technology Transfer Program is to support the mission of the Center by: (1) promoting organizational linkages, (2) ensuring outreach to industry, communities, and states, (3) facilitating the use of innovative means of information transfer, (4) supporting investigations at the interface of disciplines, (5) exploiting opportunities in science, engineering, and technology where the complexity of the research needs requires the advantages of scope, scale, duration, equipment, and facilities, and (6) capitalizing on diversity through involvement of under-represented groups. The Center will facilitate the progression of laboratory

research to field applications by supporting activities that result in idea generation, information transfer, laboratory and pilot-scale testing, field demonstrations and applications.

Technical Outreach and Service for Communities (TOSC)

The goal of the TOSC program is to provide educational resources to help citizens gain a better understanding of the environmental problem, allowing them to make informed decisions and participate more fully in activities affecting their communities. This project will meet the following program objectives: (1) creating technical assistance materials tailored to the identified needs of a community, (2) informing community members about existing technical assistance materials, such as publications, videos, and Web sites, (3) providing technical information to help community members become active participants in cleanup and environmental development activities, (4) providing independent and credible technical assistance to communities affected by hazardous substance problems, (5) reviewing and interpreting technical documents and other materials for affected communities, and (6) sponsoring workshops, short courses, and other learning experiences to explain basic science and environmental policy related to hazardous substances.

Technical Assistance to Brownfields (TAB)

Brownfields are defined by the Environmental Protection Agency as "abandoned, idled, or under-used industrial and commercial facilities where expansion or redevelopment is complicated by real or perceived environmental contamination." The TAB Program provides technical assistance to communities and other stakeholders with an ultimate goal of redeveloping brownfields sites. The objectives of this program are the same as for the TOSC program. For TOSC activities, the hazards and contamination are more clearly defined. In TAB activities, the contamination may not be clearly defined, however, there is real concern within the community.

SUMMARY

Hopefully, the above exposition helps to inform how RMRHSRC will go about solving the problems associated with the remediation of mining waste sites. Also, the people associated with the Center have a strong desire for people to understand the issues that were considered in formulating the initial action plan. To the extent that important issues have been overlooked, the intent of this paper is to solicit responses from our clients so that such issues can be addressed and included with the Center activities in the future.

RECENT COURT RULINGS ON TAKINGS AND THE POSSIBLE IMPACT ON THE ABANDONED MINE LAND PROGRAM

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Historically, governments from the local to the federal level have used different forms of zoning and the exercise of the police power in addition to eminent domain to control land use. The key justification has been to prevent public nuisance or noxious uses. Traditional uses of these powers have been zoning to control the location of industrial, commercial, and residential areas and the acquisition of land for public development. Recently there have been prohibitions on development of land in order to prevent or abate environmental degradation and threats to public safety.

In the past 25 years, with the increased use of regulatory control, have come court challenges asserting that such restrictions have violated the takings provisions of the Fifth and Fourteenth Amendments to the Constitution.

The purpose of this discussion is to chronologically review a series of rulings by state supreme courts, federal courts, and the Supreme Court. From this, some observations may be drawn as to possible ways to lessen exposure of the abandoned mine land (AML) program in this environment. There is also a caveat here. Any actions in response to court rulings should be discussed with agency attorneys.

Before proceeding with the recent rulings, note should be taken of the “grandfather” of rulings in this field. In 1922 the Supreme Court ruled on *Pennsylvania Coal Company v. Mahon*, et al. (260 U.S. 393). The court overturned a Pennsylvania law forbidding the removal of support from beneath structures even when the right of support had been deeded away. In what became a seminal ruling Justice Holmes noted that government couldn’t function if every change in law that reduced property value required compensation. However, **“When it reaches a certain magnitude, in most if not all cases there must be an exercise of eminent domain and compensation to sustain the act.”** Otherwise the use of the police power would increase until private property rights disappear. Justice Brandeis in dissent noted that private property rights are not absolute and that contracts between individuals could not bargain away the State’s police power authority.

The first of the recent regulatory rulings by the Supreme Court occurred in 1978 in *Penn Central Transportation Co. v. New York City* (438 U.S. 104). In this ruling delivered by Justice Brennan the court ruled that the New York Landmarks Law did not commit a taking when Penn Central was forbidden from building a tower over Grand Central Station. It noted that the Law didn’t transfer control of the property to the city. It only restricted its use and this didn’t go too far as Justice Holmes had noted in his ruling. The court noted that this hadn’t so frustrated investment-backed expectations as to constitute a taking, didn’t prevent Penn Central from making a reasonable return on the property, and had provisions to mitigate the impact. Justice Rehnquist in dissent noted that the law had been applied to so few private structures that it could not be considered zoning and that valuable rights had been destroyed. He pointed out that the Fifth Amendment bars the “Government from forcing some people alone to bear public burdens which, in all fairness and justice, should be borne by the public as a whole.”

In 1982 in *Loretto v Teleprompter Manhattan CATV Corp.* (458 U.S. 419) the Supreme Court ruled on a physical taking. In this case, contrary to its rulings on regulatory takings, the Court held that any “physical invasion of private property” was a taking.

In 1987 in *Nollan v California Coastal Commission* (483 U.S. 825) the Supreme Court made a significant ruling regarding regulatory restrictions on land use. The commission had tried to require the Nollans to grant an easement across their land as a prerequisite for construction of a house. As Justice Scalia pointed out the demand for an easement wasn’t related to the purpose of the permit process and therefore wasn’t a legitimate use of the regulations. It was also pointed out that the nature of the easement was such that it amounted to a seizure of the land that went beyond acceptable limits for regulation. As such the state would have to use eminent domain and pay for the easement instead of forcing the landowners to contribute to the program without compensation. Of particular interest to the AML program is the notation that the Nollans’ interest was not diminished by the fact that they acquired the land well after the beginning of the government policy. Since prior owners couldn’t be deprived of the easement without compensation, the interest must have been transferred to the Nollans with the deed.

1992 brought a very significant ruling on the ability of government to deny the use of land through regulation. In *Lucas v South Carolina Coastal Commission* (505 U.S. 1003) the Supreme Court ruled that regulations that deny all “economically viable use” of land are a form of taking that requires compensation. The ruling delivered by Justice Scalia further noted that use of the justification that an action confers benefits, expanding the concept of prevention of harmful use, cannot expand the exception to the compensation requirement. The Court noted that the only exception in this case would be if background principles of property law and nuisance that inhere in the land title itself allowed a total prohibition on development.

The United States Court of Appeals in 1995 issued a ruling that supported the regulatory powers of the Surface Mining Control and Reclamation Act (SMCRA). In the case *M & J Coal and Monogah Development Company v The United States* (47 F.3d 1148) the court found that all land is held under the restrictions against harmful or nuisance uses. Thus the regulatory exercise of police power to prevent such use, in this case mining that causes subsidence damage, is not prohibited by the Fifth and Fourteenth Amendments.

In a somewhat peripheral ruling the Supreme Court in 1998 ruled in *Eastern Enterprises v Kenneth S. Appel, Commissioner of Social Security, et al.* (524 U.S. 498) that Congress had committed a taking under the Fifth Amendment. The Court ruled that making a company retroactively pay benefits years after it left coal mining was a taking since it overturned the legal contracts on benefits negotiated while the company was in the industry.

2001 saw two rulings on regulatory takings cases. The first was *Anthony Palazzolo v Rhode Island et al.* (533 U.S. 606). This dealt with several contentious issues; the “ripeness” standard for court appeals, the right of a post-act landowner to appeal a regulation, and the question of when a regulation commits a taking.

Ripeness is the concept that the Court will not decide issues until it is necessary. From a practical standpoint this is usually interpreted to mean that an appellant has not exhausted all attempts to obtain a permit from a regulatory agency. In the Palazzolo case Justice Kennedy, speaking for the Court, ruled that, given the nature of the regulation and the rulings on previous permit requests, the landowner had made a reasonable effort and the case could be considered “ripe.” There was no need to submit an endless string of applications.

The Court also ruled that the landowner was not barred from making a takings claim by the fact that he acquired title after the act was passed. Justice Kennedy pointed out this would change the basic nature of property rights since government could put a limit on the Takings Clause in this manner and prejudice both the owners of property at the time regulation was enacted and subsequent owners since a property right would have disappeared from the ownership “bundle” they acquired. Thus transfer of title could not convert an unconstitutional taking into a “background principle” of state law.

Finally the Court ruled that, given testimony in the case the taking had not been categorical, that is a total taking. The case was thus remanded to the lower court to determine if a taking great enough for compensation had occurred under previous court rulings.

Hard on the heels of the Palazzolo ruling came the ruling of the Federal Circuit Court of Appeals in *Rith Energy, Inc. v United States* (247 F.3d 1355). In this case the court referred to the Palazzolo ruling in forming an opinion on investment backed expectations and post-act acquisition of land. It noted that a categorical taking had not occurred and that diminution of value alone did not constitute a taking. The ruling pointed out that the appellant was operating in a highly regulated industry and thus could expect unfavorable rulings. This affected the expectations for profit. It further pointed out Rith had performed a significant amount of mining, indeed turning a profit on the investment, which eliminated any claim of a taking. Subsequently the Supreme Court refused to review the case.

In the spring of 2002 the Supreme Court evaluated the concept of a taking through regulatory delay in *Tahoe-Sierra Preservation Council, Inc., et al., v Tahoe Regional Planning Agency et al.* (535 U.S.). Justice Stevens writing for the court ruled that a temporary moratorium on land use during a regulatory process did not constitute a taking. It was pointed out that reasonable delays could be expected in a regulated environment and that fluctuations in value such as those caused by such a delay were to be expected as part of ownership. Further it was pointed out that land must be taken as a whole in considering a taking, and can no more be divided into a series of limited temporal parcels than a group of individual tracts of limited area or volume.

In 2002 the Supreme Court of Pennsylvania made another significant ruling on a regulatory takings case. In a ruling on a question of a taking in *Marchipongo Land and Coal et al. v Commonwealth of Pennsylvania et al.* (J-172-2001) the court dealt with a lands unsuitable ruling. Referring repeatedly to the recent Supreme Court rulings, the court reversed the lower court ruling that a taking had occurred. Noting that the taking was not categorical in that testimony had shown some tracts had other revenue streams, it remanded the case for evaluation of the individual tracts involved under both categorical and “Penn Central” standards as appropriate. It also required the lower court to consider whether the proposed land use would be a nuisance and therefore exempt from takings under state police power authority. Finally it noted for one parcel that a taking cannot occur when the property has no value.

Finally, in somewhat of a side note, a wire service news article on May 25, 2002 reported that Broward County, Florida Circuit Judge Leonard Fleet ruled that a state law allowing judges to issue countywide warrants to cut citrus trees was a violation of the Fourth Amendment not the Fifth.

An examination of the rulings would seem to generate a mixed bag for the future of the act. The power to enforce regulatory control over mining and declare lands unsuitable has been upheld with significant potential restrictions. Several rulings have clearly stated that a change in

law cannot remove pre-existing rights in land. Thus the implication is that if a landowner had mineral rights which had a value based on economic expectations, someone acquiring the land after 1977 retains those rights. The only indicated exception is nuisance law. Furthermore, the rulings indicate that the Court may strictly limit attempts to expand the nuisance concept to include actions for “public benefit.” Thus, rulings based on scenic value and watershed value may be impacted.

Abandoned mine reclamation projects where written consent has been obtained would seem to be less impacted but still require caution. Careful coordination between realty and project personnel from the start of project planning, with an eye toward any physical “taking” of property value, is necessary. The new environment suggests less use of standard forms and more use of site-specific forms that detail proposed changes in the land. In this way the landowner will have approved any change in land in exchange for the abatement work. This would probably help alleviate any claim of a “taking.” This will put additional demands on project personnel to be aware of the economic impact of reclamation plans. When the proposed work will reduce the value of property, for example when landslide reclamation requires the grading and removal of a level home site, the project manager will need to discuss this with realty staff. The main question will be whether a site-specific form will be needed. In addition changes in the scope of work during abatement will have to be evaluated. The change may require an additional site specific right of entry form in place of an earlier standard form, or the modification of an earlier site-specific form.

The situation may even require some value friendly engineering. It may be necessary to discuss the work with the landowner and realty staff and modify the plans as a result of the discussion. The source of material to be borrowed may be changed to avoid removing a level home site. A drainage ditch may be changed to a buried pipe to reduce the impact on property value. Drainage channels may be rerouted to follow property boundaries where possible rather than cutting across the middle of a parcel of land. These are examples of modifications that with a little ingenuity can lessen the impact of work and reduce the potential problems in the current legal environment.

As opposed to issues involving voluntary consent to enter property, the ability to exercise the police power authority in emergency and high priority programs would seem to be indirectly endorsed to allow the control of nuisance or noxious situations, or to prevent harm to the public. One possible concern might be in cases where a physical taking occurs. In this case any taking may be considered subject to compensation as an act of eminent domain. A question for the staff attorneys might be, “What happens if we remove or greatly decrease the level land, i.e. the home site on a property?” Is this a physical taking that requires compensation no matter how small? The act of physically entering property, even for a limited time, may be considered a taking and permanent removal of value may also be called a taking. As such the court may rule that this cannot be offset by the value of the construction work. The first precaution to be taken in such situations is to immediately have an appraisal performed. Thus, should a police power be challenged, there will at least be a pre-existing value of the property on record, as well as an after value.

**TECHNICAL PAPER SESSION 15
ACID MINE DRAINAGE - PART 3**

Title: [**Integrating Hydrologic and Geologic Controls on Metal Loading to Streams: Mass-loading Analysis of Mineral Creek, Colorado**](#)

Authors: [**Briant A. Kimball**](#)*, Research Hydrologist, U.S. Geological Survey, West Valley City; **Robert L. Runkel** and **Katherine Walton-Day**, U.S. Geological Survey, Denver; and **Dana J. Bove**, U.S. Geological Survey, Denver

Title: [**Sulfate Reducing Bioreactor Design and Operating Issues: Is This The Passive Treatment Technology For Your Mine Drainage?**](#)

Author: [**James J. Gusek**](#)*, P.E., Sr. Project Manager, Knight Piesold and Co.

Title: [**Longevity of Mine Discharges From Above-Drainage Underground Mines**](#)

Authors: [**Jeff Skousen**](#)*, Professor of Soils, West Virginia University; **Jennifer Demchak**; and **Louis McDonald**

INTEGRATING HYDROLOGIC AND GEOLOGIC CONTROLS ON METAL LOADING TO STREAMS: MASS-LOADING ANALYSIS OF MINERAL CREEK, COLORADO.

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ABSTRACT

Stakeholders, including land-management agencies, often are faced with choosing cost-effective remediation of abandoned and inactive mines located in environmentally sensitive mountain watersheds. Remediation decisions require knowledge of the most significant sources of metals to streams and important instream processes that affect instream metal concentrations. The significance of a given source not only depends upon the concentrations of a toxic metal, but also on the total mass, or load of metal added to the stream. To determine loads, a tracer-injection to measure discharge is combined with a detailed spatial sampling of the stream and inflows to produce a mass-loading profile. A mass-loading profile meets many of the information requirements for making decisions. It allows comparison of sources, indicates where ground-water sources occur, and indicates the extent of instream physical and chemical processes. This approach is illustrated with an analysis of zinc and aluminum loading in Mineral Creek, Colorado. Along the 15-kilometer study reach, 93 kilograms per day of zinc were added to Mineral Creek. Less than half of this load came from well-defined areas that included both mined and non-mined parts of the watershed. More than half of the load came from many dispersed, subsurface inflows, which contribute a substantial load that could limit the effectiveness of remediation. The load profile of aluminum indicated dynamic transformations between dissolved and colloidal phases. Mass-loading analysis quantified the extent of physical mixing and chemical reaction in two important mixing zones, indicating which process was dominant under given conditions during transport. The mass-loading approach provides a tool for detailed watershed evaluation of metal loading and instream processes to support remediation decisions.

INTRODUCTION

Mass-loading studies have been used to provide a watershed context for the quantification of constituent loads in many hydrologic settings (Broshears and others, 1993; Cleasby and others, 2000; Kimball and others, 1994; Kimball and others, 1999a; Kimball and others, 2001; Kimball and others, 2002). These studies also provide stream-reach scale quantification of ground-water inflows and instream chemical processes (Kimball and others, 2002). The purpose of this paper is to illustrate the utility of mass-

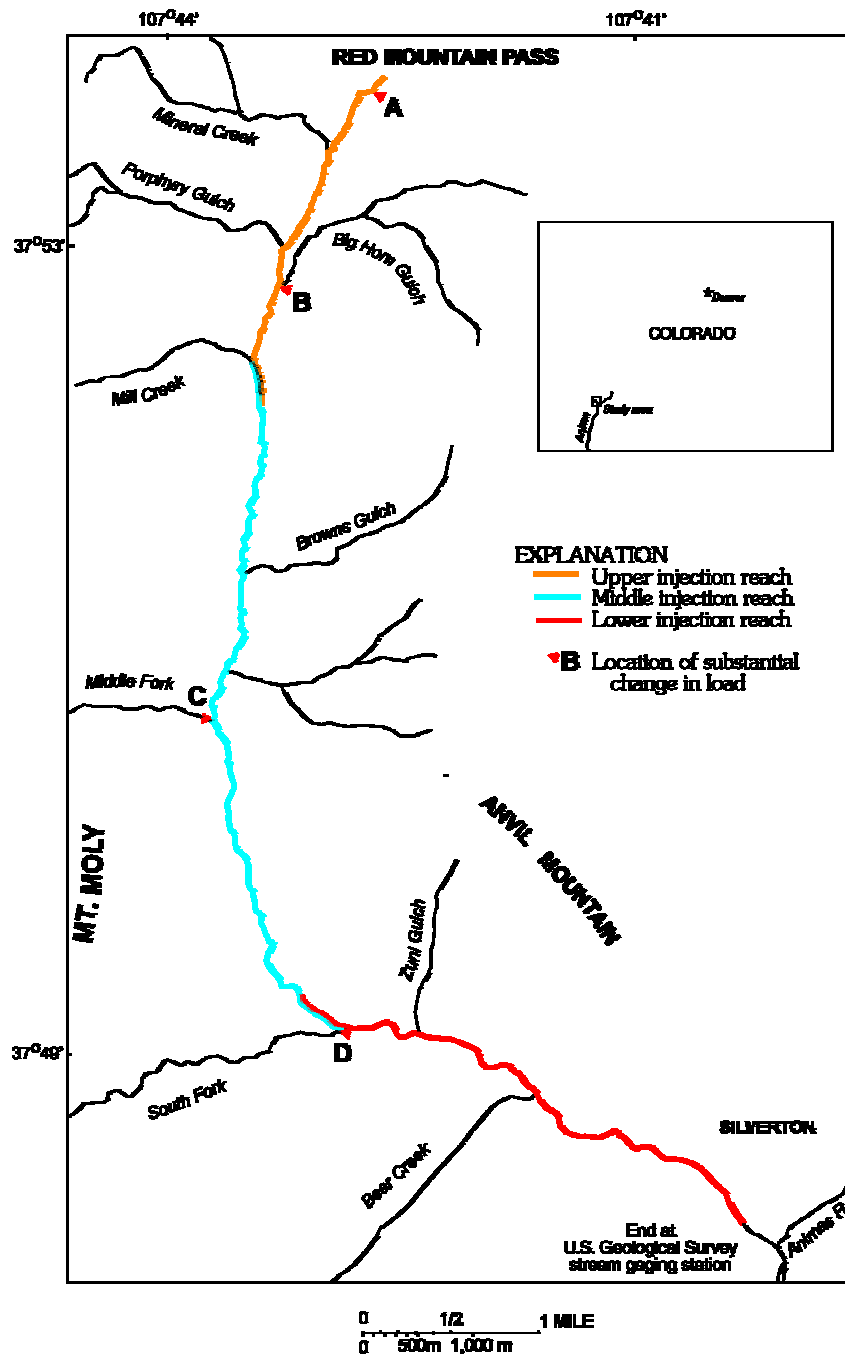


Figure 1. Location of Mineral Creek, Colorado, indicating the upper, middle, and lower injection reaches.

loading studies with selected examples from Mineral Creek, Colorado (fig. 1). A detailed report of the study in Mineral Creek is in preparation, but some of the data have been used for reactive solute-transport modeling of remediation alternatives (Runkel and Kimball, 2002).

Mineral Creek originates near Red Mountain Pass in the San Juan Mountains of southwest Colorado at an elevation of more than 10,000 feet above sea level. Mineral Creek discharges to the Animas River, near Silverton, Colorado. Over most of the 15,000-meter (m) study reach, Mineral Creek has a steep gradient with cobble and boulder bed material. The area is within the collapsed Silverton caldera, and there are several different alteration types that crop out in the watershed (Bove and others, 2000). There is regional propylitic alteration, but the types that are most prominent include a quartz-sericite-pyrite (QSP) type, an acid sulfate (AS) type, and a weak sericitic type.

METHODS

Mass-loading studies have been applied to mine drainage research as part of the U.S. Geological Survey Toxic Substances Hydrology Program to investigate loadings (Kimball and others, 1994, 1999b, 2001, 2002; Kimball, 1997; Cleasby and others, 2000). The approach includes a tracer-injection to define stream discharge and other hydrologic characteristics (Bencala and others, 1990), coupled with synoptic sampling to provide a detailed chemical characterization of the stream and its inflows along the study reach (Bencala and McKnight, 1987). The combination of detailed discharge and the chemical data provides a profile of mass loading along the study reach, allowing a comparison of loading among sources in the watershed. Because a conservative tracer is diluted by any inflow to the stream between each pair of stream sites, this method also addresses the quantification of both surface- and ground-water inflow to a stream.

Tracer Injections

The tracer-injection study began with a careful evaluation of all visible inflows to the study reach, which was accomplished by walking the entire study reach from Red Mountain Pass to the U.S. Geological Survey gaging station near the mouth (fig. 1). Sampling sites for the synoptic study are referenced in the report by the measured distance along the study reach and a few key locations are indicated by letters A through D on figure 1. Because of the substantial length of the study reach, the stream was divided into three separate injection reaches. The upper injection reach was 3,428 m long, the middle reach was 6,994 m long, and the lower reach was 5,248 m long (fig. 1). Precision metering pumps were used to inject the tracer to maintain a constant rate. No adverse effects were observed from the injection of the tracer solution.

Lithium bromide was selected for the tracer injection solution. The combination of lithium and bromide was considered a good tracer pair because of the variable pH of the stream and the lack of geologic sources of lithium and bromide in the watershed. Lithium is a conservative tracer at pH less than about 5 and bromide is conservative at pH greater than about 5. Over most of the study reach the mole balance of lithium and bromide was equal.

A continuously injected chemical tracer provides a way to measure discharge that includes the hyporheic flow of the stream because the tracer follows the water as it moves in and out of the streambed. During base-flow conditions, tracer dilution allows the detection of increases in streamflow of only a few percent. Once the tracer reaches a steady concentration at each point along the stream, called the plateau condition, discharge can be calculated at any point. During the tracer plateau, numerous samples along the stream provide a synoptic sampling. Each stream sample has a measured discharge because of the tracer concentration in the synoptic sample. Stream samples were collected by integrating methods (Ward and Harr, 1990).

Concentrations of bromide in stream environments are typically low, with preinjection concentrations at or near the lower detection limits. Also, the spatial variability in background concentrations is small, such that background concentrations are nominally uniform. Given the assumption of uniform background concentrations, stream discharge at any location downstream from the injection is given by:

$$Q_D = \frac{Q_{INJ} C_{INJ}}{C_D - C_B} \quad (1)$$

where Q_D = stream discharge, in L/s,
 Q_{INJ} = the injection rate, in L/s,
 C_{INJ} = the injectate concentration, in milligrams per liter (mg/L),
 C_D = the tracer concentration at plateau, in mg/L, and
 C_B = the naturally occurring background concentration, in mg/L.

Tracer dilution accounts for visible inflows, such as tributaries and springs, as well as dispersed, subsurface inflow. To divide the total inflow into surface- and ground-water components would require a secondary measurement of the inflow.

Synoptic Sampling and Chemical Analysis

Synoptic sampling gives a spatially intensive "snapshot" of chemistry and discharge to quantify instream loads. Reach-scale information is available for changes that occur between each pair of stream sites, which we call a stream segment. Stream segments capture both visible tributary inflow and dispersed, subsurface inflow to the stream. Some stream segments have sampled inflows and others are without sampled inflows, but both quantify the total change in load due to distinct or dispersed inflows.

Three operationally defined concentrations were obtained for each metal from the synoptic stream samples. An unfiltered sample provides a measure of the total-recoverable metal concentration (dissolved + colloidal). Tangential-flow ultrafiltration, using 10,000-Dalton molecular weight filters, provides a dissolved-metal concentration. Tangential-flow filtration, using a 0.45-micrometer (μm) filter, provides a comparison of the ultrafiltration to aquatic standards that are written for 0.45- μm filtration, and provides the "dissolved" concentration for most inflow samples. Colloidal-metal concentrations are defined as the difference between the total-recoverable and the ultrafiltrate metal concentrations for stream samples (Kimball and others, 1995).

All metal concentrations were determined by inductively coupled plasma-atomic emission spectrometry. Anion concentrations were determined from 0.45- μm filtered samples using ion chromatography (Kimball and others, 1999a). Total alkalinity was determined by titration in the laboratory. Temperature, pH, and specific conductance were determined in the field.

Determination of loads

The solute load at each stream site can be quantified by multiplying the discharge and the solute concentration. When this calculation is made for each stream site, it provides a longitudinal profile of the sampled instream load. A change in load for a stream segment is determined by subtracting the upstream load from the downstream load for a pair of stream sites. A positive difference indicates a gain in solute load and implies that there is a source of the solute between the two stream sites. A negative difference indicates a net removal of the solute load from the stream. However, a net-negative value does not eliminate the possibility that there could be a source within that particular stream segment. Summing all the positive values of change along the study reach generates a cumulative instream load. This is the best estimate of the total solute load added to the stream along the study reach, even though it is a minimum estimate because it is based on net loadings for its calculation.

Because tracer dilution accounts for the change in discharge between stream sites, there is a second approach to calculating loads. The change in discharge between two stream sites, multiplied by the total-recoverable solute concentration for a sampled inflow gives an estimate of the total inflow load for a stream segment. A cumulative sum of inflow load along the study reach indicates how well the sampled inflows account for the load measured in the stream. If we could obtain a representative inflow concentration for each segment, then the cumulative instream and cumulative inflow profiles would be equal. Sampled inflows are chosen to be representative of all the inflows along the study reach, but it is not possible to sample every surface inflow. Nor is it possible to sample all the dispersed, subsurface inflow along the study reach.

RESULTS

Synoptic sampling for all three injection reaches consisted of 86 stream segments and 65 inflow sites. This discussion will focus on the variation of the bromide tracer, pH, aluminum, and zinc.

Discharge

The variation of bromide along the study reach for all three injections and the calculated discharge are shown in figure 2. For each injection, the bromide tracer provided a clear bromide signal that was elevated above background concentrations, which were consistently less than detection (fig. 2). With a uniform background concentration, it was possible to use equation 1 to calculate discharge. The increase in discharge along the study reach was 3,255 liters per second (L/s); of which 548 L/s

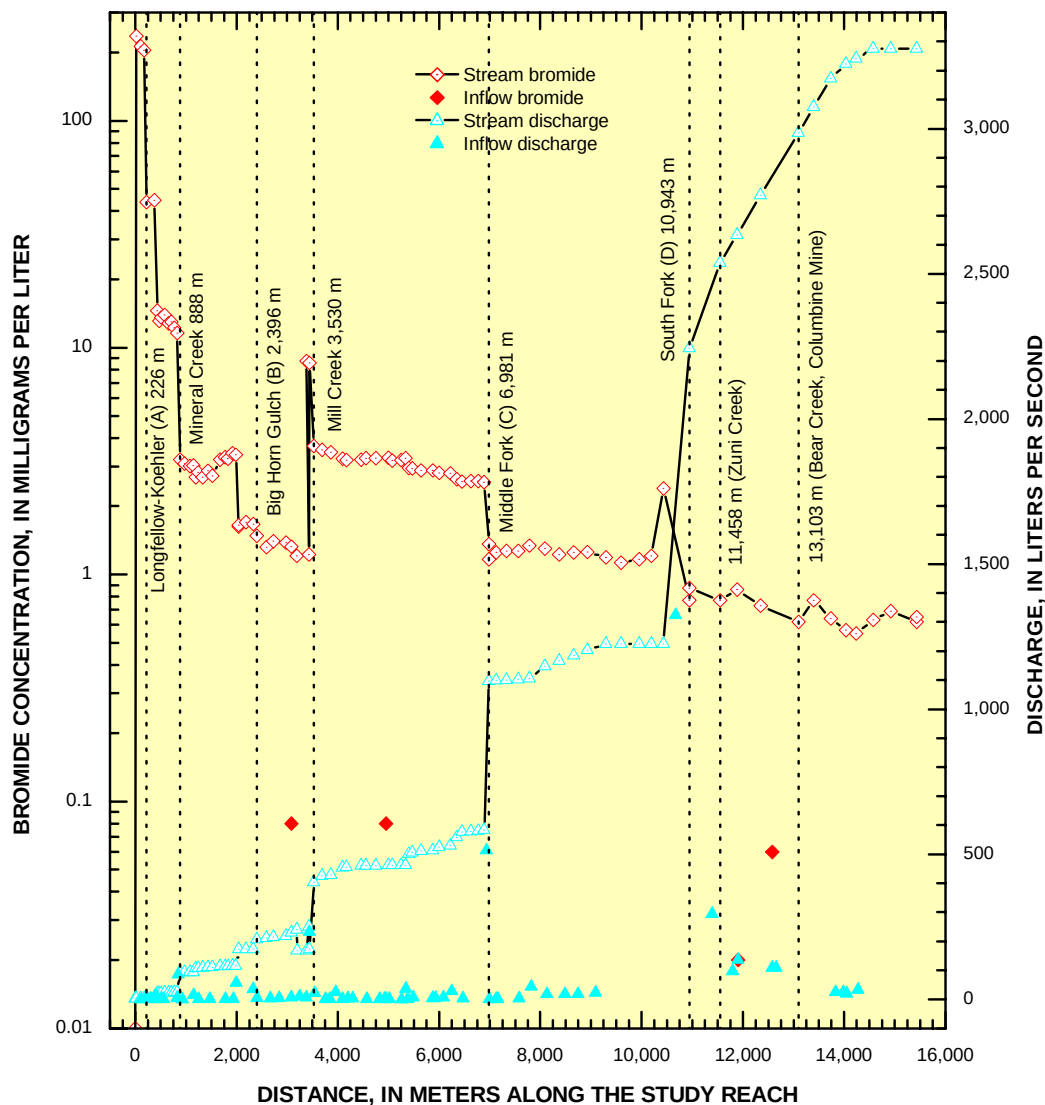


Figure 2. Variation of injected bromide concentration and calculated discharge with distance, Mineral Creek, Colorado, September 1999.

occurred in segments with no sampled inflows. This indicates that a minimum of 17 percent of the total increase in discharge that might be directly attributed to ground water. The five largest inflows account for about 77 percent of the increase in flow: South Fork (1,320 L/s), Middle Fork (512 L/s), the segment ending at 11,458 m that includes Zuni Creek (294 L/s), Mill Creek (232 L/s), and the inflow near the end of the study reach at 13,103 m (136 L/s) that includes Bear Creek.

Characterization of synoptic chemistry

Synoptic sampling of inflows gives a context for understanding loadings and instream chemical reactions. In a watershed affected by many natural processes and anthropogenic activities, inflows can range from acidic to alkaline and from dilute to saline. All the different types of inflows can affect stream chemistry. Variation of pH along the Mineral Creek study reach reflects a great diversity among inflows (fig. 3). Note the great number of samples collected for this synoptic study. Such detailed spatial sampling allows for adequate characterization of possible sources and for understanding the details of instream processes. Among inflow samples, the pH ranges from 2.43 to 7.70. Instream pH varies from 2.84 to 6.89 in response to the inflows. There are a few abrupt changes in pH, where the pH crosses a value of 5.25. These changes occur (A) downstream from the inflow of the Longfellow-Koehler discharge (226 m), (B) downstream from Big Horn Gulch (2,396 m), (C) downstream from the Middle Fork (6,981 m), and (D) downstream from South Fork (10,943 m).

Variation of aluminum concentration, both dissolved and colloidal, shows a pattern similar to pH (fig. 4). The graph shows total-recoverable aluminum divided into the amounts that were dissolved and colloidal. A great increase in dissolved-aluminum concentration occurs downstream from the Longfellow-Koehler drainage (A). Downstream from Big Horn Gulch (B), the concentration is much lower, and most of the aluminum is colloidal rather than dissolved. Downstream from the Middle Fork (C) both dissolved and colloidal aluminum concentrations increase substantially and are almost equal; dissolved-aluminum concentration is about 2 mg/L and colloidal concentration is about 1.7 mg/L for a total just under 4 mg/L. Finally, downstream from South Fork (D), the aluminum concentrations are diluted and all the aluminum is essentially colloidal.

The transformations between dissolved and colloidal aluminum correspond to changes in pH (fig. 5). At low pH, the colloidal aluminum fraction is smallest. Samples downstream from the Longfellow-Koehler drainage (A) have a colloidal fraction ranging from about 0 to 0.28. Samples downstream from the Middle Fork (C) to South Fork (D) have a greater colloidal fraction, but the pH is generally higher. In fact, the pH is in the range of transition between the two phases (Bigham and Nordstrom, 2000). Samples with a higher pH downstream from Big Horn Gulch (B) and downstream from South Fork (D), have a much greater colloidal fraction, ranging from about .76 to .99. All the samples downstream from South Fork are mostly colloidal, with a fraction greater than 0.95.

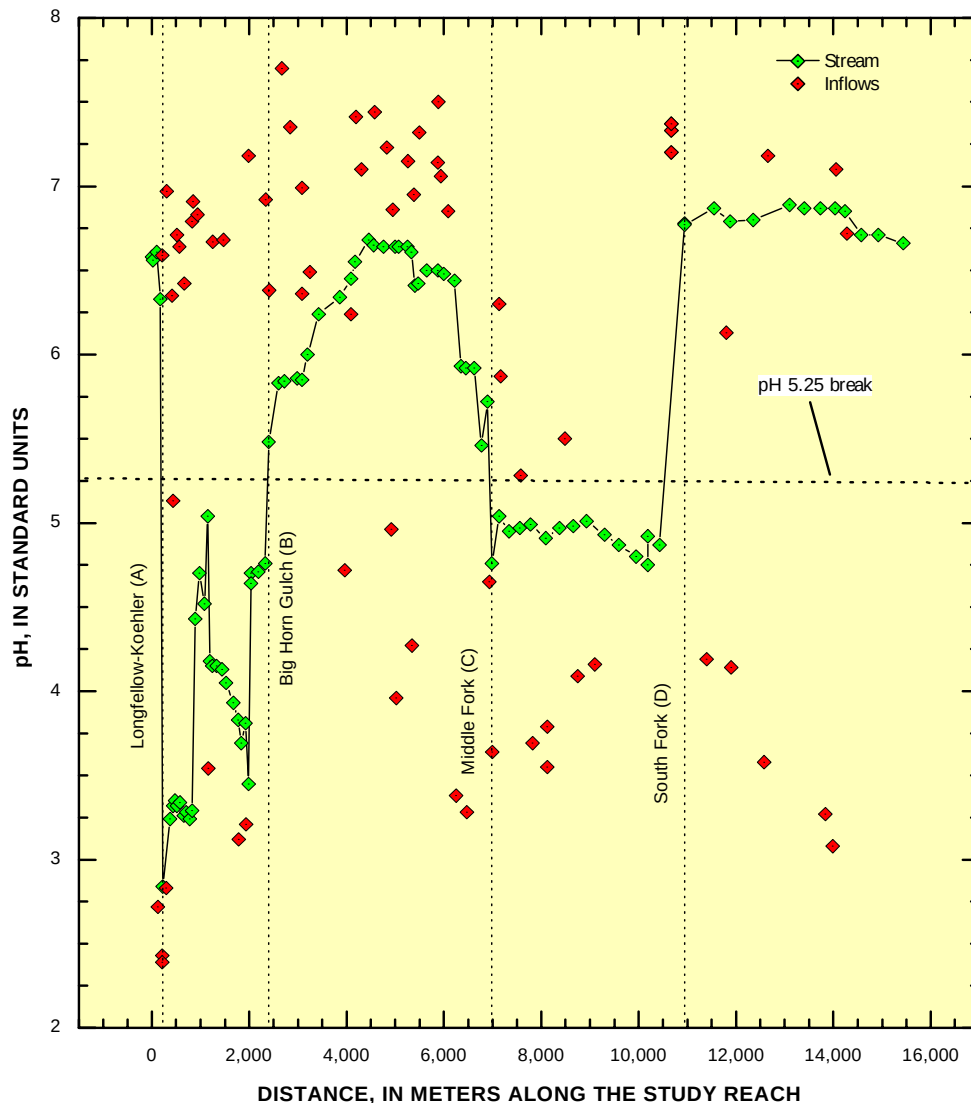


Figure 3. Variation of pH with distance, Mineral Creek, Colorado, September 1999.

The presence of colloids has important implications for understanding the dissolved concentrations of metals. Ultrafiltration has been used to obtain more truly dissolved concentrations (Kimball and others, 1992b). When colloidal solids, mostly aluminum and iron oxyhydroxides, form downstream from mine drainage, the initial particles are very small, on the order of 1-nanometer spherules (Ranville and others, 1989; Grundl and Delwiche, 1993). These particles rapidly aggregate and form a continuous range of particle aggregates, ranging in size from 1 nanometer to greater than 1 μm (Buffle and Leppard, 1995). Filtration through a 0.45- μm filter will likely include

some of this colloidal material. As 0.45- μm filtered samples are acidified for preservation, the fraction of colloidal aluminum (or iron) that has passed through the filter dissolves and is measured as “dissolved” iron rather than as colloidal. This sampling artifact can be much greater during runoff when particles are flushed into the stream (Church and others, 1997). The operational artifact would result in reporting of higher concentrations of dissolved aluminum, iron, and possibly other metals; and may result in reported concentrations that exceed aquatic standards, but may actually be below standards. The artifact may also lead to erroneous thermodynamic calculations of mineral saturation.

The pattern of zinc concentration differs substantially from that of aluminum. Zinc concentrations consistently decrease downstream from Big Horn Gulch (B) and there is a lack of colloidal zinc (fig. 6). The high zinc concentrations downstream from the Longfellow-Koehler drainage (A), and other locations that are all upstream from Big Horn Gulch (B), indicate that the principal sources of zinc are in that section of the study reach. The lack of colloidal zinc relates to the distinct chemical behavior of zinc compared to aluminum. Aluminum hydrolyzes at a much lower pH than zinc. Lindsay (1979) provides a summary of hydrolysis constants for these and other metals. The first hydrolysis constant for aluminum has a pK^1 of 5.02, while for zinc it is 7.69. Thus, the transformation to colloidal aluminum begins at a pH near 5.02, but for zinc the transformation would not begin until a pH near 7.7. The difference in chemical behavior, however, is more complex than suggested by the pK values. Aluminum tends to form polynuclear species at the lower pH, and these rapidly aggregate to colloidal particles greater than 10,000 Daltons (Da) (May, 1992; Kimball and others, 1992a). Zinc is less likely to form polynuclear species (Baes and Mesmer, 1976). When colloidal zinc occurs, it is more likely present as a sorbed species on iron colloidal material (Smith, 1999).

¹ pK is mathematically analogous to pH; it is the negative logarithm of the dissociation constant.

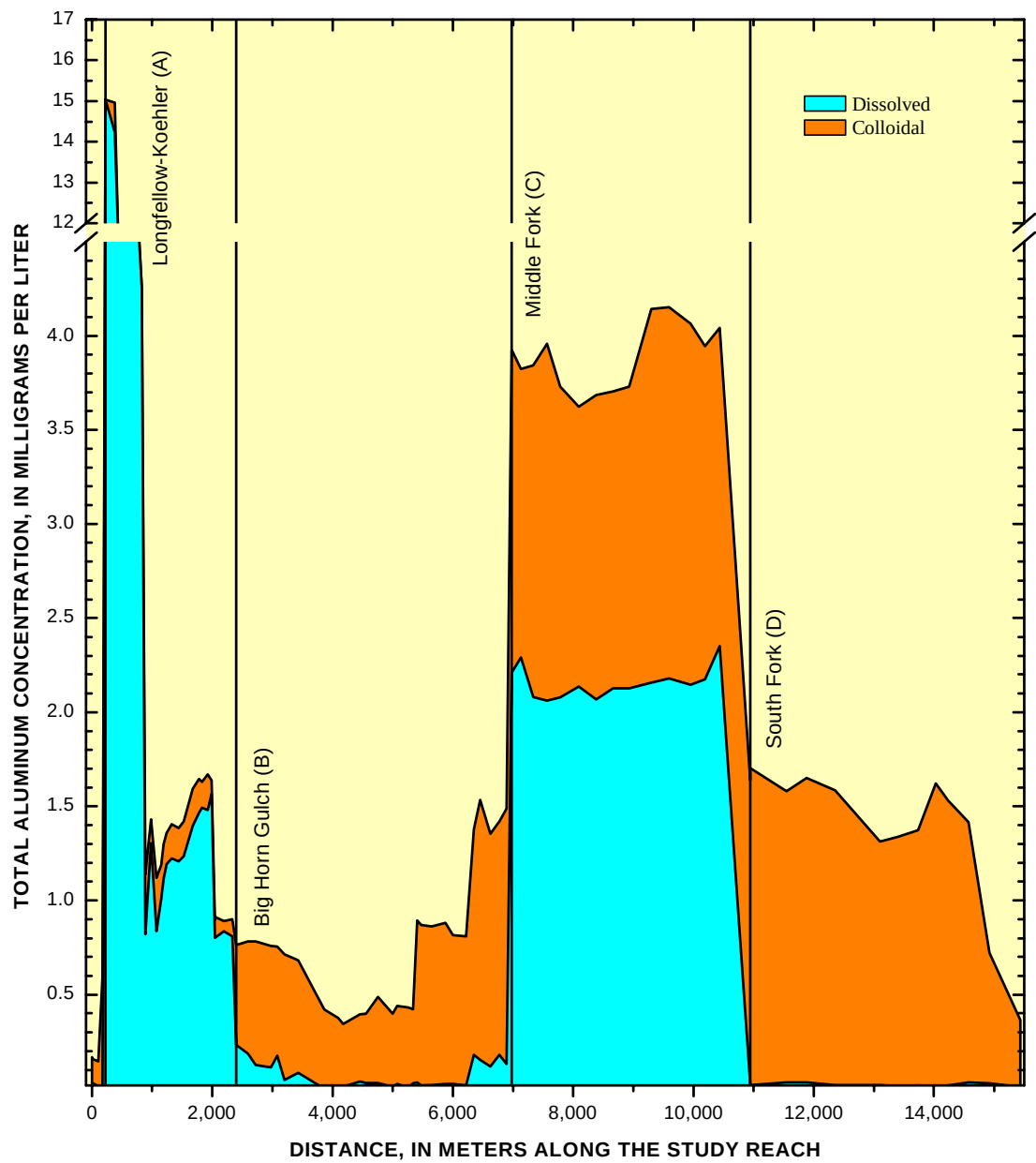


Figure 4. Variation of total aluminum concentrations with distance, Mineral Creek, Colorado, September 1999. Total aluminum concentration is divided between the portions of dissolved- and colloidal-aluminum.

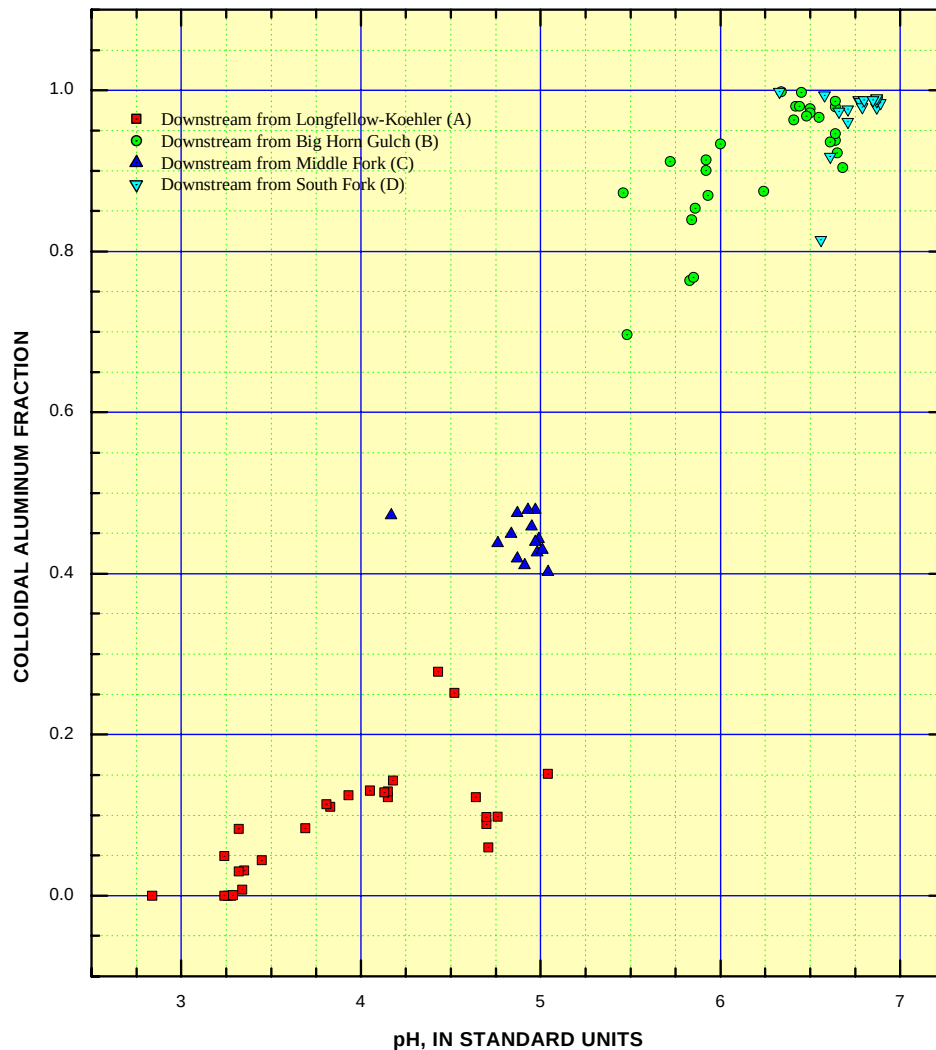


Figure 5. Variation of colloidal aluminum fraction with pH, Mineral Creek, Colorado, September 1999.

DETERMINING SOURCES: MASS-LOADING PROFILES

Changes in chemical composition of stream samples must be evaluated in the context of solute loading to determine which inflows – sampled or unsampled – have the greatest affect on the stream. The mass-loading profile of zinc provides an example of how a mass-loading analysis helps to evaluate sources in a watershed (fig. 7). The first noticeable distinction between zinc concentration and zinc load is the increase in load downstream from Big Horn Gulch, in the area where concentration decreased (fig. 6). This shows the importance of establishing the hydrologic context to evaluate metal loads

because several of the significant loads downstream from Big Horn Gulch could have been missed in remediation planning if only concentrations were considered.

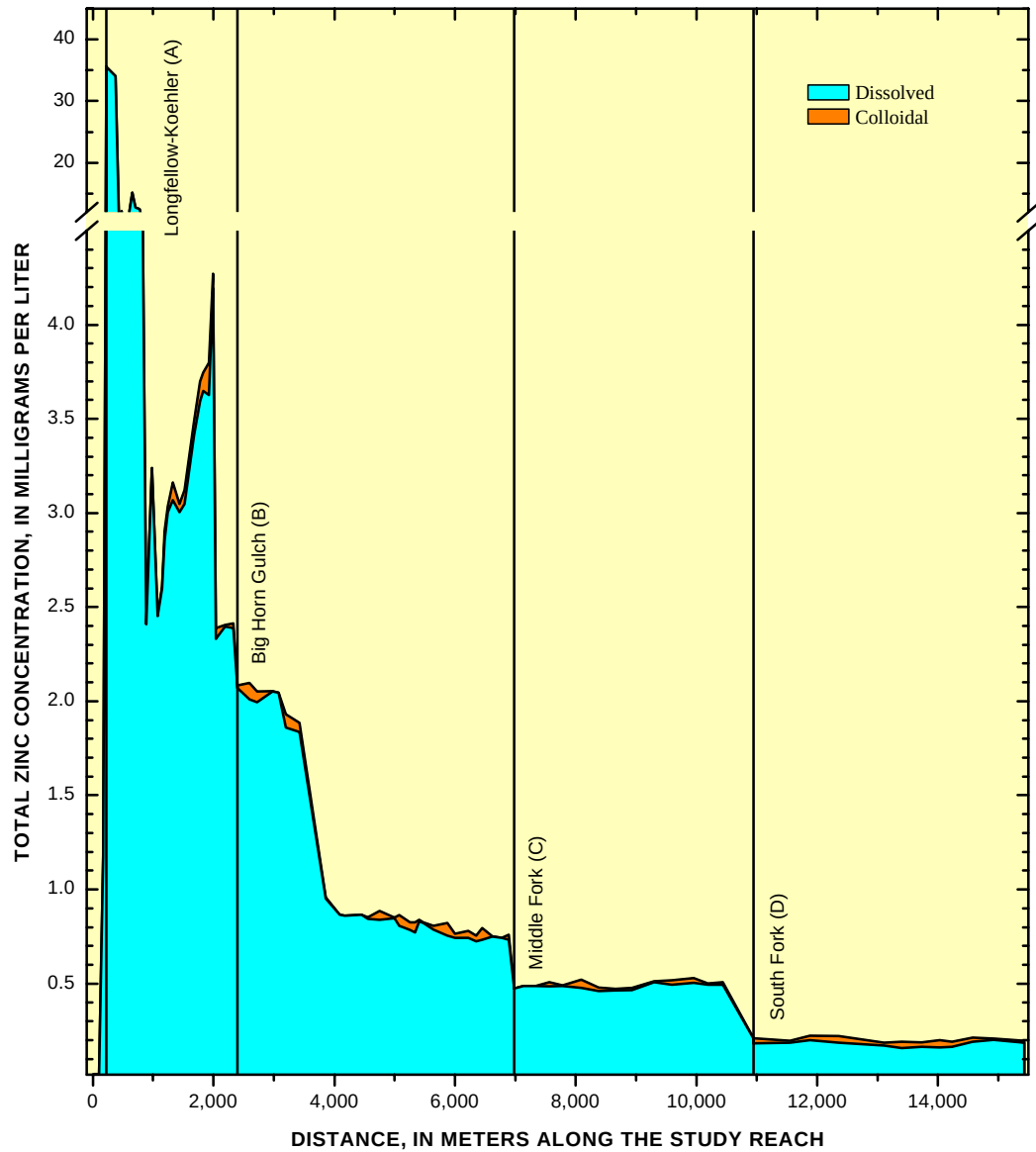


Figure 6. Variation of total zinc concentration with distance, Mineral Creek, Colorado, September 1999. Total zinc concentration is divided between the portions of dissolved- and colloidal-zinc.

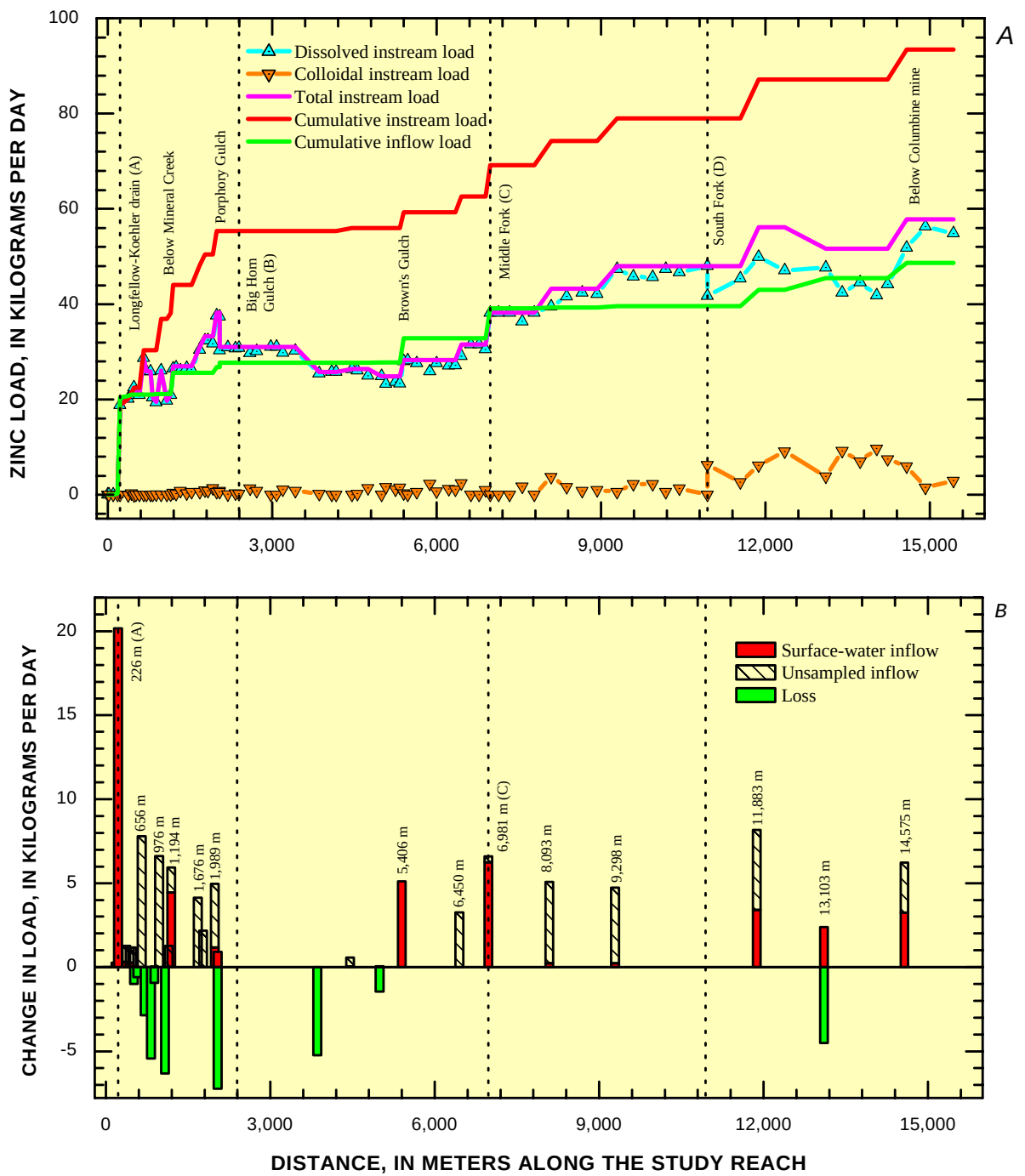


Figure 7. Variation of (A) zinc load with distance and (B) change in load for individual stream segments, Mineral Creek, Colorado, September 1999.

This method of illustrating loads distinguishes between sampled and unsampled loads. This distinction also is important for remediation planning because it can indicate the difficulty of identifying easily treatable sources. For example, the increase in load at the Longfellow-Koehler drainage (A) is a sampled inflow. Given an adequate remediation technology and funding, that source could be treated. However, other sources downstream from there, for example the sources at 656 m, 976 m, 1,989 m, 8,093 m, and 9,298 m (fig. 7B), are dispersed, subsurface inflows that are unsampled and could be much more difficult and expensive to gather and treat for remediation. Thus, the mass-loading information can guide remediation planning.

Sources of zinc mass loading are closely related to the geology of the watershed. Those sources upstream from the site at 1,989 m are all related to the alteration near Red Mountain Pass, which includes both QSP and AS types (Bove and others, 2000). Of course, some of this alteration rock has been mined, and includes the Longfellow-Koehler drainage and the Carbon Lakes drainage (1,194 m). The sources from 6,450 m to 9,298 m are all associated with the Mt. Moly QSP-type deposit. Sources from 11,838 m to 14,575 m result from the Anvil Mountain drainage, which is an AS-type alteration.

INSTREAM PROCESSES: QUANTIFYING REACTIONS

The mass-loading profile of aluminum provides information to quantify instream chemical reactions. At a pH of 5.02, which is the pK of the first hydrolysis reaction of aluminum, the total aluminum concentration predominantly consists of Al^{3+} and $Al(OH)^{2+}$ species, which are equal in concentration and are related by the reaction:



At a pH less than 5.02, Al^{3+} predominates as dissolved aluminum. At a pH greater than 5.02, $Al(OH)^{2+}$ predominates and most likely favors the formation of a colloidal-aluminum solid. If we represent the colloidal aluminum as $Al(OH)_{3, coll}$, the transition between dissolved and colloidal aluminum essentially becomes:



This reaction implies that all the $Al(OH)^{2+}$ that forms is used in the formation of colloidal aluminum. As suggested by the variations in dissolved- and colloidal-aluminum concentrations (fig. 6), this reaction is reversible. From the mass-loading, we can quantify the extent of this reaction at key locations along the study reach.

Two confluences of particular interest are with the Middle Fork (C) and with the South Fork (D) (fig. 8). The most striking features of the aluminum mass-loading profile are the dominance of the source from the Middle Fork (C) and the dynamic changes in the loads of dissolved and colloidal loads. The greatest loading of aluminum occurs at the Middle Fork (C, fig. 8B). Upstream from the Middle Fork, total aluminum load is predominated by colloidal aluminum (fig. 9A). Middle Fork, however, is dominated by dissolved aluminum. When these two loads are combined, we can compare the sum of the loads to the sampled loads downstream from Middle Fork. For the Middle Fork, the

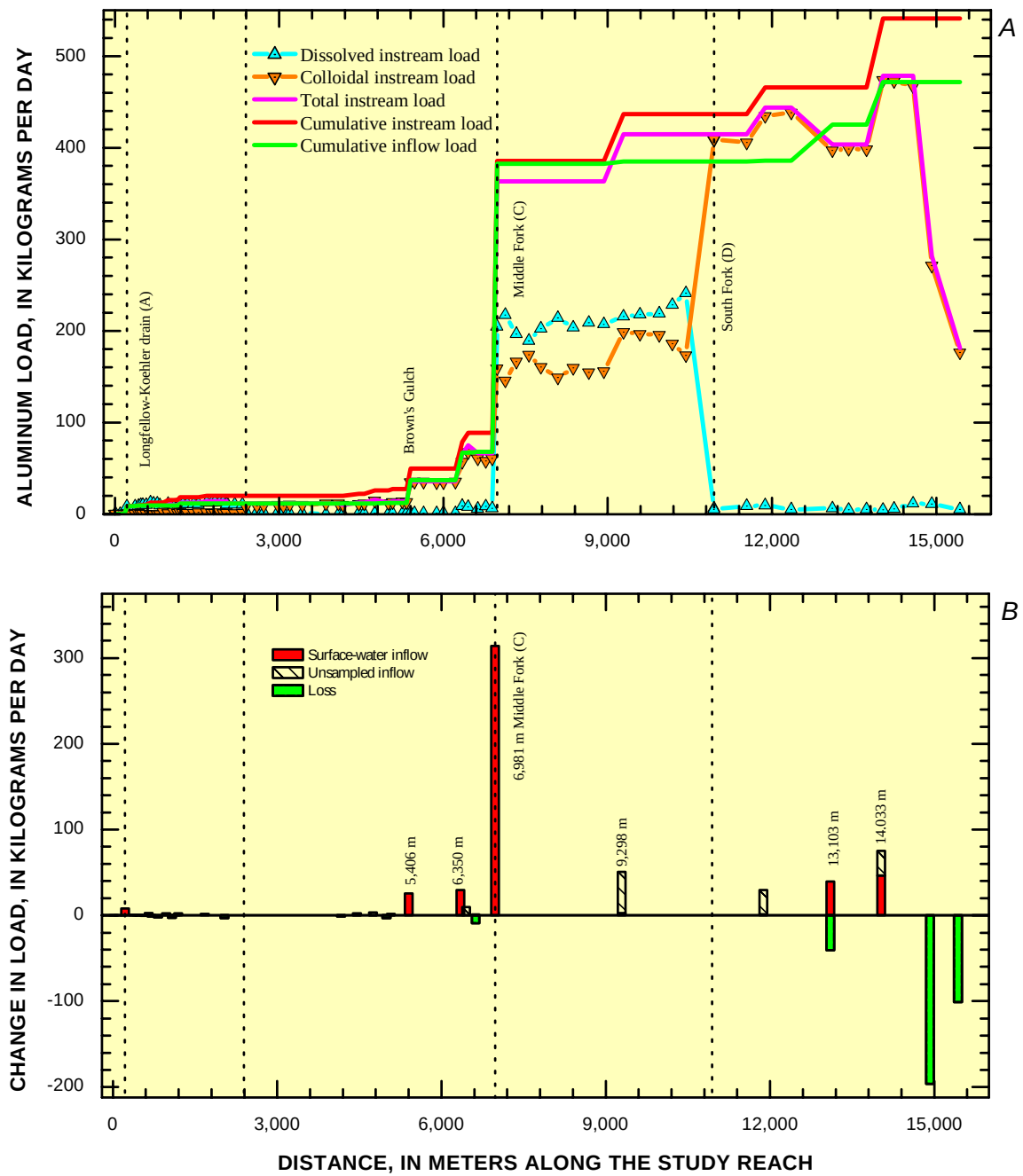


Figure 8. Variation of (A) aluminum load with distance and (B) change in load for individual stream segments, Mineral Creek, Colorado, September 1999.

calculated sum is essentially the same as the sampled distribution of dissolved and colloidal aluminum (about 5 percent, which is less than the calculated load error of 6 percent at that point along the study reach). Thus, downstream from the Middle Fork, we observe the result of mixing the two sources; any chemical reactions that occur are not detectable with our precision.

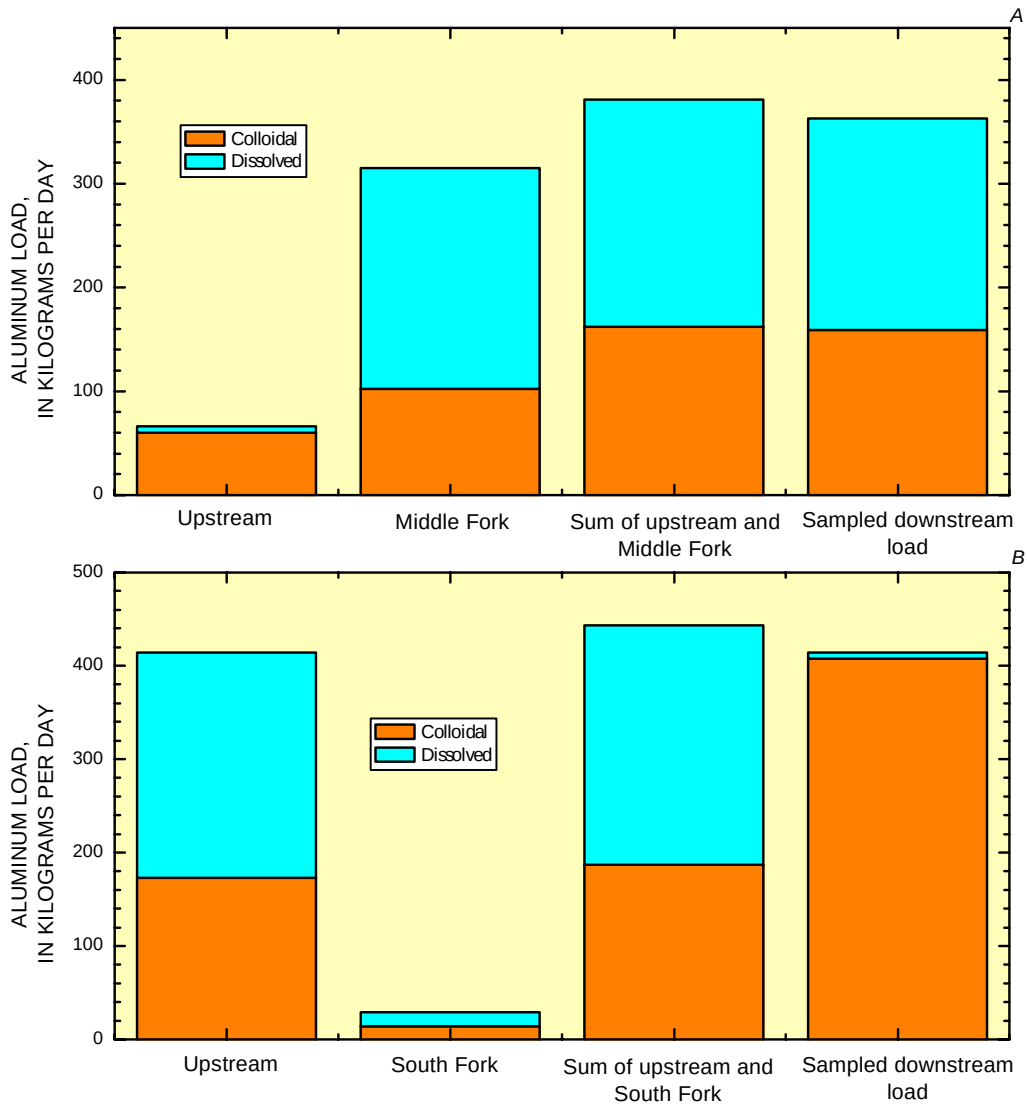


Figure 9. Mass transfer of dissolved and colloidal aluminum reactions at (A) Middle Fork confluence and (B) South Fork, Mineral Creek, Colorado, September 1999.

Returning to figure 5, showing the colloidal fraction of aluminum, the group of samples from the Middle Fork to the South Fork are separate from all the other samples. The samples range from a colloidal fraction of 0.4 to 0.5. It is likely that this group remains in this range of dissolved fraction because the average pH of the stream in that location is 4.87, close to the crossover value of 5.02. Thus, it is possible that there is a dynamic equilibrium between the dissolved and colloidal fractions and there is no net change along this stream reach.

A different scenario occurs at the confluence with the South Fork (figs. 8A, 9B). Upstream from the South Fork, the dissolved aluminum load is slightly greater than the colloidal load; the pH upstream from the confluence was 4.87. The South Fork, although the load was much smaller, was about equally split between dissolved and colloidal aluminum; the pH of the South Fork was 7.20. The sum of these two loads would result in little change in the dissolved to colloidal ratio. This would simulate the result of mixing without any reaction. However, the sampled load downstream from the South Fork was 99 percent colloidal, indicating a nearly complete transition to colloidal aluminum. The total aluminum load upstream and downstream of the South Fork was not significantly different, indicating that this transformation to colloidal aluminum was a process that occurred completely in the water column. It is also important that this reaction occurred within the time frame of transport through the stream segment, which would be on the order of seconds to minutes. This agrees with observations in the mixing zone downstream from Cement Creek, near Silverton (Schemel and others, 2000).

SUMMARY

A series of three tracer injections quantified changes in discharge along a 15-kilometer study reach of Mineral Creek, Colorado, in September 1999. Detailed spatial sampling of the stream and inflows along the study reach, along with the tracer discharge, are combined for a mass-loading profile that provides information for 86 stream segments. The mass-loading profile indicates that there were significant increases in zinc load in 21 of those segments. Six of these included inflows that can be attributed to mine drainage; these accounted for about 42 percent of the cumulative instream load of zinc along the study reach. The other 15 of the 21 gaining segments contributed 58 percent of the zinc load and likely represent weathering of altered bedrock. Unsourced inflow of zinc corresponds to occurrences of important alteration types.

Aluminum mass loading identifies the extent of physical and chemical processes in the watershed. Downstream from the confluence with the Middle Fork, it appears that colloidal aluminum was transformed to dissolved aluminum. Instead, mass loading indicates that the downstream ratios of dissolved to colloidal aluminum can be explained by physical mixing. Reaction does occur, however, downstream from the confluence with the South Fork. Because the pH is substantially higher after mixing, essentially all the aluminum was transformed to the colloidal phase.

These examples from Mineral Creek indicate the utility of mass-loading profiles in understanding the relative importance of different metal sources in a watershed. The studies also help to quantify and understand important instream processes. This

information is needed to make better science-based decisions about remediation of metals in watersheds.

ACKNOWLEDGEMENTS

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SULFATE-REDUCING BIOREACTOR DESIGN AND OPERATING ISSUES: IS THIS THE PASSIVE TREATMENT TECHNOLOGY FOR YOUR MINE DRAINAGE?

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ABSTRACT

There are basically two kinds of biological passive treatment cells for treating mine drainage. ***Aerobic Cells***, containing cattails and other plants, are typically applicable to coal mine drainage where iron and manganese and mild acidity are problematic. ***Anaerobic Cells*** or ***Sulfate-Reducing Bioreactors*** are typically applicable to metal mine drainage with high acidity and a wide range of metals. Most passive treatment systems employ one or both of these cell types. The track record of aerobic cells in treating coal mine drainage is impressive, especially in the eastern coalfields. Sulfate-reducing bioreactors have tremendous potential at metal mines and coal mines, but have not seen as wide an application.

This paper presents the advantages of sulfate-reducing bioreactors in treating mine drainage, including: the ability to work in cold, high altitude environments, handle high flow rates of mildly affected ARD in moderate acreage footprints, treat low pH acid drainage with a wide range of metals and anions including uranium, selenium, and sulfate, accept acid drainage-containing dissolved aluminum without clogging with hydroxide sludge, have life-cycle costs on the order of \$0.50 per thousand gallons, and be integrated into “semi-passive” systems that might be powered by liquid organic wastes.

Sulfate reducing bioreactors might not be applicable in every abandoned mine situation. However a phased design program of laboratory, bench, and pilot scale testing has been shown to increase the likelihood of a successful design.

Additional Key Words: Constructed wetlands, acid mine drainage, heavy metals, sulfate reduction

INTRODUCTION

It has been over twenty years since the pioneering work of a group of researchers at Wright State University documented water quality improvements in a natural *Sphagnum* bog in Ohio that was receiving low pH, metal laden water (Huntsman, et al., 1978). Independently, a group at West Virginia University found similar results at the Tub Run Bog (Lang, et al., 1982). Subsequently, researchers, practitioners, and engineers focused on developing the promising technology of using “constructed wetlands” to treat acid mine drainage (AMD) or acid rock drainage (ARD). But the term “wetland,” besides carrying legal and regulatory baggage, does not quite describe structures like “anoxic limestone drains” or “successive alkalinity producing systems.” Hence, the term “passive treatment” was coined.

The design of passive treatment systems entails the selection of treatment “modules” appropriate to the geochemistry of the mine drainage. As shown in Figure 1, there are two geochemical “zones” in a natural wetland ecosystem. The lower, oxygen-depleted, zone is where sulfate-reducing bacteria thrive. The focus of this paper is the design of passive treatment

modules that capitalize on the geochemical reactions typically found in the anaerobic zone of natural systems.

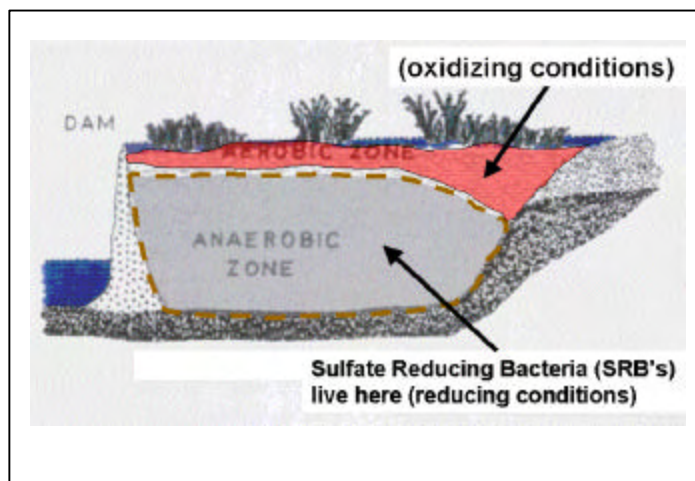


Figure 1. Typical Natural Wetland Geochemical Zones

Definition of Passive Treatment

There are many technologies for treating AMD/ARD. To properly focus the discussion, the following definition of passive treatment is proposed:

Passive treatment is a process of sequentially removing metals and/or acidity in a natural-looking, man-made bio-system that capitalizes on ecological and geochemical reactions. The process requires no power and no chemicals after construction and lasts for decades with minimal human help.

It is a **sequential** process because no single treatment cell type works in every situation or with every AMD/ARD geochemistry. It is an **ecological/geochemical** process because most of the reactions (with the exception of limestone dissolution) that occur in passive treatment systems are biologically assisted. Finally, it is a **removal** process because the system must involve the filtration or immobilization of the metal precipitates that are formed.

A truly passive system should also function for many years, without a major retrofit to replenish construction materials, and without the use of electrical power. Benning and Ott (1997) described a volunteer passive system outside of an abandoned lead-zinc mine in Ireland that has been functioning unattended for over 120 years. Ideally, a passive treatment system should be designed to last for at least several decades without reconstruction.

METAL REMOVAL AND OTHER BIO-GEOCHEMICAL MECHANISMS IN PASSIVE TREATMENT SYSTEMS

Many physical, chemical, and biological mechanisms occur within passive treatment systems reducing the metal concentrations and neutralizing the acidity of the incoming flow streams. Notable mechanisms include:

- Sulfide and carbonate precipitation catalyzed by sulfate-reducing bacteria (SRB) in anaerobic zones
- Hydroxide and oxide precipitation catalyzed by bacteria in aerobic zones
- Filtering of suspended material
- Metal uptake into live roots and leaves
- Adsorption and exchange with plant, soil, and other biological materials.

Wildeman, et al. has determined that plant uptake does not contribute significantly to water quality improvements in passive treatment systems (1993). However, plants replenish systems with organic material and add aesthetic appeal. In aerobic systems, plant-assisted reactions appear to aid overall metal removal performance, perhaps by increasing oxygen and hydroxide concentrations in the surrounding water through photosynthesis-related reactions and respiration in the plant root zone. Plants also appear to provide attachment sites for oxidizing bacteria/algae. Research has shown that microbial processes are a dominant removal mechanism in passive treatment systems (Wildeman, et al., 1993).

Sulfate Reducing Bioreactors

Sulfate reduction has been shown to effectively treat AMD/ARD containing dissolved heavy metals, including aluminum, in a variety of situations. The chemical reactions are facilitated by the bacteria *desulfovibrio* in sulfate-reducing bioreactors as shown in Figure 2 in schematic form and the photo in Figure 3.

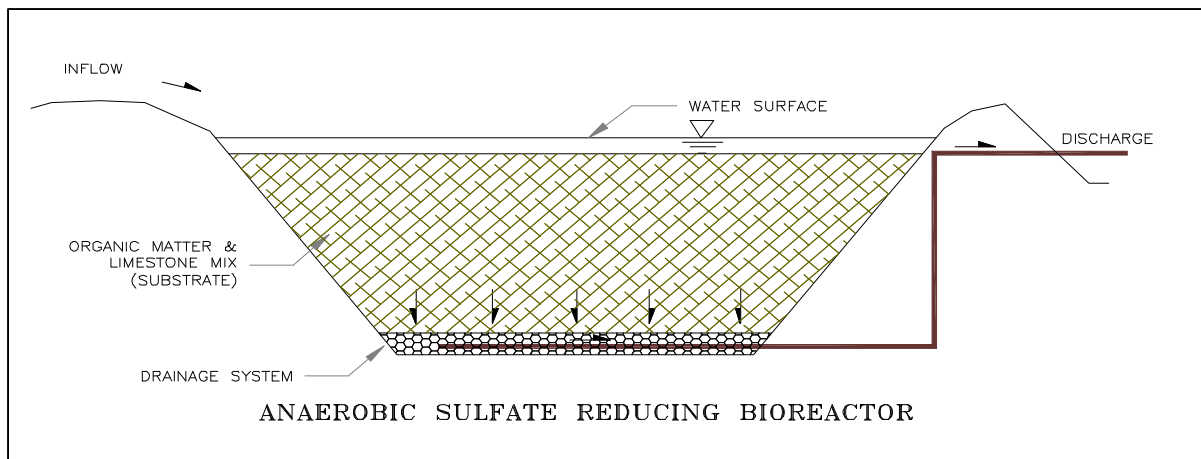


Figure 2. Sulfate-Reducing Bioreactor Schematic

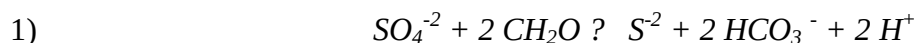


Figure 3. A Typical Sulfate-Reducing Bioreactor

The sulfate-reducing bacterial reactions (equation 1) involve the generation of:

- Sulfide ion (S^{2-}), which combines with dissolved metals to precipitate sulfides (equation 2)
- Bicarbonate (HCO_3^-), which has been shown to raise the pH of the effluent

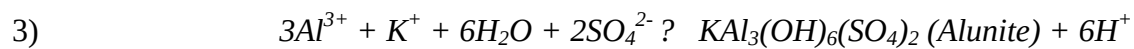
The sulfate reducing bacteria produce sulfide ion and bicarbonate as shown in the following reaction (Wildeman, et al., 1993):



The dissolved sulfide ion precipitates metals as sulfides, essentially reversing the reactions that produce AMD/ARD. For example, the following reaction occurs for dissolved zinc, forming amorphous zinc sulfide (ZnS):



Suspected geochemical behavior of aluminum in sulfate reducing bioreactors has been documented (Thomas and Romanek, 2002). It is suspected that insoluble aluminum sulfate forms in the reducing environments found in sulfate-reducing bioreactors, perhaps in accordance with the following reaction which is one of many possible:

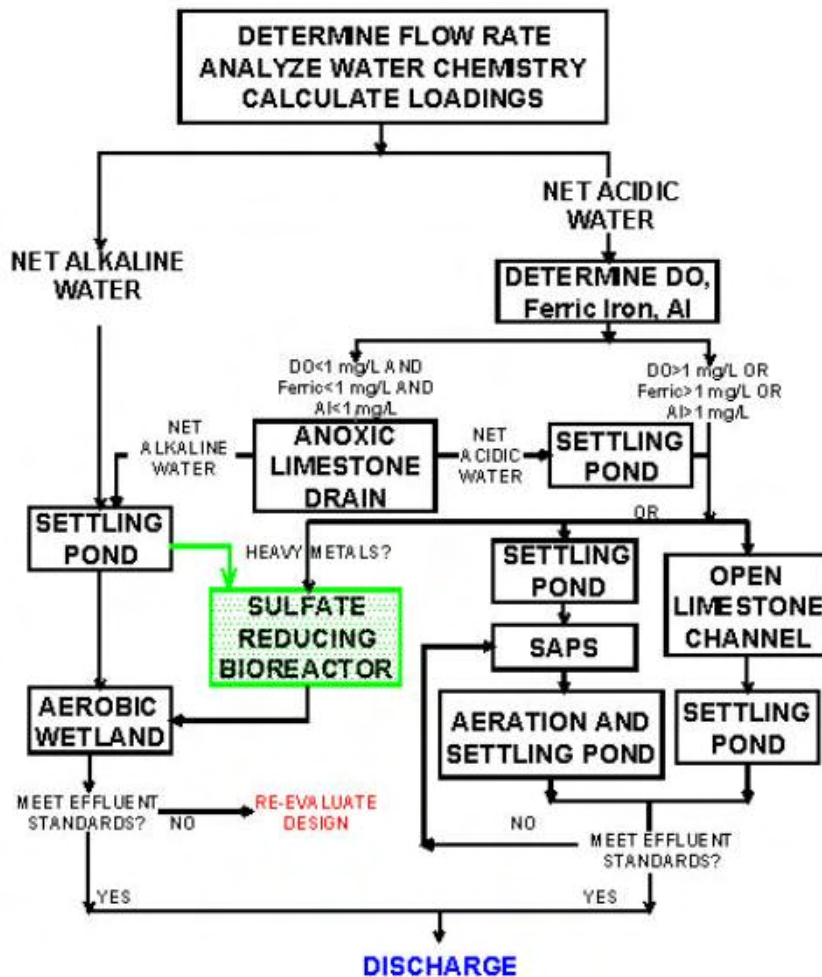


The key conditions for SRB health are a pH of 5.0 (maintained by the SRB itself through the bicarbonate reaction and/or the presence of limestone sand), the presence of a source of sulfate (typically from the AMD/ARD), and organic matter ($[CH_2O]$ from the substrate). Sulfate-reducing bioreactors have been successful at substantially reducing metal concentrations and favorably adjusting pH of metal mine drainages.

FLOW CHART FOR PASSIVE TREATMENT SYSTEM DESIGN

In the late 1980s, the design methods for aerobic passive treatment cells for iron removal were still under development. Brodie (1991) sorted out the empirical relationships in a milestone design flow chart that provided the foundation for a more comprehensive design flow chart subsequently developed by Hedin and Nairn at the former U.S. Bureau of Mines as shown in Figure 4.

This figure, in one form or another, continues to guide engineers and practitioners in the passive treatment cell design process. It has been modified by the author to include the passive treatment of heavy metal-bearing AMD/ARD based on observations since 1988. The sulfate-reducing bioreactor as shown reflects where this particular technology fits in the design philosophy. Although the technology is well suited for AMD/ARD with net acidity and/or heavy metals, it can also be effectively applied to net alkaline water sources as indicated by the arrow drawn from the settling pond on the left hand side of the flow chart



.Figure 4. Flow Chart for Selecting a Passive AMD Treatment System Based on Water Chemistry and Flow (Adapted from Hedin, et al., 1994).

PHASED DESIGN PROTOCOL

There is no “cookbook” design manual for passive treatment systems although the design flow chart above is a safe starting point. A phased approach design project is recommended; it typically begins in the laboratory with static tests, graduating to final testing phases (bench and pilot) performed at the site on the actual AMD/ARD. Bench scale testing will determine if the treatment technology is a viable solution for the AMD/ARD and will narrow initial design variables for the field pilot. A proper bench scale test will certainly reduce the duration of the more costly field pilot test. Field pilot test duration can range from days, to months, to years, depending on the nature of the technology. Depending on the nature of the equipment and personnel needed, significant costs may be incurred during the field pilot tests – about \$500 to \$1,000 per week, mostly for sampling and analysis. Compare this to \$5,000-\$10,000 per week for active treatment pilot tests. More detailed descriptions of laboratory, bench, and pilot tests are provided in Gusek (2001).

ADVANTAGES OF SULFATE-REDUCING BIOREACTORS

As shown in Figure 4, sulfate-reducing bioreactors can be applied in a number of different AMD/ARD situations. While most passive treatment systems (both aerobic zone and anaerobic zone types) offer simplicity of design and operation and economic advantages over active/chemical treatment, sulfate-reducing bioreactors have advantages worth considering.

- No aluminum plugging
- Can easily handle low flow net acidic water or high flow net alkaline water
- Uses waste organic materials
- Resilient to loading and climate variations
- Consumes sulfate; capable of treating selenium and uranium
- Generates more net alkalinity in effluent
- Burial to minimize vandalism
- Opportunities for community involvement in organic procurement
- Might be able to construct them in abandoned underground mines

Brief discussions of these issues follow.

No Aluminum Plugging

When AMD/ARD attacks clay-bearing formations at mining sites, significant amounts of dissolved aluminum can be created. The geochemistry of aluminum is complex, and this can cause problems in passive treatment systems. The formation of the mineral gibbsite $[\text{Al}(\text{OH})_3]$ is especially problematic as it is a gelatinous solid. Gibbsite tends to form in limestone-dominated passive treatment cells, and the sludge tends to plug the void spaces between the limestone rock, becoming a major maintenance problem. While the precise mechanisms are just beginning to be understood (Thomas and Romanek, 2002), the precipitation of gibbsite is avoided in SRB cells. It is suspected that unidentified alternative aluminum compounds form in the SRB cells instead of gibbsite, and these compounds are less prone to plugging. Several case histories of SRB passive treatment projects that involved treating ARD with high aluminum concentrations are provided in Gusek and Wildeman (2002).

Use of Waste Materials in Construction

Organic materials are a key component in the formulation of the substrate of sulfate-reducing bioreactors. Often these materials are considered waste materials and can be obtained for little or no purchase cost. The only expense incurred might be in their transport to the treatment site. If the site is in a remote forest environment, some of the materials such as wood chips and sawdust might be generated onsite or from local sources. A short list of organic waste materials, both solid and liquid, that might be candidates for use in a sulfate-reducing bioreactor is provided below. The list is not necessarily all inclusive as specialty wastes unique to different locales might be available.

- Wood chips
- Sawdust
- Hay and straw (spoiled)
- Cardboard?

- Yard waste
- Mushroom compost
- Animal manure
- Partially treated sewage?
- Waste alcohols including antifreeze
- Waste dairy products
- Sugar cane processing residue (Bagasse)

Using liquid organic wastes poses a specific opportunity and challenge. These materials are typically very biodegradable and as such are considered “candy” to sulfate-reducing bacteria. Thus, they are consumed quickly and need to be replenished on a nearly continual basis. This is not consistent with the strict definition of passive treatment cited earlier. However, since these materials might be stored in tanks or fed continuously from offsite sources through pipelines, systems using these waste organic sources would be considered “semi-passive” in nature. Such cells are often called “enhanced sulfate-reducing bioreactors” due to the boost provided by the liquid organic material. When alcohol is the chosen enhancer, the technique has sometimes been called “bugs on booze.”

Resilient to Loading and Climate Variations

If properly designed, sulfate-reducing bioreactors can be resilient to metal-loading variations. Pilot scale tests are the best venue for establishing the expected operating ranges of flow and metal concentrations and the reactions of the SRB cells to those varying conditions. For example, a pilot SRB cell at a lead mine in Missouri was sized for 25 gpm. Once steady state operation was observed for many months, the flow was increased to nearly double the design rate. The SRB cell began to show evidence of stress (i.e., decreased metal removal efficiency) after several months of exposure to the higher flow (Gusek, et al., 1998). Not all SRB cells might be this resilient, but this observation allowed engineers to include a significant factor of safety in the design of the full-scale system (1,200 gpm capacity) at this site.

Low temperature operation is a major concern at some sites, especially in the mountainous states in the west and Appalachia. Pilot cell data at the Ferris Haggarty Copper Mine/Osceola Tunnel Site in Wyoming at elevation 9,500 feet suggests that sulfate reduction rates decline in cold weather, but the decrease is not significant enough to render the design concept untenable. At this site, the typical water temperature is about 4°C. Winter operational data revealed that the cell continued to function at temperatures less than 1°C, and the sulfate reduction rate was estimated to be about 0.24 moles per day per cubic meter (m/d/m³) (Gusek, 2000). Compared to the benchmark design value of 0.3 m/d/m³, this constitutes a 20 percent decrease.

Sulfate-Reducing Bioreactors Consume Sulfate; Selenium and Uranium Reduced

Sulfate is a component of AMD/ARD that may be receiving more regulatory attention. It contributes to the total dissolved solids (TDS) concentration. But unlike other TDS constituents such as sodium, chlorine, and calcium, it is not conservative and can be mitigated in sulfate-reducing bioreactors. No other passive treatment technique has this capability as its primary function. Some sulfate reduction is typically observed in Successive Alkalinity Producing Systems (SAPS) (see Kepler and McCleary, 1994), but their primary function is to add alkalinity through limestone dissolution.

While sulfate-reducing bioreactors are naturally efficient at consuming sulfate, the geochemical conditions generated in a typical cell are also conducive to reducing selenium from the dissolved state to elemental selenium; this is facilitated by selenium-reducing bacteria. They are also effective in reducing uranium from the oxidized state to form insoluble uranium oxide similar to the way that some natural uranium deposits formed.

Burial to Minimize Vandalism

Any passive treatment system might be a target for vandalism. Because neither plants nor air are required for the sulfate-reducing bioreactors to function, they can be buried beneath a veneer of rock and soil provided that the feed water plumbing to the cell is not compromised. Settlement of the organic substrate needs to be considered in the design if burial is being considered. However, most organic substrate designs typically include a large component of wood chips or sawdust, which do not readily compress under minor surcharge loads developed by soil/rock covers. This aspect of the design should ideally be evaluated at the pilot stage of the design effort.

Underground In-Mine Treatment Systems

As stated above, one of the beauties of SRB systems is that they do not require plants to operate. All that is needed is a carbon source and an SRB arranged in a manner that encourages bacterial growth in concert with managed loading of AMD/ARD. In areas where land surface favorable to passive treatment system construction is at a premium due to steep terrain or the encroachment of civilization, building passive treatment systems in abandoned underground mine voids (using the mine void itself as the containment “vessel”) is an attractive possibility that has been realized in only one study at a metal mine in Montana (Canty, 1999).

Two challenges to overcome to implement this technology include the placement of large volumes of solid organic matter into mine voids through boreholes and the procurement of inexpensive organic material like forestry or paper waste and animal manure (SRB inoculum). The introduction of animal manure (even in small amounts) into ground water (i.e., a mine pool) will be a regulatory hurdle that may prove to be difficult to surmount. Carefully controlled field tests in small mines will probably be required.

Low Flow Net Acidic Water or High Flow Net Alkaline Water

At a given flow rate, the footprint of a sulfate-reducing bioreactor is governed by the mineral acidity of the AMD/ARD. The higher the acidity, the larger the surface area is required per unit of flow. The land area available for the system may be limited, especially for high flows of net alkaline AMD/ARD. In this situation, the surface area of the SRB cell might be as small as 10 square feet per gpm of flow. Thus, a net alkaline flow of 2,000 gpm might require as little as 20,000 square feet or about half an acre of cell. Cell depth will be a function of metal load.

Conversely, a very acidic AMD/ARD source might require a similar area to treat a significantly less rate of flow. For example, a flow of only 30 gpm of AMD with over 2,000 mg/L of acidity would require nearly 3 acres of surface area. However, there are no other technologies capable of passively treating AMD/ARD with this aggressive a chemistry.

Added Net Alkalinity in Effluent

Sulfate-reducing bioreactors are typically sized to deliver treated water with low concentrations of metals and a near neutral pH. However, experience has shown that SRB cell effluents typically contain excess alkalinity at concentrations above those expected from SAPS units or anoxic limestone drains. This excess alkalinity is therefore available to ameliorate acidity contributions that might be impacting the receiving stream far removed from the original passive treatment site.

New Opportunities for Community Involvement

The construction of passive treatment systems is an ideal way to make the most of community volunteerism. The transplanting of wetland vegetation is the most common activity in which volunteers can become involved with passive treatment projects. However, the collecting of organic materials for sulfate-reducing bioreactor substrate opens an entirely new opportunity for local community organizations to release pent-up volunteerism. Some pet owners are often hard pressed to find useful and environmentally sound ways to dispose of significant amounts of manure (e.g., horse). Homeowners could divert tree trimmings or yard waste away from the local landfill and into a community stockpile of wood waste to be mulched (but not composted) and used in a nearby sulfate-reducing bioreactor. Farmers would have a place to dispose of moldy hay. Community events similar to paper drives could be used to collect materials in advance of a project. This not only lowers the cost of the project but also provides additional community buy-in.

SULFATE-REDUCING BIOREACTOR DESIGN EXAMPLES

Design Example No. 1

This is a hypothetical abandoned underground coal mine in Appalachia with a relatively small mine pool. The site is adjacent to a fresh water lake. The flow varies through the year, but the AMD chemistry is fairly constant. SAPS had been considered at this site but rejected due to the elevated aluminum concentration. Pertinent design parameters are listed below.

- 67 gpm peak flow
- pH = 2.5
- Fe = 152 mg/L (ferric iron)
- Aluminum = 30 mg/L
- Acidity = 500 mg/L
- 990 moles of Fe per day

The hypothetical passive treatment system will include two sulfate-reducing bioreactors (each treating 50 percent of the flow) to raise the pH, produce net alkalinity and remove nearly 100 percent of the aluminum and 95 percent of the iron. The system would be comprised of the following components:

- 1.7 acres of SRB cell 3 feet deep

- 0.25 acres of aerobic polishing cell

The costs of developing this design from initial concept to complete construction include:

- \$30,000 to \$50,000 for bench and pilot studies
- \$315,00 design and construction (assuming no donated materials or labor)

The 8,250 cubic yards of organic substrate originally installed would require replacement every 20 to 30 years. The substrate typically comprises about 33 percent of the construction cost. This would be about \$110,000 or less depending on the availability of local materials and in-kind donations. This and other maintenance costs are summarized on an annual basis in the table below. Some of these costs might be minimized through volunteer labor and other contributions.

Maintenance Item	Annual Cost
Replace Substrate	\$3,569
Dispose Substrate (20% of replacement cost.)	\$714
Weekly inspection & pipe clean?	\$5,000
Flushing for aluminum buildup	\$0
Sampling/lab costs lump sum	\$15,000
	\$24,283

The life cycle cost of this treatment (includes capital and operating cost) is about \$0.70 per thousand gallons treated.

Design Example No. 2

This is another hypothetical abandoned underground coal mine in Appalachia but with a relatively large mine pool covering over 100,000 acres. The site contributes nearly 50 percent of the metal load to a nearby river. The flow is relatively steady through the year, and the AMD chemistry is constant as well. The site has only 6 acres available for construction of a main treatment system, but there are no restrictions on effluent polishing. This is a major project due to the flow rate. Pertinent system design parameters are listed below.

- 3,000 gpm from a deep mine pool
- Sulfate = 1000 mg/L (50 effluent goal)
- pH = 5.5
- Fe^{+2} = 150 mg/L
- Al = 2 mg/l
- Mn = 2.7 mg/L (0.05 effluent goal)
- Acidity = 50 mg/L (“Hot Acidity”)

The 6-acre restriction eliminates a standard sulfate-reducing bioreactor. However, an enhanced sulfate-reducing bioreactor (ESRB) is feasible due to the steady availability of a waste alcohol product and other factors. The enhancement allows the footprint of the ESRB cell to

shrink and easily fit in the space available. The ESRB effluent will have a neutral pH and some excess alkalinity. However, it will also have elevated biological oxygen demand (BOD) and manganese, which require further polishing. Key features of this hypothetical system include:

- 4 acres of enhanced sulfate-reducing bioreactor cell 6 feet deep
- 9 acres of aerobic polishing cell (for Mn and BOD treatment)

The costs of developing this design from initial concept to complete construction include:

- \$200,000 for bench and pilot studies
- \$1.36M design and construction

The operating cost of the enhanced sulfate-reducing bioreactor (including paying \$2.00 per gallon for the alcohol) is \$674,000 per year or \$0.43 per 1000 gallon treated. The system effluent would meet drinking water standards. To be conservative, the above cost assumes that the substrate in the ESRB be replaced every 20 to 30 years due to metal sulfide precipitate buildup.

Design Example No. 3 - Do SRBs Need More Room?

This design example compares the area requirements for using a standard aerobic wetland and a standard sulfate-reducing bioreactor to treat a relatively large net alkaline flow. The design assumptions are listed below.

- 3,000 gpm from a deep mine pool
- pH = 6.5
- $\text{Fe}^{+2} = 50 \text{ mg/L}$ (817,560 grams/day or 14,638 moles per day)
- Net alkaline
- No manganese
- 10 acres available for main treatment cells

If an aerobic wetland dominated by cattails and other vegetation was designed on the standard assumption of 11 grams/day per square meter of iron loading criteria (which was established by U.S. Bureau of Mines researchers), approximately 18 acres of wetland habitat would be needed.

A sulfate-reducing bioreactor with an identical treatment capacity would cover 8 acres (probably split into four 2-acre cells plumbed in parallel). The cells would be 7.5 feet deep, and the AMD/ARD would enter them at the bottom and exit at the top. This upflow configuration allows the top of the cell to function as a primary dissolved oxygen polishing cell. The remaining available 2 acres would be fitted with a final aerobic polishing cell to complete the facility. In this situation, both cell types would work geochemically, but only one – the sulfate-reducing bioreactor – would be feasible.

SUMMARY

Sulfate-reducing bioreactors are not the only type of passive treatment technique available to the design engineer, and they are not applicable in every situation. However, they can handle a wide variety of flows and AMD/ARD chemistries in hostile cold climates, and they can treat aluminum-bearing AMD/ARD without plugging. Furthermore, they can generate excess alkalinity in their effluent that further enhances the quality of the receiving stream.

Sulfate-reducing bioreactors typically require large amounts of organic materials that are usually considered waste. Enhanced SRB cells can consume liquid organic wastes like antifreeze or cheese whey.

While not readily practiced, it may be feasible to build them in mine voids to provide in situ treatment at sites with limited land area.

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LONGEVITY OF MINE DISCHARGES FROM ABOVE-DRAINAGE UNDERGROUND MINES

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ABSTRACT

The duration of acid mine drainage flowing out of underground mines is important to watershed restoration and abandoned mine land reclamation projects. Reclamationists usually employ remediation strategies once (land regrading, revegetating, and installing water treatment) with the hope that these methods will adequately improve the water for a long time. An understanding of the changing acid water conditions from these portals over time will help in designing treatment methods. Past studies have reported that acid water flows from underground mines for hundreds of years with little change, while others state that poor drainage quality may last only 20 to 40 years. Several factors are important in making a prediction of the drainage quality over time, such as coal seam characteristics (primarily sulfur content), time since mine closure, flooding, mining method and amount of coal remaining, collapse of roof and other disturbances within the mine, and subsequent nearby surface mining. Over 50 above-drainage (those not flooded after abandonment) underground mine discharges were located and sampled during 1968 in northern West Virginia, and we revisited those sites in 2000 and measured water flow, pH, acidity, alkalinity, Fe, Al, and sulfate. Most of the discharges were from mines in the Pittsburgh and Upper Freeport coal seams, both seams were extensively mined in this area during the past 70 years. There was no significant difference in flows between 1968 and 2000 from these discharges, so we felt that the water quality data could be compared. Across all sites, significant changes in water quality were found between 1968 and 2000 for all parameters: pH increased from 3.1 to 4.0, average acidity declined from 1,140 to 295 mg/L (as CaCO_3), Fe decreased from 352 to 61 mg/L, Al decreased from 143 to 38 mg/L, and sulfate declined from 2,918 to 1,037 mg/L. Pittsburgh seam discharge water was much worse in 1968 than Upper Freeport seam water and drainage water from both seams improved from 70 to 80% over 32 years (roughly 1800 and 750 mg/L as CaCO_3 in 1968 compared to 375 and 250 mg/L as CaCO_3 in 2000). The implications of this research provide a framework for estimating time periods when underground mine drainage will have less impact on nearby streams and rivers.

INTRODUCTION

Acid mine drainage (AMD) is a serious problem from both surface and underground coal mines. According to the U.S. Environmental Protection Agency (1995) approximately 10,000 km of streams have been affected by AMD in the four states of Pennsylvania, Maryland, Ohio, and West Virginia. Many mines currently discharging AMD were operated and abandoned before enactment of the Surface Mining Control and Reclamation Act (SMCRA) of 1977. The Act provided standards for environmental protection during mining operations and placed the responsibility of AMD control and treatment on the operator (SMCRA 1977). The Act also provided a means for reclaiming

abandoned mines by taxing current coal operators, which generates funds for abandoned mine land reclamation programs. Even with millions of dollars spent in reclaiming abandoned mine lands, these abandoned mines still generate more than 90% of the AMD in streams and rivers in the region and most of this acidic drainage flows from underground mines (Faulkner, 1997; Zipper, 2000).

Because these sites were abandoned before 1977, no company or individual is responsible to treat the water and therefore the receiving streams are polluted and are essentially unusable. High flows and high levels of pollution (high acidity and metal concentrations) necessitates the use of chemicals for treatment, which tend to be expensive and labor intensive (Skousen et al., 2000). Costs for chemicals, dispensing equipment, electricity for pumps, and manpower all add up to significant public expense if the treatment entity is a government agency or utility. Perhaps the largest cost to the public is the unavailability of the waterbody for use and the accompanying impaired aesthetics and degraded water quality. Therefore, simple and inexpensive treatment approaches are being sought as well as a better understanding of the natural processes within mines that affect water quality over time.

An understanding of the behavior of acid-producing materials within abandoned mines would allow an estimate of the longevity of the acid discharge, which will aid in determining remediation strategies and the short and long-term costs of treatment. However, the changes in flow and water quality over time from surface and underground mines are not well documented. Surface mining generally removes 90% or more of the coal (which often contains the highest sulfide content and hence the acid-producing potential) thereby leaving little in the backfill for continued reaction and acid generation. The coal that does remain was broken apart by blasting and the acid products are leached fairly rapidly, typically within 16 to 20 years (Meek, 1996). Special handling of toxic materials may reduce the amount of pyrite oxidized, and the addition of alkaline material during mining may neutralize acid *in-situ*, both of which decrease the total acid load coming from the site (Brady et al., 1990; Perry and Brady, 1995; Rich and Hutchinson, 1990; Rose et al., 1995; Skousen and Larew, 1994). During the 20 years after reclamation, discharge water quality may reach pre-mining levels. Acid discharge from underground mines usually lasts much longer, sometimes 50 to 100 years (Wood et al., 1999).

The earliest model for the longevity of AMD from underground mines was the former British Coal Corporation's 'rule of thumb' for below-drainage mines. Iron concentrations in an abandoned mine were assumed to decrease by 50% during each subsequent pore volume flushing (the time period required for the mine pool to be filled with water). For example, if 10 years are required for a mine to fill with water, the iron concentration should decrease by half every 10 years. This suggests an exponential decay as described by Glover (1983).

Other researchers have observed that the most severe drainage occurs within the first few decades and even the largest systems settle to lower levels within 40 years. For mines in the UK, a neutral pH was reached within 30 years, and after 40 years the iron concentrations were less than 40 mg/L (Wood et al., 1999). Jones et al. (1994) also showed that underground mine water in Pennsylvania changed from acidic to neutral over a period of decades.

Lambert and Dzombak (2000), studied underground discharges in the Uniontown Syncline of Pennsylvania and found that the discharges could be divided into three distinct areas: 1) an unflooded, above-drainage area, which had been mined out by 1940; 2) a flooded, below-drainage area, which had been mined out by 1940; and 3) a flooded, below-drainage area, which had been mined out by 1970. Water quality measurements were taken in 1974 and 1999. The water quality from unflooded above-drainage mines after 40 to 60 years after closure showed water pH to be between 3 to 3.5 (slightly improved during the subsequent 25 years), Fe to be 10 mg/L in 1974 and <2 in 1999, and sulfate to be 800 mg/L in 1974 and declining to 600 mg/L in 1999 (water in all cases to be net acidic). The water quality from the older flooded, below-drainage mines was pH 6.0 to 6.4, Fe improving from 45 to 25 mg/L, and sulfate to be 1700 mg/L in 1974 to 1000 in 1999 (net alkaline water). In the younger, flooded, below-drainage mines, pH increased from 3.1 in 1974 to 5.9 in 1999, Fe decreased from 140 mg/L to 70 mg/L, while sulfate decreased from 2000 mg/L to 900 mg/L in 1999. Therefore, the researchers concluded that underground mine water quality changed from acidic to alkaline within 30 years after closure and flooding in their geologic setting. They also showed that above-drainage, unflooded areas improved in drainage, but still remained net acidic (but low metal concentrations) after 60 years since closure. Other researchers have found similar results in this region (Brady et al., 1998; Capo et al., 2001).

Donovan et al. (2000) monitored the water quality of the Montour mine, which had a section that had been flooded since the 1970s and also a section that became flooded in 1982. In 1984, the mines were interconnected and water quality changes from 1983 to 1998 were monitored at a pump and treat station. Water conditions were strongly acidic (pH ~3.0, acidity ~2200 mg/L) for the first two years, after which acid began to decline exponentially. Seven years after flooding (five years after peak acidity), the water became net alkaline and has stabilized at a pH of 6.4, net alkalinity at 200 mg/L, and iron around 60 mg/L.

Younger (1997) divided the acid load flowing from underground mines into two categories. “Vestigial” acidity is associated with the first-time flushing of acid products from the mine during initial abandonment and flooding. “Juvenile” acidity is produced from ongoing pyrite oxidation due to fluctuations in the water table, and may persist for hundreds of years depending on the pyrite content and hydrology of the underground mine system. The longevity of AMD at a given site is dependent on the rate of depletion of both the vestigial and juvenile acidity.

In above-drainage underground mines, water continually flows out at the down-dip side of the mine and acid-generation may continue for decades until the pyrite is exhausted (Lambert and Dzombak, 2000; Younger et al., 1997). In these situations, the rate of dilution is greatest where the recharge rate of the mine is high, water flow out of the mine is high, and the mine volume is small (Younger, 1997). The fluctuating water level and pooling effect due to seasonal variations in precipitation also aid acid generation. During low water levels, pyrite oxidation forms iron hydroxysulfate solids, which settle on coal and rock surfaces due to evaporation. When the water level rises, these acid products are dissolved and released into the mine pool. Pyrite oxidation can continue to occur on the wet, oxidized mineral surfaces, producing a continuing cycle of acidity production (Younger, 1997). Therefore, these above-drainage underground mines can discharge poor water quality for longer periods than flooded mines.

Discharge chemistry is affected by several primary factors. One important factor is the coal seam, and more specifically the pyrite content of the mined coal. Each coal seam is unique with relatively predictable chemical and physical features, which may affect discharge water quality. However, it does not appear that pyrite must be exhausted in order for drainage quality to improve.

The mining method and degree of coal removal within a mine are other variables affecting discharge chemistry. Room and pillar underground mining (the most common method in this area) often left more than 50% of the coal as support for the roof. After abandonment, this coal continues to weather and crack away from the pillar, allowing more of the pyrite in the pillar to react. Remining old underground mines by surface mining has the potential to improve pre-existing acid discharges by removing coal pillars and then reclaiming the site to current reclamation standards, which often includes mitigating any acid mine drainage potential (Hawkins, 1994; Richardson and Dougherty, 1976).

Previously mined sites with acid discharges can be also affected by subsequent, adjacent surface mining. The flow may decrease because the surface overlying the recharge area has been reclaimed and vegetated, which could decrease infiltration into the underground mine. This effectively decreases the size of the mine pool and the subsequent flow rate out of the mine. Adjacent surface mining may also cause collapse of the roof in portions of the mine and reduce the void space, thereby changing flow paths or altering interconnection of certain areas. The collapse of pillars or roof rocks could create fresh pyrite surfaces for AMD reactions to take place and increase acid production. The degree of disturbance in a mine is difficult to measure and its ensuing impact on mine water chemistry is also difficult to predict over time.

A study in 1968 identified and sampled over 200 underground mine discharges in the northern West Virginia coal region. Most of these discharges were coming from above-drainage underground mines in the Upper Freeport and Pittsburgh coal seams. We revisited those sites in 1999 and 2000 and analyzed the water from the same discharge points. Several of the sites also had been sampled and analyzed in 1980, which provided an intermediate sampling time to assess acidity and iron concentrations from the mine. From this data set, we determined the change in water quality during this 30-year period and evaluated the factors that may have been responsible for their change. We tried to correlate these changes to disturbance effects and coal seam differences.

METHODS AND MATERIALS

Fifty underground mines and their associated discharges were sampled and used for water quality comparison. The sites were located in Preston and Monongalia Counties of West Virginia, and Fayette County in Pennsylvania. The sites were found according to marked locations on Valley Point, Cuzzart, Kingwood, Masontown, and Morgantown North USGS quadrangle maps. The discharges all drained underground drift mines to various streams within the Monongahela River Basin. Most mines operated in the Upper Freeport and Pittsburgh coal seams, but a few sites mined the Bakerstown, Upper Kittanning, and Lower Freeport seams. The drift mining method was generally used in hilly areas where coal seams outcrop along the contour and where the seam is nearly flat or slightly dipping.

The Pittsburgh coal seam is the lowest member of the Monongahela Series. The seam has a moderate sulfur content (1.5 to 2.0%) and a low ash content (6%). The Pittsburgh coal is composed of alternate layers of coal and slate or shale. A typical Pittsburgh coal cross-section shows a 3-m layer of good coal, a 0.7-m layer of bone coal or slate, and another 3-m layer of good coal. The Pittsburgh coal along the Monongahela and Cheat Rivers is located close to the surface (Hennen and Reger, 1914).

The Upper Freeport coal seam is the topmost strata of the Allegheny Formation of the Pennsylvanian System. Freeport coal is relatively low in sulfur (<1.5%) and has a moderately low ash content (8 to 12%). It is a multiple-bedded seam that is divided into a top coal and bottom coal, separated by a shale interlayer, all averaging a total of six feet in thickness (Hennen and Reger, 1914). The overlying strata in the Conemaugh Group contains several massive sandstones and some shales. Limestone or alkaline-bearing rock units are not generally found within 50 m above the Upper Freeport coal in this area, so very little overlying geologic material is available for acid neutralization (Hennen and Reger, 1914).

1968 Study

A previous study was conducted from 1968-1970 where field crews were sent out to identify all coal mines within the Monongahela River Basin and to sample their discharges. Each crew worked from 7.5-minute USGS topographic maps on which they outlined mine boundaries and indicated mine openings. Field sheets were also completed at each site with location and overburden information. Sites with a discharge were identified on the maps, flow rates were determined, and the water was sampled. The flow was measured when possible with a bucket and stopwatch. For larger flows, the crew installed a V-notch weir and measured flow rate. These values were recorded on the field sheet. In the field at the time of water collection, the pH of the discharge was measured using an electrometric pH meter, and temperature was checked with a lab grade thermometer. These values were recorded on the field sheet.

Two water samples were taken at each discharge in this early study: 1) a plastic quart bottle was filled, put on ice, and then analyzed in the laboratory for acidity, alkalinity, hardness, sulfate, and pH; and 2) a glass bottle was filled, treated with acid, and then analyzed in the laboratory for metals (total iron, manganese, aluminum). Water samples were delivered to the laboratory each Friday where they were analyzed using methodology from the latest edition of Standard Methods. Water analyses were monitored for accuracy and precision by running periodic samples of reference standards (Personal communication, Gary Bryant, U.S. EPA, 1999).

1999 Study

Mine sites and their associated point discharges were located on the USGS topographic map marked by the 1968 crew. Based on observations of the surrounding conditions, each site was categorized as disturbed or undisturbed. Undisturbed meant that the site appeared to have remained untouched since 1968 and that no obvious influence had occurred to the mine site or within the underground mine. Disturbed suggested that either surface mining had occurred in the area since 1968 or the area has been reclaimed or remined.

Discharges were sampled as close to the mine portal as possible. Flows were calculated using a measured cross-sectional area and flow velocity or an estimate was made. Two water samples were taken at each sample point: 1) a 250-mL unfiltered sample was taken for general water chemistry (pH, conductance, acidity, and alkalinity); and 2) a 25-mL, filtered sample was acidified to pH <2 with 0.5 mL concentrated nitric acid and used to determine metal concentrations.

Water pH, alkalinity, and acidity were determined by a Metrohm pH Stat Titrino System (Brinkman Instruments, Wesbury, NY). Conductivity was measured using an Orion Conductivity meter Model 115 (Orion Instruments, Beverly, MA). The metal analysis was performed using an Inductively Coupled Spectrophotometer, Plasma 400 (Perkin Elmer, Norwalk, CT). Sulfate was measured turbidimetrically by flow injection analysis (Lachat Instruments, Milwaukee, WI).

Statistical Analysis

A subset of 28 sites for which we obtained a complete data set (pH, acidity, iron, aluminum and sulfate) was used for the statistical analysis. These 28 discharges emanated from 24 different mines. Analysis of variance was performed using a full model with main effects of Year, Disturbance, Coal Seam, and all possible interactions as class variables using PROC GLM (SAS Institute). Based on Type III sums of squares, the least significant term was dropped and a new analysis performed. This process was repeated until an optimal model for each parameter, the one that minimized the mean square error (MSE), was determined. Means for significant ($\alpha = 0.05$) model terms were separated using Tukey's Honestly Significant Difference ($\alpha = 0.05$).

RESULTS AND DISCUSSION

Generally, models were significant for all parameters (Table 1) even though R^2 values were somewhat low. A low R^2 is not entirely unexpected given the large, inherent variability of this data set and the relatively simple model used. Other variables likely to affect the variance in this data set include mine age and size (Table 2), mining practices and mine pool stratification (Ladwig et al., 1984). A slow mixing of water at various depths occurs between the dilute, newly-recharged waters at the top of the mine pool and the more dense, deeper waters containing high dissolved solids. Depending on the location of discharge (whether pumped from low levels in the mine pool, or discharged freely at the top of the pool), the water quality coming from the same mine pool may be quite variable.

None of the main effects or interactions was significant for the parameter Flow (Table 1). The fact that there was no Year effect for Flow suggests that these two sampling years (1968 and 2000) were similar and that water quality data can be compared directly. This is an important consideration because water quality parameters are sensitive to flow, and the within and between year variability can be large. Flow can affect water quality by diluting concentrations being released from the mine or can make the discharge appear more severe during low flow conditions.

The main effects of Year and Coal Seam were significant for the water quality parameters Acidity, Iron, Aluminum, and Sulfate; but only the Year effect was significant for pH (Table 1). Water quality was better in 2000 than in 1968 and worse if draining

from the Pittsburgh coal seam (Table 3). There was a significant Year*Coal Seam interaction for Acidity and Sulfate. There were small but significant improvements in Acidity and Sulfate on the Upper Freeport sites, but the largest improvements occurred on the Pittsburgh sites (Figure 1). Significant differences were found in water quality between the Upper Freeport and Pittsburgh sites in 1968, but these differences vanished in 2000. That is, the main effect of Coal Seam on Acidity and pH is due principally to the water quality differences in 1968. The same general trends were also observed for Iron and Aluminum. There was a significant Disturbance main effect for only Flow and Aluminum, suggesting that it is time and not disturbance that has the largest effect on water quality discharging from a mine. These trends support the idea that natural attenuation occurs within underground mines.

This attenuation may be similar to what occurs on surface mines. As water infiltrates into the mines, acid products are leached from the rocks, and eventually water quality can reach pre-mining levels (Meek, 1996). This process may not be as straightforward in an underground mine, due to subsidence and ever changing flow paths. The attenuation can also be related to Younger's description of vestigial and juvenile acidity. The samples collected in 1968 may have been close enough to the time of mine closure to still be experiencing vestigial acidity. The samples collected in 2000 are examples of the juvenile acidity that continues to be released from the mines for up to 100s of years (Younger, 1997). Our data set also suggests that the models established by Jones et al. (1994) and Younger (1997) can be applied to above-drainage, shallow, drift mines.

It is important to consider the age of the mines in order to determine the break-off between vestigial and juvenile acidity (Table 2). For six of the twenty-eight discharges, 1980 data was found and used to analyze the trend of vestigial and juvenile acidity (Figure 2). The data at these six discharges show the overall trend of improving from 1968 to 1980, and then improving more between 1980 and 2000, except for Lake Lynn 3 and Martin Creek 2. Cheat River 5 began operation in 1935, meaning it would be 45 years old when sampled in 1980. The vestigial acidity should have been released by this time, but the mine should continue to release lower levels of juvenile acidity. In 1980, the youngest mine was Martin Creek 2. It shows dramatic decreases in both iron and acidity concentrations as compared to the 1968 sample, even though sulfate increased. This one mine shows that it has released its vestigial acidity in less than 25 years. It would be valuable to have large data sets over time to determine the exact break-off point when acidity comes primarily from vestigial to juvenile.

CONCLUSIONS

Our data indicate that the water coming from above-drainage underground mines shows significant improvement over time. A 65 to 80% reduction in acidity, iron, aluminum, and sulfate were found for these mines in northern West Virginia between 1968 and 2000. This suggests that remediation strategies for above-drainage underground mines may be augmented depending on the age of the mine and that passive treatment methods may be applicable for water treatment as acidity and metal concentrations decline with time.

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Table 1. Summary statistics for overall GLM model and significance level (Pr>F) for main effects and interactions.

	Parameters					
	Flow	pH	Acidity	Fe	Al	SO ₄
	L/min	s.u.	-----	mmol/L	-----	
Overall Model						
Mean	74.5	3.4	14.3	3.8	3.3	20.6
MSE	28345	1.60	161.70	10.09	10.34	260.51
R ²	0.09	0.21	0.48	0.52	0.42	0.48
Pr>F	0.0773	0.0068	<0.0001	<0.0001	0.0003	<0.0001
Individual Model Terms						
	----- Pr > F -----					
Year	0.1135	0.0248	<0.0001	<0.0001	<0.0001	<0.0001
Coal Seam	na	0.0604	0.0019	0.0113	0.0483	0.0022
Disturbance	0.1011	na	Na	na	0.2463	na
Year * Coal Seam	na	0.1731	0.0077	0.0613	0.1101	0.0016
Year * Disturbance	na	na	0.2541	na	Na	0.0723
CoalSeam*Disturbance	na	na	Na	na	0.2336	na
Year*CoalSeam*Disturbance	na	na	Na	0.3727	0.2740	na

na: not applicable; signifies a term dropped from the model because excluding it decreased MSE.

Table 2. Mine name, the year the mine opened, disturbance category, coal seam mined and mine area affected, for each discharge point sampled in 1999-2000.

Discharge Point	Mine Name	Year Opened	Category	Coal Seam	Mine Area (ha)
Bull Run 1	Kimberly	1962	Undisturbed	UF	21
Bull Run 2	Roxy Ann	1957	Undisturbed	UF	923
Bull Run 3	Roxy Ann	1957	Disturbed	UF	923
Bull Run 4	Sherrey	1955	Undisturbed	UF	282
Cheat River 1	Morgantown North E		Undisturbed	Pittsburgh	
Cheat River 2	Morgantown North D		Disturbed	Pittsburgh	
Cheat River 3	Frederick No. 1 Mine		Disturbed	Pittsburgh	
Cheat River 4	Morgantown North A		Undisturbed	Pittsburgh	
Cheat River 5	Canyon Mine	1935	Disturbed	Pittsburgh	448
Cheat River 6	Mountain Run	1952	Disturbed	UF	311
Cheat River PA1	Morgantown North B		Disturbed	Pittsburgh	
Cheat River PA2	Morgantown North C		Undisturbed	Pittsburgh	
Fickey Run 1	Valley Point C		Undisturbed	UF	
Fickey Run 8	Tri State	1952	Disturbed	UF	78
Glade Run 1	Liston	1955	Disturbed	UF	26
Glade Run 2	Valley Point F		Undisturbed	UF	
Lake Lynn 1	Hollow	1943	Undisturbed	Pittsburgh	34
Lake Lynn 2	Canyon Mine	1935	Disturbed	Pittsburgh	448
Lake Lynn 3	Canyon Mine	1935	Disturbed	Pittsburgh	448
Martin Ck 2	Me	1955	Disturbed	UF	11
Martin Ck 3	Me	1955	Disturbed	UF	11
Middle River 1	Mountain Run	1952	Disturbed	UF	311
Muddy Ck 11	Ruthbell #3	1943	Disturbed	UF	35
Muddy Ck 2	Cuzzart C		Undisturbed	UF	
Muddy Ck 3	Shermike		Disturbed	UF	
Muddy Ck 6	Cuzzart B		Undisturbed	UF	
Muddy Ck 8	Cuzzart F		Undisturbed	UF	
Muddy Ck 9	Tri State	1952	Disturbed	UF	78

Table 3. Mean water quality for the main effects of year and coal seam.

		Flow	pH	Acidity	Iron	Aluminum	Sulfate
		L/min	s.u.	-----mmol/L-----			
Year	1968	na	3.1	22.8	6.4	5.3	30.4
	2000	na	4.0	5.9	1.1	1.4	10.8
Coal Seam	Pittsburgh	na	na	21.7	5.2	4.6	29.8
	U. Freeport	na	na	10.3	3.0	2.6	15.5

na: not applicable; signifies a term dropped from the model because excluding it decreased MSE.

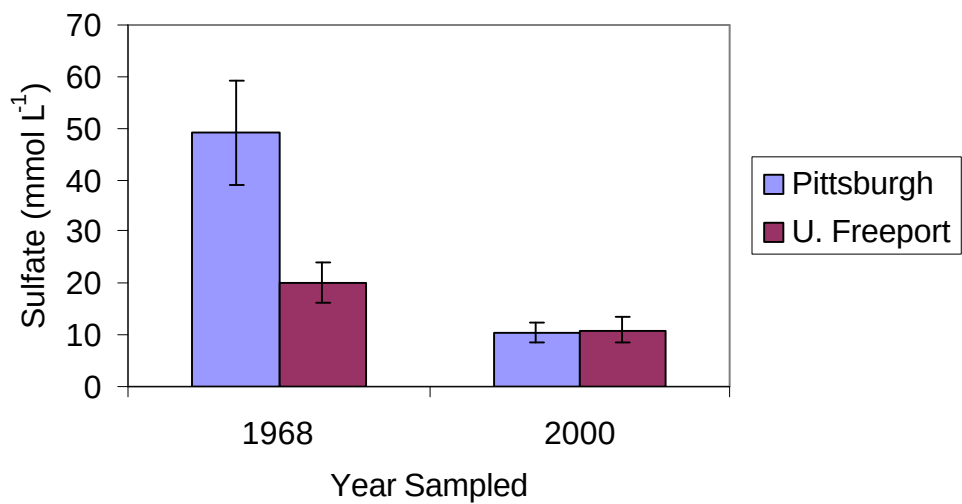
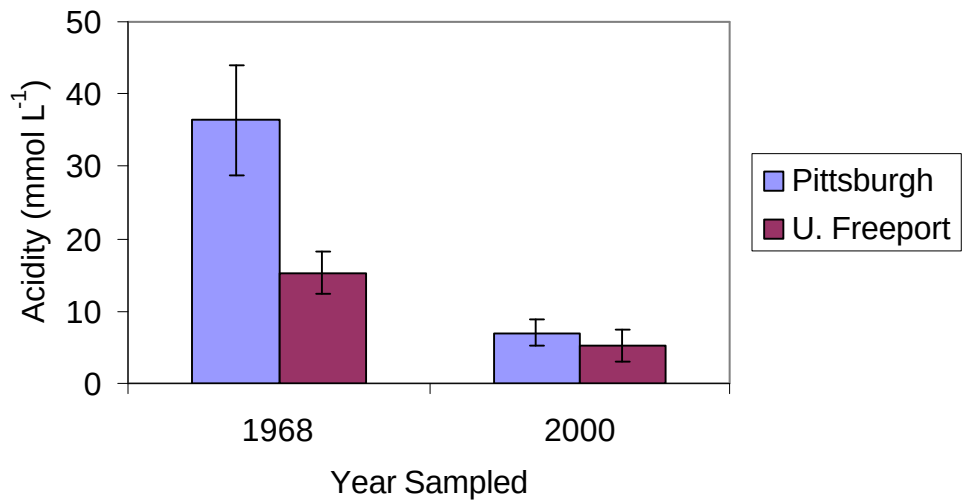


Figure 1. Year*Coal Seam interactions for sulfate and acidity. There is a significant difference between the Pittsburgh and Upper Freeport coal seam in 1968 for both acidity and sulfate, but not in 2000.

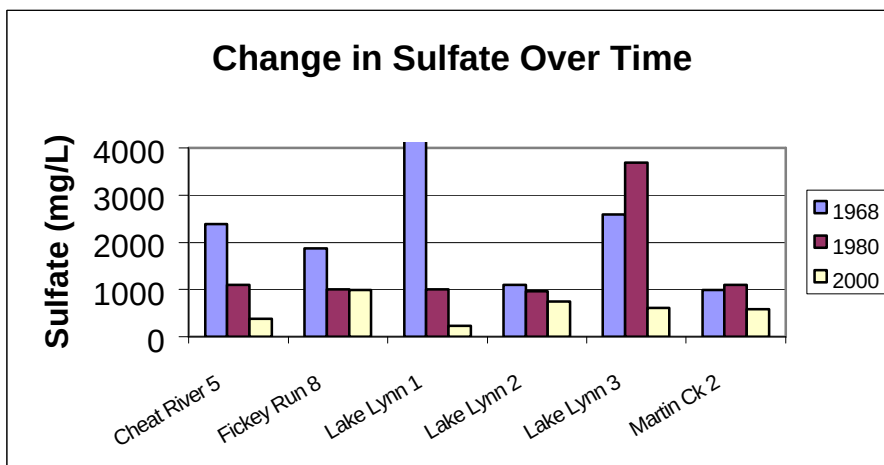
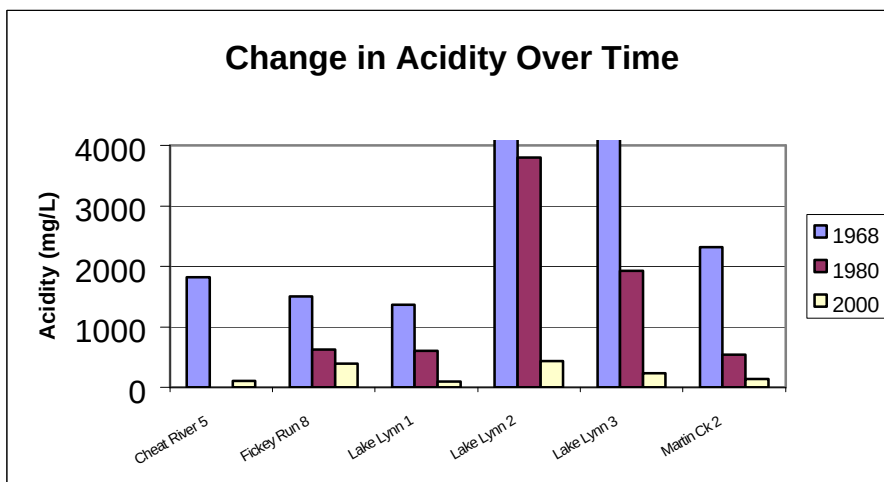
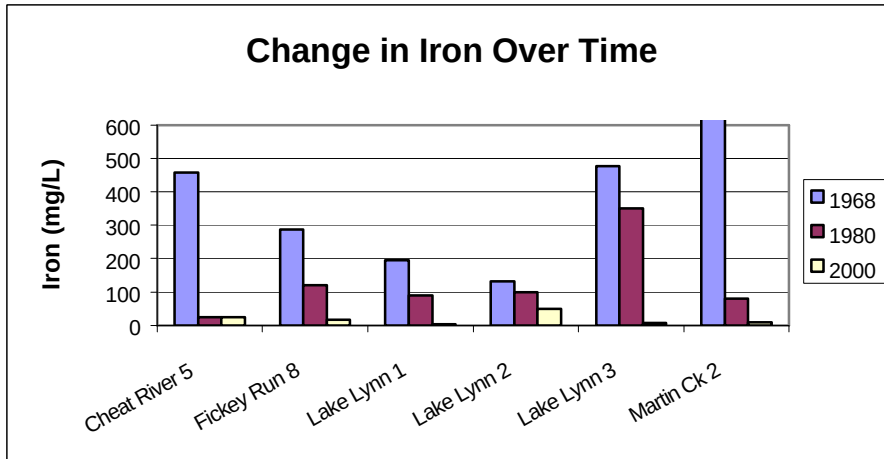


Figure 2: Water quality in 1968, 1980, and 2000 for six discharges.

Table 4: Water quality in 1968, 1980, and 2000 for six discharges.

Discharge	Year	pH	Flow	Acidity	Iron	Aluminum	Sulfate
		s.u.	L/min	-----	mmol/L	-----	
Cheat River 5	1968	2.6	19	1825	458	101	2392
	1980	2.6			25		1100
	2000	3.5	38	104	24	11	379
Fickey Run 8	1968	3	49	1505	288	84	1872
	1980	2.3	1	625	120		100
	2000	3.5	4	390	17	34	996
Lake Lynn 1	1968	2.8	38	1368	495	100	8861
	1980	2	1	605	90		1000
	2000	3.5	6	102	4	9	240
Lake Lynn 2	1968	3.2	38	4690	131	302	1105
	1980	2	1	3800	100		960
	2000	2.8	38	434	49	33	745
Lake Lynn 3	1968	3.1	480	4988	477	532	2593
	1980	2	1	1930	350		3690
	2000	2.9	6	237	7	33	619
Martin Ck 2	1968	2.7	57	2315	640	161	990
	1980	2.4	1	545	80		1100
	2000	4.2	38	135	10	4	587

**TECHNICAL PAPER SESSION 16
CULTURAL RESOURCES AND BROWNFIELDS**

Title: **Uranium Mining in Cottonwood Wash: A Quick Look at 50+ Years**

Author: [Lee Bennett](#)*, Archaeologist/Manager, Bennett Management Services, LLC

Title: **Abandoned Mine Reclamation in Culturally Sensitive**

Areas: An Example from Cottonwood Wash, Utah

Author: [Kathy Huppe](#)*, Cultural Resources Coordinator, Cottonwood Wash Abandoned Mine Reclamation Project, Bureau of Land management

Title: [A Brownfields Redevelopment Opportunity at an Abandoned Mine Lands Site](#)

Author: [Joseph Gendron](#)*, Brownfields Coordinator/Trails & Open Space Coordinator, Town of Silver City, New Mexico

Title: [Economic and Community Development Opportunities for Mine Scarred Lands](#)

Author: [Christopher M. LaRosa](#)*, Community Revitalization Policy Specialist, Marasco Newton Group Ltd.

A BROWNFIELDS REDEVELOPMENT OPPORTUNITY AT AN ABANDONED MINE LANDS SITE

Joseph Gendron, P.E., Brownfields Coordinator, Town of Silver City, New Mexico

ABSTRACT

In 1999 the Town of Silver City, New Mexico purchased a 500-acre historic mining area known as Boston Hill located immediately southwest of the Town. It was the Town's first open space acquisition. In 2000, the Town received an EPA Brownfields Demonstration Pilot Grant with an extra \$50,000 to assess and plan for development of Boston Hill as a greenspace.

The Town has also been approved for a grant to develop a trail system on Boston Hill from the New Mexico Recreation Trails Advisory Board and would like to emphasize the mining heritage represented by the landscape. Even though the New Mexico Abandoned Mine Lands Bureau (AMLB) had treated the site in the late 1980's, their work was incomplete and several shafts remain on the property. Efforts to get the AMLB to return to Boston Hill have so far been unsuccessful.

The Town has developed a partnership with the Bureau of Land Management to pursue mitigation of remaining mine shafts on adjacent public land with the hope that there will be a spill over effect onto Town owned land. The Town is under severe budget constraints due to the recent layoffs associated with the closing of the Phelps Dodge Chino Mine and does not have funding to address the mitigation of the shafts remaining after the last AMLB project.

The Town plans to use a portion of the trail system grant to install educational signage to alert visitors to potential hazards along with low impact and unobtrusive barriers to delineate areas where extra caution is advised. Visitors to the site, therefore, would be educated about remaining abandoned mine hazards as they entered the site at trailheads as well as with site-specific or hazard-specific interior signage.

The Boston Hill mining area is adjacent to a community of 12,000 that is struggling to grow beyond the typical boom-bust economy built around mining. Emphasis of the areas mining heritage is seen as an opportunity to attract tourists while preservation of open space and development of a trail system improves the overall quality of life in the community.

INTRODUCTION

Boston Hill is an abandoned mine lands property purchased by the Town of Silver City, New Mexico in 1999 as an open space preserve. It was the Town's first open space acquisition and is located adjacent to, and accessible from, the historic downtown area. Prior to the purchase, a contractor for the New Mexico Environment Department performed a Phase I and a partial Phase II environmental site assessment under the state's Targeted Brownfield Assessment program. Isolated occurrences of certain heavy metals were noted but concentrations were not sufficient to pose a threat to human health from exposure resulting from recreation use¹.

In 2000, the Environmental Protection Agency awarded the Town a \$200,000 Brownfields Demonstration Pilot Grant and an additional \$50,000 grant to evaluate green space opportunities at the Town's brownfield properties, including Boston Hill. In 2002, the Town Council approved a *Trails and Open Spaces Plan* to guide in the implementation and creation of a trails and open spaces network for the Town². Boston Hill was identified as the Plan's #1 priority. Also in 2002, the Town was awarded a \$38,500 grant from the New Mexico Energy, Minerals and Natural Resource Department (EMNRD), with concurrence from the Federal Highway Administration (FHWA), to develop a trail system on the Boston Hill Open Space Preserve.

The Town of Silver City has developed a partnership with the Las Cruces office of the BLM to develop a mitigation plan for shafts and other abandoned mine land features on BLM land with the hope that there will be a spillover effect to address similar features located on Town land. The Town is also exploring a partnership, in conjunction with the BLM, with WERC, a consortium for environmental education and technology development that includes New Mexico State University, the University of New Mexico, New Mexico Tech and the Sandia and Los Alamos Laboratories.

It is the Town's intent, through its Brownfields Demonstration Pilot, to preserve a portion of the Town's mining heritage and re-develop the abandoned mine area of Boston Hill in such a way as to provide a national model for other areas with similar opportunities. How does Silver City's emphasis on public recreation and heritage conservation at an abandoned mining area jive with mottos such as "Stay Out and Stay Alive"? Are the public safety concerns at abandoned mine lands sites so great that these lands should forever remain "abandoned and underutilized", or worse, have their heritage value destroyed or diminished in the process of making them "safe". Are there creative ways to overcome these redevelopment barriers?

GEOGRAPHY, GEOLOGY AND HISTORY

The approximately 550-acre area known as Boston Hill is located at the southern extremity of the Silver City Range, a portion of which forms the Continental Divide. Elevations on Boston Hill range from 6000 to 6380 feet. The climate is considered mild with summer temperatures rarely exceeding 100 degrees F. and with winter producing only occasional light snowfalls. Most precipitation occurs during the months of July, August and September with total precipitation averaging about 18 inches per year. Plant and animal life is typical of pinyon-juniper habitat. Copper mining, government, tourism and education are the mainstays of the local economy.

Geologic formations on Boston Hill range from Pre-Cambrian to Quaternary with a nearly complete section of Paleozoic formations making up the majority of the surface exposures³. All the sedimentary rocks older than Quaternary have been cut by sills and dikes believed to be of Laramide age. The dikes occupy pre-existing faults. A quartz monzonite porphyry known as the Silver City intrusion forms the eastern boundary of the area. The site resides structurally in a northwest-trending transition zone between the Colorado Plateau on the north and the Basin and Range province to the south. An on-site well has a static water level of 51 feet with the regional groundwater flow to the southeast⁴.

Silver ores, smelted in adobe furnaces, were the focus of early mining beginning in 1870. The area we know as Boston Hill actually consists of three hills. The north face of the smaller hill, known in the early days as Legal Tender Hill (or ledge), is where the Massachusetts and New Mexico Mining Company (also known as the Boston Company) conducted mining operations in 1879⁵. Adjacent mining claims were owned by the Plymouth Rock Company, a separate company but with the same board of directors. A mill was built on Yankie Creek at the base of the hill. By 1883, the Company was in financial trouble and the mine changed hands shortly after, but not before adding a eastern name to this western town.

The completion of the Silver City, Deming and Pacific railroad in 1883 allowed for the transportation of heavy machinery and construction of two smelters. These operated until 1907 and by 1914 the mining of silver ore ceased in the area. The mining of manganiferous iron ore on Boston Hill commenced in 1916 with the ore shipped to Pueblo, Colorado for smelting. World War II saw a peak in manganiferous iron ore production of 86,000 long tons grading out at 13% manganese and 37% iron⁶. Production after World War II was sporadic and ended in the late 1970's, a factor in the withdrawal of rail service to Silver City at the same time.

Because the Town of Silver City is so close to Boston Hill, separate residential communities of miners did not develop. Cultural resources on Boston Hill, besides the unique mine altered landscape itself, include a powder magazine, a blasting cap magazine, numerous trash scatters, erosion control structures and remnants of the alignment of the Silver City, Pinos Altos and Mogollon railroad that operated between July 1906 and June 1908. The archeological survey performed by the Town also identified 13 vertical shafts, 55 open cuts, 383 prospects and 123 waste rock concentrations⁷.

ABANDONED MINE LANDS RECLAMATION

A 1986 environmental assessment by the New Mexico Abandoned Mine Lands Bureau (NMAMLB) of the Mining and Minerals Division (MMD) of the Energy, Minerals and Natural Resources Department (EMNRD), identified 150 sites on Boston Hill as high priority⁸. These included deep shafts, air and light holes over room and pillar mined areas with an average drop to floor of 40 feet (on adjacent private, county and BLM property) and thin overburden over the Globe (county) and Silver Spot (BLM and private) workings. The preferred alternative called for filling 19 shafts, 38 stope holes and one adit. Blasting down thin overburden over portions of the Globe and Silver Spot workings and adding fill to cover the resulting high walls, and filling stoped holes in the Legal Tender (BLM and private) mine roof was also planned. The intent was that no trespassers or landowners would be in danger

of falling through the roof of a mine working or down a shaft. No work was proposed at the several pits with high walls.

After the environmental assessment document was made available to the public, the author and a biology professor at Western New Mexico University (WNMU) questioned the NMAMLB about its plan for the Legal Tender Mine knowing that this mine was a critical local bat habitat. This led to a biological reassessment and a modification in the plan for the Legal Tender even though the U.S. Fish & Wildlife Service had given clearance for the project⁹. The area would be fenced rather than filled to protect the bat habitat with WNMU charged with maintenance of the fencing. The adjacent Globe Mine, owned by the County, was also fenced.

The NMAMLB project that took place in 1989 addressed several of the high hazard areas of Boston Hill but, as discovered during the archeological survey commissioned by the Town in 2000, at least 13 shafts remain un-mitigated. A feature that was considered the highest ranked hazard by one investigator because it was outside any fenced area and adjacent to a major City street was not addressed¹⁰. All the fences installed during the project have been compromised and WNMU has not provided maintenance.

In 2000, during the development of the grant application for the Brownfields Assessment Demonstration Pilot Grant, a letter of support was solicited from Kerrie Neet, the Mine Regulatory Bureau Chief of the MMD. In her letter of support, she stated that:

“MMD is supportive of the utilization of this abandoned mine area as public open space as an alternative post reclamation mine land use. The Abandoned Mine Land Program of MMD has expended in excess of \$400,000 safeguarding mine features in the area (including an adjacent area known as Chloride Flats) which were hazards to public health and safety. Although MMD is supportive of the development of this area for public use, further participation under the Abandoned Mine Lands program is likely limited in scope and dependent upon project qualification and funding availability¹¹.”

THE BROWNFIELDS ECONOMIC REDEVELOPMENT INITIATIVE

Brownfields are industrial and commercial sites that are abandoned or underutilized because of real or perceived contamination. Redevelopment and reuse of these sites can bring important benefits to communities, particularly those such as Silver City that is experiencing a depressed economy. The recent closure of the Phelps Dodge Chino Mine has left county and municipal government struggling to make ends meet. The selection of the Town of Silver City by the Environmental Protection Agency (EPA) to receive a Brownfields Demonstration Pilot grant has paved the way for the Town to look at economic development opportunities associated with brownfield properties.

The program strategy for the Town of Silver City's brownfields program is “to take advantage of the Town's unique qualities and develop its underutilized and degraded resources to improve the quality of life in our small town and revitalize our community”. Community revitalization, and the **“removal of tarnish from Our Silver”**, is seen as the key to attracting new business to our community¹².

The Town's purchase of Boston Hill was made possible by a bequest from a former resident, Lenny Merle Forward. As the newly hired brownfields coordinator, my first job was to apply for a grant to develop a trail system on Boston Hill. The application was

successful and the Town recently signed a Joint Powers Agreement with the EMNRD, administrator of the National Recreation Trails Act in New Mexico. The project calls for the development of three trailheads, including one in historic downtown Silver City, and a ten-mile trail system. The first trail building work party on Boston Hill took place on the first weekend in August 2002, in partnership with the local Silver Spokes bicycle club and the International Mountain Biking Association.

Even prior to the development of this trail system, Boston Hill is used today by many citizens for hiking, bicycling, jogging, and walking their dogs as well as solitude from town life and appreciation of the vast vistas that can be seen from elevated areas. Western New Mexico University has utilized Boston Hill for geology and biology studies while the local Native Plant Society periodically sponsors hikes in the area to explore its unique fauna that grows so well on the highly mineralized soil.

The Town Council has consistently shown support for the Boston Hill project beyond the initial purchase and the approval of the Trails and Open Spaces plan. In June of this year, the Council unanimously approved the purchase of an additional 14.5 acres that was critical to the protection of the Boston Hill Open Space preserve with remaining money in the Forward fund.

There is a national trend by state and federal agencies to reduce public danger and potential liability at abandoned mine land sites by discouraging public access, often by destroying the mine features¹³. Creative strategies are needed to buck this trend and several communities across the West like Silver City are exploring the benefit of emphasizing their mining heritage to attract tourists. The recently signed brownfields legislation that will fund the national program in FY 2003 and beyond carries a new emphasis on “mine scarred lands” as brownfields and will present more opportunities for communities across the nation to consider the heritage value of these lands when considering redevelopment and reuse plans.

ADDRESSING PUBLIC SAFETY CONCERNS AT BOSTON HILL

Shafts, subsidence, and high walls are all elements of concern that have been associated with Boston Hill. What is the Town’s approach to these issues and the Town’s plan to address these?

Shafts are the major concern because their openings are small and not easily seen and may have incompetent material around the opening. Some contain water. These areas have been signed and may be fenced pending development of the mitigation plan.

Subsidence has been considered a potential problem at Boston Hill by the NMAMLB in areas with thin roofs over underground workings. To my knowledge there has never been a subsidence event on Boston Hill including during the mitigation of air and light openings when heavy equipment was used to haul material to fill the openings during work in 1989. We have, however, seen runoff water on adjacent county land work its way through the soil cover over these openings that were filled, creating new “fissures”. Without evidence to the contrary, subsidence is not considered a major concern on Town land at Boston Hill by people using the area for non-motorized recreation. The BLM plans to bring in a mining engineer associated with WERC to assess the stability of the roof of the Legal Tender underground workings as part of their mitigation work.

High walls most closely resemble natural features found throughout our public lands. In places there is incompetent material along the edge that is being worked on by gravity and

freeze-thaw cycles that could give way unexpectedly. The same is true in the natural environment. While the steep drop offs associated with high walls could easily kill or seriously injure someone who falls off the edge, this alone is not reason to deny public access. We have several national parks that highlight canyons. One of the most amazing hiking experiences I have had has been on the Angels Landing trail in Zion National Park. Those of you familiar with this trail know there is a point where the trail, with a width of about four or five feet, passes between two steep canyon faces with a sheer thousand feet or more drop off **on each side**. It is one of the most popular hikes in Zion¹⁴.

The Town's first step after completion of the archeological survey and locating the shafts was to contact the NMMLB to see what assistance they would be able to provide. A face-to-face meeting in Santa Fe on March 21, 2001 was promising; it appeared there was some money available to address the remaining high priority concerns and since they had another project in nearby Lordsburg, we were hopeful that assistance would be forthcoming. Silver City, due to its distance from Santa Fe, is used to being somewhat isolated from state government interaction and opportunities compared to communities closer to Santa Fe. There is a lot of expertise and professionalism in the State's AMLB, however, that we were eager to engage.

As of this writing, sixteen months have gone by and we are still waiting and wondering if our AMLB will ever return to Silver City and continue with the work left uncompleted after their 1989 project. Ironically, an open space project with a proposed trail system in the Cerrillos Hills near Santa Fe is receiving NMMLB assistance to mitigate eighty-six shafts in the area. Included in the mitigation design are plans to install grates across some of the mineshafts so the public can walk over them and see what they look like¹⁵.

Fortunately for the Town, one of our neighbors on Boston Hill is the Bureau of Land Management. When they were contacted about the abandoned mine lands situation on public land on Boston Hill, they showed up to assess the situation. They also provided the Town with carsonite posts and mine hazard warning stickers that have since been installed at all unmitigated shafts and other areas of concern. The BLM often partners with the NMMLB on projects across the state but as of this writing they have been unable to get a commitment of assistance with the Boston Hill project.

In FY 2003, the BLM anticipates receiving funding to address the shafts located on BLM land that is considered an extension of the Boston Hill Open Space. We are hopeful that there will be a way to also address the shafts on Town land with the same funding through a cooperative arrangement.

The Town perceives that one of the keys to public use and enjoyment of the Boston Hill Open Space is education of the recreating public. Access to Boston Hill will occur primarily at the three proposed trailheads. Appropriate signage at the trailheads, and at site-specific areas on the property, is an opportunity to educate the public about where caution needs to be exercised while they enjoy Boston Hill. In this way, the Boston Hill brownfield is transformed from an abandoned and underutilized property not contributing to the vitality of the Town, to a unique and easily accessible greenspace that preserves the Town's mining heritage while enhancing its quality of life.

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ECONOMIC AND COMMUNITY DEVELOPMENT OPPORTUNITIES FOR MINE-SCARRED LANDS

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ABSTRACT

On January 11, 2002, the Federal Brownfields Revitalization and Environmental Restoration Act of 2001 was enacted. The act codifies a federal brownfields program and authorizes \$250 million annually in grants and loans including \$50 million to be distributed to state and tribal response programs. In addition, the law provides funding for cleanup and assessment activities and also clarification of federal liability.

Historically, brownfields have been viewed as vacant industrial and commercial properties where perceived or real environmental contamination complicates redevelopment. The new federal brownfields law expands this definition to include most property types, including mine-scarred lands. By including mine scarred lands in the definition, abandoned mine lands will benefit from applicable provisions of the brownfields law, and may also be eligible for an array of cleanup and redevelopment resources provided by agencies such as the U.S. Economic Development Administration and the U.S. Department of Housing and Urban Development. These and other resources provide new opportunities to address mine sites that have economic and community development potential.

As part of the U.S. EPA's current activities to implement the new law, work has begun on issues including defining the term "mine scarred land," developing related guidance, and identifying types of technical assistance to cleanup and develop mine scarred lands in the brownfields context.

The proposed paper and technical session to be presented at the 2002 NAAML P Annual Conference is a key initial step in information exchange between the brownfields and mine reclamation communities as they collaborate to implement brownfields programs. The paper and technical session will achieve the following: 1) provide a historical background on the evolution of brownfields policy and its linkage to mine reclamation; 2) describe the various financial and technical resources that are available for brownfield redevelopments; 3) based on case study research, suggest general criteria for using a brownfield redevelopment approach at selected mine sites; 4) provide a basic explanation of how state and tribal response programs may benefit from the legislation; and 5) request input on a number of technical and policy items from NAMLP members through a survey.

INTRODUCTION

The period from December of 1980 to December of 2001 witnessed a shift in public approaches to blighted and contaminated lands in the United States from an orientation towards environmental cleanup and federal control to economic reuse and state and tribal empowerment. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), more commonly known as Superfund, was passed in 1980. Twenty-one years later, the enactment of the Brownfields Revitalization Act of 2001 marks an adaptation of a comprehensive federal system of ranking hazardous sites and addressing cleanup through federal lawsuits and a massive national fund to a framework of liability clarification, incentives and

financial assistance for encouraging parties involved with blighted lands to collaborate with government.

This shift is also characterized by a broader definition of brownfields—one that recognizes underutilized and possibly contaminated properties as not only an urban epidemic but also a rural one. Over the last several years, a standard definition of brownfields has been “abandoned, idled or underutilized industrial and commercial sites where expansion or redevelopment is complicated by real or perceived environmental contamination.”¹ The recently enacted brownfields law adds to this definition and broadens it to include specific property types including mine-scarred lands. The inclusion of mine-scarred lands in the federal statutory definition of brownfields provides new economic and community development opportunities for former mine sites and may be viewed as an important step in broadening the ways in which mine reclamation and economic development officials approach mine lands with community and economic development potential.

As an initial step in the information exchange between the brownfields and mine reclamation communities, this paper: provides background on the evolution of brownfields policy and its linkage to mine reclamation; provides a basic explanation of how state and tribal response programs may benefit from the legislation; describes the various financial and technical resources that are available for brownfield redevelopments; offers brief examples of local community and brownfield revitalization approaches; and recommends areas for further exploration, analysis, and outreach.

BROWNFIELDS POLICY BACKGROUND

In the years that followed the passage of CERCLA and the establishment of the Superfund program, it became increasingly evident to communities and policy makers, that although the program demonstrated success in assigning liability and generating some resources for cleanup, the pace and costs of cleanup were not proportional to the number of sites that were given Superfund status and the funding needed to remediate them. According to a 2001 American Bar Association publication, only about 1,250 of the nation’s hundreds of thousands of contaminated sites are included on the National Priorities List, a compilation of the nation’s most hazardous sites.²

In countless instances, properties that present environmental difficulties also become economic problems. The cost of cleanup and fears of past or future liability drive away investment, causing communities to suffer job loss, real estate value depreciation, and general degradation. Existing or potential environmentally catastrophic properties become economically obsolete and plague both urban and rural communities across the nation. The U.S. Government Accounting Office estimates that there are 130,000 to 450,000 contaminated commercial and industrial sites around the country.³

U.S. Environmental Protection Agency Region 5 Office of Public Affairs, Basic Brownfields Fact Sheet (1996).

² Davis, Todd S., et al Brownfields: A Comprehensive Guide to Redeveloping Contaminated Properties. American Bar Association, 2002, p. 7.

³ Government Accounting Office, GAO/RCED-95-172, Community Development – Reuse of Urban Industrial Sites (1995).

To address this problem, the U.S. Environmental Protection Agency, with direction and support of the Clinton Administration, undertook an initiative to engage stakeholders in the issues surrounding brownfields. Agency executives and policy-makers recognized that, under the Superfund system, hundreds of thousands of properties with real or perceived environmental complications would continue to be economic problems as long as environmental conditions and potential liability were unknown.

In 1993, the EPA established the Brownfields Redevelopment Initiative. This initiative has been supported by a pilot program in which local government units apply for federal funds to inventory and assess brownfields sites and to create the public-private partnerships necessary to break down barriers to reuse and encourage reinvestment. The pilot program began with the designation of a handful of pilot cities that were provided with financial and technical assistance to address brownfields sites.⁴ Success was documented in those initial cities and the pilot effort has since grown to a program with over 350 pilot communities in which activities include site assessment, environmental remediation job training, and revolving loan funds for cleanup. To date, the EPA Assessment Demonstration Pilot Program has documented substantial results. An average EPA grant of \$200,000 has leveraged \$1 million in other funds and a total of \$4.2 billion has been leveraged from outside sources. Additionally, redevelopment activities are underway at 470 properties, and 20,600 new jobs have been created on brownfield sites.⁵

These results undoubtedly contributed to the support necessary to ensure the passage of the Brownfields Revitalization Act of 2001—a bill that passed the U.S. Senate by a vote of 99-0 and was signed by President Bush on January 11, 2002.⁶ The new brownfields law codifies a federal brownfields program and moves it beyond “pilot” status. The passage of the law provides for a number of upgrades from the pilot program. In its most recent years, the brownfields pilot program provided approximately \$90 million in federal funds, while the new law authorizes \$250 million a year in funding until 2006. While pilot grants were made to a limited number of states and tribes, \$50 million of the \$250 million authorization under the new law must be used to enhance state and tribal response programs. The greatest change involves funding for site cleanup. The majority of pilot program funding had been allocated to assessment with a relatively small amount used to capitalize revolving loan funds for cleanup. However, the new law provides grants of up to \$500,000 for cleanup and makes premium costs for environmental insurance an eligible expenditure.⁷

In addition to increased and more flexible funding, Subtitle B of the new law provides important liability protections. These protections are in three general forms: protection to properties contiguous to CERCLA sites, protection to prospective purchasers, and protection to innocent landowners. The intent is to provide parties with the legal comfort to become active in helping move properties into productive use. As part of the law’s provisions for state and tribal response programs, Subtitle C provides a federal enforcement bar, thus deferring responsibility to state and tribal programs when the state or tribe has met the federal law’s requirements that it

⁴ Fields, Timothy J., Former Assistant Administrator of the USEPA for the Office of Solid Waste and Emergency Response. Personal interview. 30 Mar. 2002.

⁵ Brownfields Management System. Information Database. Marasco Newton Group Ltd., Arlington, VA.

⁶ H.R. 2869, 107th Cong., 1st Sess. (2001) available at <http://thomas.loc.gov>

⁷ Environmental insurance coverage can provide a cost cap for cleanup and liability protection and has been a useful tool for both public and private entities involved in brownfields reuse. Yount, Kristen R. Environmental Insurance Products Available for Brownfields Redevelopment, 1999. Northern Kentucky University, KY, 1999.

maintain and make public a list of sites at which response actions have been taken or are planned. With the federal funding provided, state and tribal response programs may select from eligible activities which include using funds to establish or enhance a response program, capitalize a cleanup revolving loan fund, and purchase or develop a risk sharing pool, an indemnity pool, or other mechanisms to provide financing for response actions.

THE BROWNFIELDS LAW AND MINE RECLAMATION

In addition to the broad accomplishments of the law in the areas of creating a grant program, clarifying liability, and addressing state response programs, the brownfields law provides opportunities for communities challenged by abandoned mine lands or mine-scarred lands. In defining brownfield sites, Subtitle A of the Brownfields Revitalization Act of 2001 states “IN GENERAL- The term ‘brownfield’ site means real property, the expansion, redevelopment, or reuse of which may be complicated by the presence of hazardous substance, pollutant, or contaminant.” Additionally, the law explains that, “the term ‘brownfield’ site includes a site that—(III) is mine-scarred land.”⁸ With the inclusion of mine-scarred land in the brownfields definition comes the eligibility for all relevant provisions of the brownfields law including eligibility for federal funding to assess and potentially redevelop mine-scarred lands.

In addition to funding provided by EPA, by being defined as a “brownfield” provides mine-scarred sites with greater access to the resources committed by the National Brownfields Partnership, an interagency workgroup made up of a number of federal agencies including, but not limited to, the U.S. Economic Development Administration (EDA), the U.S. Department of Housing and Urban Development (HUD), the Appalachian Regional Commission (ARC), the U.S. Department of Agriculture’s Rural Development (USDA RD), and the Department of the Interior’s Office of Surface of Mining (OSM).⁹ Through the National Brownfields Partnership, agencies participate in a formal dialogue on how they can collaborate to ensure that communities and landholders are able to navigate through the brownfields cleanup and redevelopment process with limited bureaucratic difficulties. Additionally, through the National Brownfields Partnership Action Agenda, member agencies make a commitment of tangible financial and technical resources to brownfields reuse.¹⁰

The resources and commitment from various federal agencies apply to all communities embarking upon brownfields redevelopment, including those communities blighted by mine-scarred lands. In those instances when a community possesses one or more abandoned mine sites where there is legitimate reuse potential, an array of resources may be assembled to not only reclaim the mine site to adequate environmental standards, but also to generate economic expansion, diversification, job growth, and better land use. Essentially, communities can harness the brownfields resources to make what would otherwise be a financially unfeasible redevelopment project possible and potentially profitable.

⁸ The Brownfields Revitalization Act of 2001, Title II of the Small Business Relief and Brownfields Revitalization Act, H.R. 2869, 107th Cong., 1st Sess. (2001).

⁹ United States Environmental Protection Agency, The Brownfields National Partnership Action Agenda Accomplishments Report, November 1999.

¹⁰ Ibid.

COMMUNITY AND ECONOMIC DEVELOPMENT APPROACHES TO ABANDONED MINE SITES

Taking steps above and beyond the environmental restoration of mine sites may mean the inclusion of community and economic development related strategies into reclamation plans. Outcomes on these sites might involve the creation of new employment opportunities, economic diversification of the local economy, and the creation of community assets such as parks or learning centers. Additional steps may involve reclaiming and investing in sites in ways that more easily and efficiently accommodate future development. Creating level, developable parcels, maintaining mining access roads to be converted into industrial or commercial access roads, and installing basic utilities are practices which add value to sites and make them marketable to public and private investors interested in locating residential, commercial, industrial, or institutional developments. Obviously, not every abandoned mine site can be redeveloped into an industrial park or residential development. Additional infrastructure investments to attract future development are only practical for those limited number of mining sites that are within a reasonable distance of stable population centers and adequate transportation corridors.

The choice to pursue future opportunities for abandoned mine sites may be entirely up to the community that has mine-scarred lands within its reach. Communities as small as 500 residents may identify the needs for new job opportunities and in the rugged terrain of Appalachia, for example, a shelved out mine site may be the only place to locate a light manufacturing facility that will provide 100 full time employment positions. Indeed, communities all over Appalachia are struggling with the challenges of economic restructuring now that the natural resource-based aspects of their local economies have waned. The same is true for mining communities in other areas of the United States.¹¹

In its most basic form, community development centers on creating assets for places that otherwise lack them. In areas with limitations on developable land and challenging topographical and geological features, creating places for economic expansion can be cost-prohibitive. However, the existing reality that most private mining interests incur the costs to access and excavate land combined with the potential that communities can harness federal and state resources through brownfields and economic development programs, abandoned mine sites may be strong candidates for the site of new economic development. In many ways, brownfields status enables some agencies to do more than they could on an untouched green field. Virginia Department of Housing and Community Development Community Development Block Grant (CDBG) Director, Todd M. Christensen explains, “by being a labeled as a brownfield and therefore being considered a blighted property, we are able to assist local governments in addressing the blight and investing in future of the site in ways we could not if the property were not seen as a brownfield.”¹²

Government entities like Virginia’s community development agency are increasingly recognizing the community development potential of working with localities on abandoned mine

¹¹ Johansen, Harley. “Mining to Tourism: Economic Restructuring in Kellogg, Idaho.” Local Economic Development: a geographical comparison of rural community restructuring. New York: United Nations University Press, 1998.

¹² Christensen, Todd M., Personal Interview. 2 July, 2002.

sites. While some are adapting long time established programs such as CDBG to meet the needs of mining communities, others are formulating new policies to address these issues. The West Virginia state legislature recently enacted the Coalfield Community Development Act which directs the state Development Office to do more than restore sites to their previous condition, but to incorporate long term land use plans and economic development strategies recommended by redevelopment authorities into the reclamation plans of surface mining permits.¹³ These initiatives in Virginia and West Virginia demonstrate that policy-makers and program administrators alike are seeing the need to integrate long-term economic development into mine reclamation.

RESOURCES FOR BROWNFIELDS AND MINE-SCARRED LANDS

The label of “brownfield” no longer carries only a stigma. With the label comes an array of resources that can be used to redevelop brownfields into economic engines. The resources available to brownfields in general and mine-scarred lands specifically can be categorized into three broad categories: tax and financial incentives, direct funding assistance, and limitations on government intervention. The Federal Brownfields Tax Incentive, signed into law in 1997, enables parties who undertake cleanup on a brownfield site to fully deduct the cost of cleanup in the year that costs were incurred.¹⁴ A number of states also offer various types of state tax incentives for cleaning and redeveloping brownfields.¹⁵ Federal brownfields grant funds can also be used to purchase or subsidize the cost of environmental insurance products. These innovative products offered by the likes of AIG Environmental, ECS, Inc., Kemper Environmental, Zurich-American, and other insurers are used to provide cleanup cost overrun protection, pollution liability protection, or other types of coverage. Financial tools such as tax incentives and insurance are often the necessary to make a brownfields deal feasible.

In addition to the direct assessment and cleanup grants now authorized under the Brownfields Revitalization Act of 2001, funding for assessment, cleanup and redevelopment is available from a number of other sources. HUD administers the Brownfields Economic Development Initiative (BEDI), which has been funded at \$25 million in both of the last two years.¹⁶ BEDI grants can be used for economic development projects sited on brownfields and are typically coupled with loan financing through the Section 108 loan program.¹⁷ Brownfield sites may also qualify for HUD’s Economic Development Initiative (EDI), a program funded at more than \$300 million in 2002, which provides assistance to broadly defined economic development projects.¹⁸ By being grouped with brownfields and HUD’s definition of “blight,”

¹³ West Virginia Development Office, Office of Coalfield Community Development. Available at: <http://www.wvdo.org/index.cfm?main=/technology/index>.

¹⁴ U.S. Environmental Protection Agency, Brownfields Tax Incentive Fact Sheet, August 2001. Available at: <http://www.epa.gov/brownfields/bftaxinc.htm#about>

¹⁵ Bartsch, Charles. Brownfields: State of the States. Northeast-Midwest Institute. Fourth Annual Edition, Nov. 2001.

¹⁶ U.S. Dept. of Housing and Urban Development. Office of Community Planning and Development. Available at: <http://www.hud.gov/offices/cpd/economicdevelopment/index.cfm>

¹⁷ If passed by Congress and signed by the President, H.R. 2941 will decouple BEDI from Section 108 loan funds and make the BEDI program more accessible for smaller communities.

¹⁸ U.S. Dept. of Housing and Urban Development. Office of Community Planning and Development. Available at: <http://www.hud.gov/offices/cpd/economicdevelopment/index.cfm>

mine-scarred redevelopment projects that eliminate blighting influences or create benefits to low- to-moderate income individuals, are eligible for the Community Development Block Grant Program (CDBG), a \$4.4 billion annual program that addresses the housing, infrastructure, and economic needs of communities. CDBG is one of the largest, most flexible grant programs in the federal government and is considered discretionary funding, therefore enabling it be used as a non-federal match for the funding requirements of some federal programs.¹⁹

Other members of the National Brownfields Partnership have also committed resources to assist in brownfields reuse. The U.S. Economic Development Administration (EDA) provides a number of initiatives to help communities develop economic adjustment strategies, install critical infrastructure, or provide workforce development facilities to serve existing or new industrial sectors. Of particular interest to many mining communities, are the offerings of the United States Department of Agriculture's Rural Development and the Appalachian Regional Commission. Both agencies have numerous initiatives designed to assist rural communities and each agency is a member of the Brownfields National Partnership. In addition to the host of federal resources available, many states provide brownfields redevelopment programs and general industrial development and community revitalization assistance.

While public funding has proved to be essential in many brownfields redevelopment projects, many more brownfields revitalization projects owe their success to the liability clarification that is provided to developers of brownfields sites. For several years, EPA and its state equivalents have issued some form of clarification to brownfields owners and communities that fully participate in assessment and, when necessary, cleanup programs. This clarification often comes in the form of "No Further Action" letters. These letters essentially state that the EPA or state enforcement agency will take no further action against a party for past pollution. For those states that meet criteria for state response programs outlined in the brownfields law, a federal enforcement bar applies giving brownfields party owners confidence that if state cleanup requirements have been met, they will not be subject to additional U.S. EPA intervention.²⁰ This general deference to state enforcement roles over the U.S. EPA's responsibilities are reflected in most of the memorandum of agreements (MOAs) that EPA has signed with nineteen states.²¹ Limitations on the federal government's role in enforcement on brownfields cleanups and the liability clarifications provided in the new law combined with liability protections and amnesty that applicable state statutes may grant, help provide parties with the comfort and confidence that they may need to move forward on brownfield and abandoned mine site redevelopment projects.

MINE-SCARRED LAND REVITALIZATION: EXAMPLES AT THE LOCAL COMMUNITY LEVEL

Despite the reality that protections, incentives, and funding for brownfields revitalization are relatively new both to the area of abandoned real estate reuse in general and more specifically to mine-scarred lands, there are instances throughout the United States where communities have

¹⁹ Ibid. CDBG Guidance.

²⁰ The Brownfields Revitalization Act of 2001 identifies a number of exceptions to the state enforcement bar in order to give the U.S. EPA the ability to respond if a site presents a significant threat to health and human safety.

²¹ U.S. Environmental Protection Agency, Memorandum of Agreements on State Voluntary Cleanup Programs. Available at: <http://www.epa.gov/brownfields/html-doc/statemoa.htm>.

realized the potential of abandoned mine sites. Though standard research methodologies do not readily reveal data on communities where mine sites have been redeveloped into assets such as industrial parks, community centers, or housing developments, practical experiences in the field of community development do identify cases where economic and community development approaches have been taken to address mine sites.

Within the 420 square-mile Backlick Creek Watershed in Pennsylvania, a population of 70,000 people is dispersed along with numerous abandoned coal mine sites.²² One community in particular, Vitondale, Pennsylvania has reclaimed an abandoned mine site into a recreational area that has received national attention for the integration of the land's mining past with hiking, picnic and landscaping characteristics. The site's central feature is a stream of acidic water that percolates out of the mine and flows down a limestone lined canal into aerating basins and finally to a wetland. Alongside the water's path a "litmus garden" made up of rows of various vegetation types are programmed so that their autumnal colors reflect the water's purifying stages as it becomes less acidic.²³ The park is a community asset that serves not only Vitondale residents, but also draws visitors, thus having positive economic impacts on the community.

In Jefferson County, Ohio, the initial phases of an industrial park were completed at a former surface mine in 1998. After an aggressive recruitment effort and collaboration by federal, state, and local officials to assemble the necessary infrastructure funding and incentives, Wal-Mart Inc. announced its plans to construct an 880,000 square-foot distribution center on the 150-acre site. The facility will cost \$75 million to construct and is expected to create 600 new jobs for the Ohio Valley—a region that has suffered job loss in recent decades due to the decline of the steel industry.²⁴

While Vitondale, Pennsylvania, and Jefferson County, Ohio represent two diverse site-specific reuses for mining sites, the Town of Kellogg, Idaho has and continues to incorporate the redevelopment of its many mine-scarred sites into its long-term strategy of economic restructuring. Until 1982, Kellogg was the site of largest smelter and mine complex in the region and was a thriving industry community.²⁵ Following closure of the Bunker Hill Mining and Smelter Company, the U.S. EPA designated the smelting facility and many of its accompanying mines as a superfund site. Over the last decades, Kellogg has been working with federal and state agencies as well as economic development consultants to devise and carryout an economic restructuring strategy that involves positioning Kellogg as a tourist destination and developing a light-manufacturing base. Many of the community's former mining sites have become prime candidates for the location of new manufacturing and tourist related operations. Cleanup and redevelopment is completed, underway, or planned at a number of former mining sites.²⁶ The examples of Kellogg, Idaho, Vitondale, Pennsylvania, and Jefferson County, Ohio are a few instances of mine-scarred land redevelopment efforts. Undoubtedly, through their daily work, mine reclamation and community development practitioners are aware of many other instances where former mine sites have been reused for economic or community development purposes.

²² Ferguson, Bruce K. "Regional Priorities for Abandoned Mine Reclamation in the Backlick Creek Watershed," *Journal of Environmental Management*. Oct. 84: 249-259.

²³ Time.Com. *Innovators: Architecture and Design*.
http://www.time.com/time/innovators/design/profile_bargmann2.html

²⁴ Alliance 2000. "Annual Report" for 2001. Available at.
<http://www.alliance2000.org/annualreport2001.pdf>, page 2.

²⁵ Johansen, Harley. "Mining to Tourism: Economic Restructuring in Kellogg, Idaho."

²⁶ Ibid.

FUTURE STEPS FOR BROWNFIELDS APPROACHES TO MINE-SCARRED LANDS

Two primary forces should continue to drive brownfields redevelopment approaches to mine-scarred lands. The first is the broad information sharing and outreach that has been and will continue to be associated with brownfields redevelopment. Energy associated with implementation of the new law and the federal resources that it makes available should continue to assist various stakeholders in better understanding and promoting brownfields redevelopment. One of the great strengths of the brownfields reuse movement has been the broad support it has enjoyed by economic development, environmental, urban planning, real estate development, and other groups. While top down information dissemination will continue to help promote brownfields redevelopment in general and for mine-scarred lands specifically, the second driver of mine-scarred reuse is likely to come from local practitioners. The ingenuity, energy, and commitment of local reclamation and economic development practitioners must continue to be harnessed to increase the likelihood that suitable mine sites are redeveloped.

To help accelerate mine-scarred land redevelopment, it is recommended that further steps be considered. First, at the national policy level, participant agencies in the National Brownfields Partnership with roles in rural development, mine reclamation, and economic development should begin a dialogue to discuss how each agency may commit both financial and technical resources to assist local practitioners in their efforts to reuse abandoned mine lands. Through communication tools that promote the use of relevant agency funding for mine redevelopment and through a commitment of financial resources to enable practitioners to be pioneers and “test pilot” brownfields reuse approaches to mine redevelopment, agencies such as HUD, USDA, EDA, ARC, EPA, and OSM can become active partners with communities seeking to take full advantage of all local assets—including mine-scarred lands.

To assist practitioners in understanding the feasibility of mine land redevelopment, federal and states agencies as well as stakeholder groups may consider providing the resources to conduct an analysis of the factors affecting mine redevelopment. These factors include, but are not limited to: the number or percentage of sites that are located within a reasonable distance of adequate labor forces, utilities, and transportation corridors; the financial and environmental costs of streamlining economic development related investments such as site clearing and infrastructure construction into the reclamation process; and the extent to which financial resources available from the public sector can subsidize the cost of redevelopment in order to make mine redevelopment economically feasible.

Though increases in formal technical analysis, public sector collaboration, and information sharing are necessary for mine land redevelopment opportunities to reach their full potential, one of the first and most critical steps is recognition by the mine reclamation and the community and economic development fields that mutual benefits can be gained by working together on the redevelopment of mine-scarred lands. The Brownfields Revitalization Act of 2001 encourages these two fields to collaborate, and the resources provided by federal and state programs and local practitioners represent the array of tools necessary to make mine land redevelopment encompass community and economic development outcomes.