Controlling and Remediating Surface and Groundwater Pollution from Inactive and Abandoned Mines: A Survey of Management Practices

by

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Robin Frisch-Gleason
EXECUTIVE SUMMARY

The Arizona Department of Environmental Quality (ADEQ) contracted the Arizona Geological Survey (AZGS) to compile a survey of management practices for controlling and remediating surface and groundwater pollution from inactive and abandoned mines (IAMs). The purpose of the survey is to provide land managers and land owners in Arizona who have IAMs on their property with guidance on how to abate pollution from IAMs.

The initial objective of the project was to compile a guidebook on Best Management Practices (BMP's) to facilitate pollution abatement efforts. However, the AZGS found little published information from Arizona or any other state on the control or remediation of water pollution from IAMs. Further, AZGS determined that appropriate control and remediation methods were determined by numerous factors specific to the site, including: type of mine; type of waste; extent and method of mining; volume of waste; mineralogy of waste; hydrology, geology, topography and climatology of mine site; availability of air and water; distribution of sulfide minerals; accessibility of mine site; threat to human health; threat to the environment; chemistry of the host rocks; and concentration of deposit in waste rock.

Given the necessarily site-specific nature of pollution abatement methods, ADEQ and AZGS deemed it far more useful to provide an overview of the possible options for pollution abatement at IAMs. Brief descriptions of existing abatement technologies, with an extensive annotated bibliography, list of contacts and agencies performing similar investigations, and a list of databases containing information on IAM pollution abatement are contained in this report. This information, coupled with the specific information on the IAM site of interest, will enable a more directed problem-solving effort.

Findings

Prior to site remediation, a site must be carefully characterized, including assessment of the physical characteristics, toxicity of materials present, media into which the waste has traveled, and logistical considerations of remediation effort. An exhaustive survey of possible water pollution abatement methods should be conducted prior to deciding on a specific remedial approach at any IAM site. In addition to the overview of abatement options presented in this report, Appendices A, B, and C provide numerous resources for obtaining further information on these methods, and for learning about new methods as they are developed. Contacts at numerous agencies and organizations are provided to encourage discussion about the applicability and merits of a particular method at a given site. A list of acronyms used in this report is provided in Appendix D.

This survey of methods and information resources is not exhaustive; rather it provides starting points for further research. The management practices discussed herein are based upon reviews of current literature and are for information only. Neither their use in this report, nor the exclusion of other methods, represents endorsement or disapproval by ADEQ. Any control or remediation method implemented, whether discussed herein or elsewhere, must comply with all local, state, and federal regulations.
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1. INTRODUCTION

Mining waste generated by more than a century of mining in this country has had a significant impact on land and water (U.S. Bureau of Mines and Colorado Center for Environmental Management, 1994; U.S. EPA, 1975a). Because of the reactive nature of mining waste rock containing metallic mineralization, this material has the potential to provide a source of toxic material to land and water resources throughout the country. This is a growing concern for governmental bodies, private industry, and the public. Though there is little agreement about the dimensions of the environmental problems associated with mining waste, there is an increasing consensus that inactive and abandoned hardrock mines, which are subject to limited regulatory compliance, are a key contributing factor (Drabkowski, 1993; U.S. Bureau of Mines, 1993). These mines and the materials and structures associated with them are responsible for significant physical hazards, environmental deterioration, and risks to human health (U.S. Bureau of Mines, 1993; U.S. EPA, 1987b).

Of particular interest here is surface and groundwater contamination from Inactive and Abandoned non-coal mines (IAMs). Definitions of IAMs for the state of Arizona are presented in Arizona Revised Statutes 27-301 and 27-303 and are synopsized in a report for the Western Governors' Association Mine Waste Task Force, which addresses the scope of the environmental problems presented by IAMs and presents a preliminary identification of policy options for addressing such IAM problems. This report was prepared by the Western Interstate Energy Board (WIEB, 1991) and presents the following definitions:

Arizona law defines an ABANDONED MINE as an excavation where mining operations have been permanently terminated or for which no operator, owner or other claimant can be located. Similarly, an INACTIVE MINE, is defined as an operation not conducting mining for more than six months or where operations have been temporarily suspended. MINING means those activities conducted to develop or extract minerals from a mine including on site transportation, concentrating, milling, leaching, smelting or other processing of ores or other minerals.

1.1 Background And Purpose

Given the potential severity of environmental and health threats from IAMs, the Arizona Department of Environmental Quality (ADEQ) requested the Arizona Geological Survey (AZGS) to prepare a guide to assist land managers and land owners with mitigating mine waste hazards on their land. Initially ADEQ intended to include case histories and demonstration projects from Arizona that would serve as examples for future efforts. However, in the course of research, the AZGS found that little IAM site remediation had been performed in Arizona or, if performed, was not published. Further, AZGS determined that control and remediation methods were so site-specific that it was impossible to write a meaningful general-use handbook on how to remediate a specific problem at a specific site.

A great many factors influence the control and remedial processes selected for a site including: type of mine; type of waste; size of mine; extent and method of mining; volume of waste; mineralogy of waste; hydrology, geology, topography, and climatology of the mine site; availability of air and water; the distribution of sulfide
minerals; accessibility of mine site; threat to human health; threat to environment; chemistry of the host rock; and concentration of deposit in the waste rock. Abatement technologies are problem-specific, that is, the remedy depends entirely on the problem at hand and the surrounding circumstances.

Therefore, controlling water pollution from mines is a very complex issue which commonly involves at-source controls (i.e., the mine) as well as remediation of the discharge. No single manual can possibly address all of the possible control practices. Though there has been minimal remediation of IAM sites nationwide, a great deal of literature exists on environmental pollution control technologies and site remediation. The published studies describe: bench-scale studies, actual site case histories, computer modeling to evaluate site-specific remediation plans, and a variety of other issues.

It was therefore decided that, in the time available for this report, it would be most useful to outline some of the control and remediation methods available and provide references. The objective of this document, therefore, is to help orient the reader as to the types of control and remediation methods available, show examples of the different types of methods, and provide resources for further information. Each method description includes references for further reading. Neither the references nor the bibliography are intended to be exhaustive compilations of available literature. They are rather intended as a starting point to aid the reader in finding useful information for their specific mine pollution problem. The references for each method are listed in the bibliography, included as Appendix A to this report.

1.2 Nature Of Problem

The most damaging and persistent environmental problem associated with mines, including IAMs, is drainage from mines and mill tailings entering surface and groundwater. Mine drainage is therefore a highly studied aspect of environmentally-related mining issues. Water contaminated by acid and toxic metals results from both noncoal and coal mining operations. Acid mine drainage emanating from metal mines generally results in heavy loading of dissolved metals which will precipitate out when the pH increases, usually when the stream is diluted by water in other streams. Historically, mine and mill dumps have been located near streams providing contact with water (WIEB, 1991). Metal contamination is therefore common in the vicinity of IAMs.

Acid mine drainage (AMD) is the most common type of mine drainage and is characterized by low pH and high concentrations of dissolved metals. Streams with high metal concentrations will not support desirable plant and animal life. Generally, streams with a pH of less than 4 are sterile except for acid-tolerant bacteria or algae (Robinson, 1992). Owing to federal regulations on active mine discharges, AMD is less of a problem at active mines than at IAMs, where drainage control is made more difficult due to locations, water volume, and limitation of public funds available for pollution abatement.

Sulfide minerals responsible for the formation of a large portion of mine drainage pollution are commonly associated with ore and mineral bodies. Underground mining exposes these sulfides to sufficient oxygen and water to allow oxidation and flushing of pollutants from the mine. Four elements are required for acid formation: 1) sulfide minerals, 2) oxygen, 3) water, and 4) oxidizing bacteria. Eliminating any one of these will effectively halt the process of acid formation. Many of the remedial possibilities mentioned below attempt to eliminate one or more of these factors, thereby forestalling acidification.
There is a disproportionate amount of information available on AMD - in large part because AMD is a common problem in areas of coal mining. Abandoned coal mines, predominantly in the eastern and midwestern sections of the U.S., have enormous problems with AMD. Remediation of AMD sites has been subsidized largely by the Abandoned Mine Land (AML) Program, which was developed and implemented under the 1977 Federal coal law, the Surface Mining Control and Reclamation Act (SMCRA). According to U.S. Bureau of Mines and Colorado Center for Environmental Management (1994):

SMCRA law provides for AML Program funding through a State share of money collected under a national coal production tax. These funds may be used to reclaim both coal and noncoal mine land abandoned prior to 1977. SMCRA priorities mandate that, with the exception of severe noncoal safety hazards, funds must be spent on reclamation of lands, waters, and facilities adversely affected by coal mining before noncoal mining reclamation or facilities work can begin.

In order to subsidize this AML Program, a tax on coal is implemented in many coal-producing states. According to the United States Office of Surface Mining Reclamation and Enforcement (1992):

Fees of 35 cents per ton of surface mined coal, 15 cents per ton of coal mined underground, and 10 cents per ton of lignite mined are collected on all active coal mining operations. The fees are deposited in the interest-bearing Abandoned Mine Reclamation Fund, which is used to pay reclamation costs of AML projects. Expenditures from the fund are authorized through the regular congressional budgetary and appropriations process. SMCRA specifies that 50 percent of the reclamation fees collected in each state with an approved reclamation program, and within Indian lands where the tribe has an approved reclamation program, are to be allocated to that state or tribe for use in its reclamation program. The remaining 50 percent is used by OSM to fund emergency projects and high-priority projects in states without approved AML programs; to fund the Rural Abandoned Mine Program (RAMP), administered by the U.S. Department of Agriculture; to fund the Small Operator Assistance Program (SOAP); and to fund reclamation of abandoned mine problems directly through state reclamation programs.

In some states, particularly in the West, problems stemming from abandoned non-coal mines are more severe than those caused by coal mines. OSM may approve the expenditure of AML funds to abate hazards on those lands where the state certify that threats to public health and safety exist from non-coal sources and that all abandoned coal sites have been addressed.

Because of this fund, and because of the enormous environmental impact of AMD, a great deal of research has been done on the subject. However, AMD is extremely difficult to remediate.

The most common AMD control strategy is treatment of contaminated water at the discharge point. The high expense of this method is not offset at IAM sites by revenue from sales, making the costs prohibitive. In addition, the discharge points at IAM sites are commonly not known, so the drainage often cannot be treated until long after it reaches surface or groundwater. As stated in Kleinmann and Erickson, (1987):
A better alternative to AMD control at IAM sites is inhibition of pyrite oxidation. At least in the theoretical sense, every system component is susceptible to alteration that would reduce acid production rates. For example, if oxygen can be excluded, as it is limited prior to mining, pyrite oxidation occurs at an insignificant rate. Similarly, if the iron-oxidizing bacteria can be eliminated, the rapid catalytic reaction cycle cannot occur. Although it is easy to conceptualize such steps from basic knowledge of pyrite reactivity, it is difficult to find methods that accomplish complete reaction control under field conditions...

Mine drainage is less of a problem in arid regions than it is in wet regions. However, even predominantly dry areas, such as portions of Arizona, have occasional water sources which encounter IAMs, creating mine drainage and associated environmental problems.

The obvious consideration that next arises is the question of how to control and remediate surface and groundwater pollution from IAM sites. Water pollution at abandoned noncoal mines can be associated with access and haul roads, waste rock piles, mills, leach pads, and the like. The potentially contaminated runoff and drainage may be characterized as point or nonpoint source, depending on whether or not a discreet conveyance location of pollutants is known. Point sources of discharge are subject to more stringent regulatory requirements than nonpoint sources. However, many abandoned mine sites are categorized as nonpoint source discharges. They are therefore not subject to NPDES requirements, and commonly remain ignored for long periods of time while they harmfully impact their surroundings. As stated in Drabkowski (1993):

The remote location of many abandoned hardrock mines tends to obscure the pollution problems caused by runoff waters and fugitive dust from weathering mine wastes and residues which find their way into surface and groundwater systems. The impact of nonpoint pollutants may not be realized until discovered in the watershed and aquifers many miles downstream.

Mining operations expose vast quantities of previously undisturbed land and material in the process of exploration, extraction, processing, and transportation. Before any mining controls were enforced, ceased mining operations were abandoned leaving behind the waste rock, tailings, and slag piles as well as the explosives, equipment, and structures used in the process. These wastes and discarded materials were most often dumped in stream valleys and along floodplains. Such remnants were left to the natural weathering process of oxidation and erosion to produce the major elements of nonpoint source pollution, including acid mine drainage and dissolved metals, heavy metals contamination in soils, and erosion and sedimentation (EPA, 1976).

The U.S. EPA further states in Drabkowski (1993):

That discharges from mine sites can cause and have degraded waters of the United States is well documented. The States, in their nonpoint source assessment reports developed under section 319 of the CWA, have identified mining activities, including abandoned mines, as being the second largest sources of nonpoint pollution to the States' surface waters (8% in rivers, 7% in lakes) (EPA, 1992). The 1990 National Water Quality Inventory Report to Congress
also identified resource extraction (mining operations) as being a significant cause of pollution to rivers (14%) and lakes (8.6%) (EPA, 1992a).

Clearly, mining discharges have contributed greatly to environmental degradation in this country.

1.3 Magnitude Of Problem

There is a growing body of literature on water contamination from IAMs and ongoing investigations to identify and inventory IAMs and associated environmental impacts (U.S. Bureau of Mines and Colorado Center for Environmental Management, 1994). The WIEB (1991) study presents some statistics on the number of IAM sites in a number of states and the acreage of land and miles of water affected by IAM problems. The study cautions, however:

The findings presented are not comparable among states because of the variability in the definitions of IAMs used by states, and variability in the type and quality of data available to states. Neither the number of sites, nor the cost of remediation, reported by individual states can be totaled to present a consistent national total. Nevertheless, the numbers presented by the states are the best indication currently available of the size and character of the IAM problem.

Despite the statistical inconsistencies, the data presented by WIEB are still effective at illustrating the magnitude of the problem. Table 1 presents data from western states that contributed findings to this report in a parallel format with other states.

According to the WIEB (1991), the account of the number of mining sites in Arizona differs, depending on who is counting the sites and which counting criteria are used. Old mine workings in Arizona number between 3,000 and 100,000. The U.S. Bureau of Mines counts approximately 3,000 mines in Arizona. The State Mine Inspector estimates that between 60,000 and 100,000 mine workings and related structures exist in Arizona, most of which are IAMs. The discrepancy is accounted for by the following example, presented by the Arizona State Mine Inspector in WIEB (1991):

The Amole Mining District occupies less than a square mile in southwest Tucson. The U.S. Bureau of Mines list one past producer in the district. The Arizona State Mine Inspector physically inventoried the district and found sixty five open holes as well as a large mine dump, a tailings pile and smelter slag. The State Mine Inspector finds sixty-eight old mine workings and related structures where the U.S. Bureau of Mines lists one.

The State Mine Inspector's estimate is derived from a pilot program conducted in 1987 and 1988. During this period two of Arizona's 246 mining districts were inventoried for potential hazards to public safety and health. The Arizona State Legislature wisely established a law to address the safety and health hazards associated with abandoned and inactive mine workings by enacting Arizona Revised Statute #27-318. The law directs the State Mine Inspector to locate all the old mine workings in Arizona which constitute a danger and to notify the owner of the violation. It requires the owner to secure the hazard in a timely
fashion. The law also enables the State Mine Inspector to eliminate the hazard, if funds are available. The legislature funded the program for two years, 1987 and 1988. The Arizona State Mine Inspector selected a representative area and inventoried 2000 mine sites. Three hundred were found to have hazards. Thirty-one of those exhibited potential threats to the environment and they were appropriately forwarded to the Arizona Department of Environmental Quality for restoration. The remaining two hundred seventy were processed through title and the claim holders notified. Owners voluntarily eliminated nearly all hazards (99% compliance to date).

Based on the pilot program inventory, the Arizona State Mine Inspector estimates between 60,000 and 100,000 old mine workings exist in the State. Using 80,000 as a highly subjective yet reasonable number, statistics show 15% or 12,000 mine sites will pose a threat to public safety. Of these, 10% or 1200, will exhibit a threat to the environment.

Upon publication of the WIEB (1991) report, Leroy E. Kissinger, then Director of the Arizona Department of Mines and Mineral Resources (ADMMR), wrote a letter to the WGA indicating that ADMMR studies only revealed approximately 10,500 old mine workings in Arizona. He conjectured about the possible reasons for the discrepancy between ADMMR data and the WIEB data, and suggested that “a more thorough evaluation must be done before any conclusion can be drawn regarding the ‘cost of remediation’” (WIEB, 1991).

Independent research from the U.S. Bureau of Mines shows more than 200,000 mining-related sites across the U.S., most of which are abandoned or inactive. The Bureau of Mines Abandoned Mine Land Inventory and Hazard Evaluation Handbook (1993) reads:

The obviously hazardous sites, especially those proximal to urban areas, have been targeted under the Comprehensive Environmental Response Compensation, and Liability Act of 1980 (CERCLA or Superfund). Of the more than 1,200 sites on the National Priorities List (NPL), 59 (4.9%) are directly related to mining. However, of the remaining mine sites, those that deserve priority attention and, just as important, those which can be ignored, are largely unidentified. Most of these sites are in rural areas, often on or surrounded by public lands and thus the responsibility of Federal land-management agencies. In the absence of a clear understanding of the scope and severity of hazards associated with inactive and abandoned mine lands (AML), the public and Government agencies are very concerned about the true risks posed by these lands. This concern, and regulatory mandates, have prompted a need for detailed inventories of AML and analyses of AML hazards.
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Blank cells indicate value is unknown or not reported.

Federal Acreage includes BLM, Forest Service and Indian Reservations

Table 1. Land areas disturbed by mining in western states.
This Bureau of Mines Handbook was written to facilitate standardized, consistent IAM inventories. It provides investigators with sufficient knowledge and guidance to conduct an effective, efficient IAM inventory and evaluate the environmental and public safety hazards present.

Whichever yardstick is used, IAMs and their associated waste clearly pose significant potential threats for surface and groundwater contamination, air and soil contamination, and potential harm to biotic communities (U.S. Bureau of Mines, 1993; U.S. EPA, 1975a). The future environmental health of the United States depends, in part, on the ability to deal effectively with mine waste problems of the past and present, and, most importantly, to prevent problems in the future.

1.4 Use Of This Document

To best address the issues of surface and groundwater pollution abatement, discussion is broken down into the following broad categories:

* Site Characterization and Monitoring

* Surface and Groundwater Pollution Control Methods, including:
  - Controlling Water at the Source
  - Controlling Mobilization of Contaminants
  - Controlling Contaminated Water

* Erosion and Sediment Control Methods

A description of each category is presented, followed by specific abatement methods. Many of the methods discussed fit into more than one of these broad categories; some of the methods do not fit well into any category. However, for purposes of discussion, these categories are used as embarking points.

Depending on the specific circumstances of the IAM site, the reader may find that more than one approach may be useful. Where possible, each method is followed by references for detailed discussions of the method principles, case histories, and/or comparisons with other methods. After selecting candidate methods and corresponding references, the reader may then find descriptions of each reference in the bibliography. Where possible, abstracts from the references are included; where abstracts were unavailable, brief overviews are included.
2. SITE CHARACTERIZATION AND MONITORING

The first step in any remediation program is characterization of the site. This characterization includes an assessment of the following: 1) geology, hydrology, topography, and climatology of the site; 2) types of mine waste present and their chemical and physical characteristics; 3) contaminants that are present and in the media that contact them (i.e., water, air, soil); 4) spatial distribution of contamination; 5) sources of pollution, if possible; 6) location at which contamination is occurring; 7) special site-specific factors. As with pollution control and remediation, the site characterization will depend largely on the specifics of the mine site.

After remediation, the sites must be monitored to evaluate success of the work and to identify maintenance necessary for continuing health and safety, and environmental protection. Monitoring practices depend on the environmental media affected, including land (mine openings and waste), groundwater and surface water (mine drainage), vegetation and wildlife. Monitoring methods are closely related to site characterization; the two topics are therefore commonly discussed together.

References on site characterization and/or monitoring

Aljoe and Hawkins, 1991
Doyle, 1990
Drabkowski, 1993
Evoy and Holland, 1989
Idaho Department of Lands, 1992
Juntenen, 1994
Lootens et al, 1991
Office of Technology Assessment, 1986
Richmond, 1993
Robinson, 1992
U.S. Bureau of Mines, 1993
U.S. Bureau of Mines, 1994
U.S. Bureau of Mines, 1988a
U.S. Environmental Protection Agency, 1975a
3. SURFACE AND GROUNDWATER POLLUTION CONTROL METHODS

3.1 Controlling Water at the Source

Water infiltration control techniques are designed to reduce the volume of water entering an abandoned mine and thus, reduce the amount of mine water discharge. A reduction in the amount of flow usually results in a reduction of the total pollution load discharging from the mine and associated waste. When a mine has been abandoned, infiltrating water commonly floods the mine workings and/or discharges from the mine into surface and groundwater (U.S. EPA, 1975b, p. 45).

The infiltrating water may enter underground mines from above, below, or laterally through adjacent rock. Fractures such as faults, joints, and roof fractures resulting from subsidence are commonly conduits for water entrance into underground IAMs. Numerous factors affect the quantity of water entering the mine, including the depth of mine, location of water-bearing strata, and groundwater flow patterns (U.S. EPA, 1975b, p. 45).

The techniques discussed in this section are effective in reducing the volume of surface and groundwater available to enter the mine system and transport pollutants. Characteristics of the individual mine system and surrounding area must be considered in the selection of a control technique(s). The techniques are followed by references which include discussions of case histories and research on each technique, as well as detailed descriptions and cost information, where available. (See also the section below on Erosion and Sediment Control.)

3.1.1 Drainage Diversion.

This water diversion technique involves the interception and conveyance of water around mine openings and surficial mine waste, thereby controlling the amount of water infiltration, reducing contact time, and decreasing the volume of mine water discharge and contaminated runoff. (Carlson and Cummings, 1993, pp. 93-95). Types of drainage diversion include the following:

3.1.1.1 Diversion Dike/Ditch.

This method is a runoff interceptor built to divert surface water away from mine areas (Idaho Dept. of Lands, 1992, pp. 69-70).

3.1.1.2 Interceptor Trench.

This is a trench built along the contour of a slope to store and/or divert water runoff. An interceptor trench is smaller and less permanent than a diversion dike/ditch and is designed to carry surface runoff only, not streams (Idaho Dept. of Lands, 1992, p. 71).

3.1.1.3 Siltation Berm.

This technique is an impermeable barrier placed around a disturbed site to capture and contain surface runoff so that sediment can be filtered prior to discharging the water (Idaho Department of Lands, 1992, p. 74; Oberly and Mohr, 1992, p. 5).
3.1.1.4 Drain Fields.

This method involves a drainage system that is designed to discharge infiltrating water and/or groundwater away from a site. These drain fields can also be used to intercept and divert seeps. They must be designed with either a gravity flow outlet or the water must be discharged from the drainage system by pumping (Idaho Dept. of Lands, 1992, pp. 78-79).

3.1.1.5 Channel Reconstruction/Alteration.

Vertical fracturing and surface subsidence above underground mines often create openings on the ground surface. Streams flowing across these openings may enter the underground workings at these points, and leach out potential contaminants. Similarly, surface deposits of waste rock or tailings may be encountered by streams which may leach out contaminants. Where possible, these stream channels can be diverted and rerouted to flow away from the openings or surface deposits. The reconstructed channel bottom may be lined with an impervious material to prevent seepage or flow to the underground mine or contact with nearby waste material (Idaho Dept. of Lands, 1992, pp. 80-81; U.S. EPA, 1975b, pp. 77-80).

3.1.2 Surface Sealing.

Water infiltration into underground mines and surface waste rock can be controlled by reducing surface permeability. This may be accomplished by placement of impervious materials, such as concrete, soil cement, asphalt, rubber, plastic, latex, clay, etc., on the ground surface (Ackman and Jones, 1988, pp. 232-239; U.S. EPA, 1975b, pp. 70-72).

3.1.3 Subsurface Sealing.

This method involves placement of a seal below the surface, in an area of lower permeability. The seal is formed by injecting an impermeable material, such as asphalt, cement, gel, or latex materials, into the substrata. The advantages of this type of sealing over surface sealing are: 1) it is less affected by mechanical and chemical actions; 2) land use would not be restricted; and, 3) the seal would be located in an area of lower natural permeability (U.S. EPA, 1975b, p. 70-72). The disadvantage is that it is difficult to monitor the effectiveness of this type of seal.

3.1.4 Sealing Boreholes with Packers and Cement Grout.

Boreholes into underground mines may be conduits into the subsurface for water infiltration. These vertical or near-vertical boreholes can be successfully sealed by placing packers and injecting a cement grout. The packers should be placed below the aquifers which overlie the mine, but should be well above the roof to prevent damage to the seal from roof collapse (U.S. EPA, 1975b, pp. 54-58).
3.1.5 Sealing and Grading Subsided Areas (Surface Depressions).

Water infiltration in subsided areas can be controlled by increasing surface water runoff. This method involves sealing impermeable materials in subsided areas with rubber, clay, concrete, or cement grout, followed by regrading the surface to increase flow velocities (U.S. EPA, 1975b, pp. 46-53, 59-69).

3.1.6 Relocate Tailings Outside the Floodplain.

When mine waste or tailings are situated within a floodplain, it may be less costly to relocate the material than to control water on a floodplain. Viability of tailings relocation will depend on the volume of tailings and the distance to hydrologically isolated areas, as well as the accessibility of the site.

3.1.7 Protect Disposal Site From Surface Water Infiltration and Erosion.

This can be accomplished by proper siting, water diversion, proper grading, soil amendment and vegetation, and drainage systems.

3.1.8 Identify How Floods Flow Through Vulnerable Areas.

This information should be factored into all surface mitigation efforts.

3.1.9 Divert Mine Drainage From Flowing Through Waste or Tailings Deposits.

Where mine drainage is inevitable, the problem can be minimized by preventing the mine drainage to flow through and leach mine tailings. This can be done with the drainage diversion methods listed above.

3.1.10 Construct Stream Crossings to Protect Stream Water Quality.

This involves the construction of culverts, bridges, and the like to carry contaminated water over streams while protecting stream water quality.

3.1.11 Groundwater Interception.

This method would reduce water percolation through the mine. It involves interception or diversion of uncontaminated groundwater before it reaches the mine site. To a limited extent, surface water can also be intercepted by this method. This method involves driving headings around the mine perimeter and longholing into groundwater resources (Carlson and Cummings, 1993, p. 95).


This method involves placing some type of cover on the waste rock to isolate it and prevent it from exposure to air and water. A soil cover will serve as a cap, to some degree, and enable vegetation to grow over the dump, thereby stabilizing it. This is commonly used in land reclamation efforts. A clay cover is a more effective means of isolating waste rock, although it does not support vegetative growth. A third method is to use cement or grout to impregnate waste and tailings piles. All of these methods minimize contact with water and control
3.1.13 References on Controlling Water Infiltration at Source:

- Ackman and Jones, 1988
- Bell et al, 1994
- Bennett et al, 1988
- Bowders et al, 1994
- Broetzman, 1993b
- Brown et al, 1988
- Carlson and Cummings, 1993
- Chiado et al, 1988
- Cox et al, 1993
- Dolzani et al, 1994
- Evoy and Holland, 1989
- Idaho Department of Lands, 1992
- Jones and Wong, 1994
- Mine Waste Technology Pilot Program, 1994b
- Murray et al, 1988
- Oberly and Mohr, 1992
- Schueck and Sheetz, 1993
- Sheetz et al, 1993
- Thames and Verma, 1975
- Tremblay, 1994
- U.S. Bureau of Mines, 1994b
- U.S. EPA, 1975b
- Yanful et al, 1994

3.2 Controlling Mobilization of Contaminants

3.2.1 Mine Sealing and Closure Methods

Mine openings and surface and underground mines can be dangerous and environmentally damaging. Numerous methods have been explored for underground mine closure. These include both permanent and temporary, as well as an occasional closure designed to preserve the historical value of a site. In general, most mine closures fall within the following categories:

* Temporary closures - fencing, cable nets, grates, or bat nets
* Intermediate closures - concrete caps, plugs, and bulkheads
* Permanent closures - backfilling with mine waste rock, sealing by blasting, grouting, or polyurethane foam.
Permanent mine closures reduce health and safety hazards, reduce the need for future monitoring and maintenance, and reduce the threat of additional environmental disturbance. Conversely, temporary closures allow continued access by wildlife, and access for geologic, archaeologic, and other purposes. The specific circumstances of each site will determine the longevity goal, as well as the level of environmental protection, for each closure. For purposes of environmental protection, permanent closures, and specifically mine sealing, are generally the most effective closure techniques.

According to the U.S. Environmental Protection Agency (1975b), "Mine sealing is defined as the closure of mine entries, drifts, slopes, shafts, subsidence holes, fractures, and other openings in underground mines with clay, earth, rock, timber, concrete blocks, brick, steel, concrete, fly ash, grout, and other suitable materials. The purpose of mine sealing is to control or abate the discharge of mine drainage from active and abandoned mines."

There are three different categories of mine seals, each of which are useful under different circumstances, and require different conditions and information. The three categories include the following, each followed by references for further descriptive, construction, and cost information:

3.2.1.1 Dry Seal.

This involves the placement of impermeable materials or structures in mine openings to prevent air and water entry into the mine. This type of seal is suitable for openings where there is little or no water flow, and little danger of a hydrostatic head developing (U.S. EPA, 1973, p. 251; U.S. EPA, 1975b, pp. 87-92).

3.2.1.2 Air Seal.

This type of seal involves the sealing of all openings of the mine with impermeable materials to prevent air from entering the mine, but allowing normal mine discharges to flow through the seal. In a successfully air-sealed mine, the oxidation of sulfide minerals will be retarded, and thus, the formation of mine drainage pollutants controlled (U.S. EPA, 1973, pp. 255-256; U.S. EPA, 1975b, pp. 93-105).

3.2.1.3 Hydraulic Seal.

The construction of a hydraulic seal involves placing a plug in a mine entrance where water is discharging. This plug prevents discharge, thereby flooding the mine. Flooding excludes air from the mine and retards the oxidation of sulfide minerals. The following seals are all hydraulic and are effective in different circumstances:

- Double Bulkhead Seal. This seal is constructed by placing two retaining bulkheads in the mine entry, to provide a form for the center seal. An impermeable (grout or concrete) seal is then placed in the space between the bulkheads. This type of seal floods the mine and stops acidic discharge (U.S. EPA, 1973, pp. 228-230; U.S. EPA, 1975b, pp. 109-118).

- Single Bulkhead Seal. This seal is generally constructed of poured concrete, quick-setting cement material, or grouted aggregate. These seals can be used in both accessible and inaccessible mine entries. They form a plug in the mine opening which then floods the mine and eliminates discharge (U.S. EPA, 1973, pp. 234-237; U.S. EPA, 1975b, pp. 119-131).

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- **Permeable Limestone Seal.** This involves the placement of a permeable alkaline aggregate in mine openings where acid water may pass through it. As the acidic water passes through the alkaline material, the water becomes neutralized and a precipitate forms, in-filling the voids in the aggregate. With time, the seal becomes a solid bulkhead and floods the mine (U.S. EPA, 1973, pp. 143-145; U.S. EPA, 1975b, pp. 132-145).

- **Gunite Seal.** These seals are constructed by placing successive layers of gunite in a mine opening until the opening is completely filled and stops the discharge of mine drainage (U.S. EPA, 1973, p. 231-233; U.S. EPA, 1975b, pp. 147-159).

- **Grout Bag Seal.** This type of seal is constructed by the placement of successive layers of expandable grout containers in the floor of the underground mine openings. These bags are inflated with cement slurry to conform to the shape of the mine entry. Eventually, this completely seals the mine opening and stops discharge (U.S. EPA, 1973, pp. 246-247; U.S. EPA, 1975b, pp. 159-163).

- **Shaft Seal.** This involves backfilling the shaft to an identified "sealing zone" (a zone which is coherent enough to be sealed), and then placing an impermeable seal in the "sealing zone." The remainder of the shaft is then backfilled to ground level (EPA, 1975b, pp. 164-169).

- **Gel Material Seal.** This technique involves injecting a chemical grout and filler into a mine cavity through a vertical borehole. The chemical grout has a controllable setting time which allows a stiff, gel-like plug to be formed in the mine cavity without the benefit of retaining bulkheads (U.S. EPA, 1973, p. 257; U.S. EPA, 1975b, pp. 169-173).

- **Regulated Flow Seal.** This technique is designed to release mine water in amounts that the receiving stream is capable of assimilating at any given time. This method is useful when complete inundation of the mine is impractical (U.S. EPA, 1973, pp. 248-250; U.S. EPA, 1975b, pp. 173-174).

- **Curtain Grouting.** This method is commonly used in conjunction with hydraulic sealing of underground mines to control leakage around seals and stabilize outcrop areas. The grout mixtures are pressure-injected through vertical boreholes. The material then sets to form a still gel or hardened cement-type material that creates an impermeable barrier in the grouted medium (U.S. EPA, 1973, pp. 238-240; U.S. EPA, 1975b, pp. 175-179).

- **Clay Seals.** These seals are useful for hydraulic underground mine seals where low water pressure is expected. Clay is compacted into the mine opening to form a seal (U.S. EPA, 1973, pp. 241-242).

- **Remote Sealing and Support.** Three different methods are suggested for these seals, to use in subsiding mines. One method for remote sealing of underground abandoned mines is to remotely place point support in the mine through boreholes; a second method involves the use of a co-rotating twin-screw pneumatic pipefeeder to meter fill material into a pipeline for transport of distances over 400-ft.; the third method is to fill an abandoned mine tunnel using a high efficiency pneumatic ejector and the pneumatic pipefeeder (two previously-developed stowing technologies) (Burnett et al, 1993).

### 3.2.1.4 Other Mine Closures.

Other types of mine closures may help mitigate water pollution from the mine, directly or indirectly, but do not necessarily involve hydraulic sealing of the mine. These include the following:
- **Backfill Closures.** These closures consist of filling mine openings with onsite or imported fill. This is normally done with heavy equipment, but can be done by hand for remote or shallow sites (U.S. Bureau of Mines, 1994c, unpaginated).

- **Blast Closures.** These closures consist of filling or collapsing mine openings through the use of explosives. This is commonly used on openings which are too unstable or unsafe for other methods (CSP Associates, Inc., 1991; Robinson, 1992, p. IV-32-35).

- **Concrete Cap Shaft Closures.** These closures consist of placing concrete caps or slabs over shaft openings. This method allows re-entry of the mine, although not without considerable effort to move the cap. This method is not effective where there is drainage into or out of the mine (Robinson, 1992, pp. IV-35-42; U.S. Bureau of Mines, 1994c, unpaginated).

- **Monolithic Plug Shaft Closures.** These closures consist of pouring a layer of concrete over a mine shaft that has collapsed and has no apparent opening, or into a subsidence pit. The layer is designed to be thick enough to support the collapsing shaft (Robinson, 1992, p. IV-42-43).

- **Polyurethane Foam (PUF) Closures.** This method consists of installing a bottom form, spraying PUF over the form to a minimum thickness, and then backfilling with common fill (Robinson, 1992, pp. IV-51-58; U.S. Bureau of Mines, 1994c, unpaginated).

- **Bulkhead Adit Closures.** These are constructed either of native rock and grout, and built into the adit opening, or constructed of concrete blocks, reinforcing steel, and grout, and built over the opening of an adit or inclined shaft (Robinson, 1992, pp. IV-58-62; U.S. Bureau of Mines, 1994c, unpaginated).

- **Riprap Bulkhead.** Riprap is placed inside and around the portal of adit or inclined shaft to provide a permanent and complete blockage. If the opening drains water, a noncorrosive drain pipe must be installed, and water must be treated (U.S. Bureau of Mines, 1994c, unpaginated).

### 3.2.1.5 References on mine sealing and closure techniques:

Bowders et al, 1994  
Burnett et al, 1993  
Carlson and Cummings, 1993  
CSP Associates, 1991  
Idaho Department of Lands, 1992  
Richmond, 1993  
Robinson, 1992  
U.S. Bureau of Mines, 1994c  
U.S. Environmental Protection Agency, 1973  
U.S. Environmental Protection Agency, 1975b  
U.S. Office of Technology Assessment, 1986
3.2.2 Discharge Quality Control Methods

Despite all of the methods mentioned above, mine drainage pollution is a persistent problem in IAM areas. As mined sulfide minerals are exposed to oxygen and water, it is difficult to completely prevent contact and oxidation. The water inevitably flushes some pollutants from the mine resulting in mine drainage with potentially harmful environmental impacts.

The following techniques are designed to control the quality of water discharging from an abandoned mine:

3.2.2.1 Mine Backfilling.

Underground mine backfilling is a method of disposing of mine waste which is practiced in both active and abandoned underground mines. Abandoned underground mines underlying populated areas are commonly backfilled to prevent surface fractures from subsidence. Though the degree of mine drainage pollution control resulting from backfilling has not been demonstrated, the control of mine roof collapse and subsidence will restrict infiltration of air and water through vertical fractures (U.S. EPA, 1975b, pp. 226-230).

3.2.2.2 Pressurizing with Inert Gas.

This method of abating acidic mine drainage is accomplished by reducing the free air oxygen in the mine. A significant reduction in oxygen content will decrease acid production. Pressurizing an underground mine with inert gas works in a similar way that flooding works. This method requires that the pressure within the mine be slightly greater than the outside barometric pressure, thus eliminating the entrance of air to the mine (U.S. EPA, 1975b, pp. 231-233).

3.2.2.3 Underground Precipitation.

This method is implemented by injecting alkaline water slurries into abandoned underground mines. The alkaline slurry neutralizes water within the mine, resulting in the precipitation of a sludge which fills the mine void. This process can be utilized either as a method of sealing drainage openings or for continuous neutralization of effluent mine water (U.S. EPA, 1975b, pp. 234-237).

3.2.2.4 Reference on Discharge Quality Control Methods:

U.S. EPA, 1975b

3.3 Controlling Contaminated Water

3.3.1 Drainage

In many cases, even when other mitigation methods have been implemented, some discharge will occur from abandoned mines. This section describes methods to reduce the environmental impact of such discharge. Contaminated water control may include methods for conveying water from the mine, regulating mine discharge to the environment, or reducing the pollution load of the discharge. These methods may or may not be applied in
conjunction with other abatement and remediation methods, and there is some overlap between water handling and infiltration reduction methods.

3.3.1.1 Evaporation Ponds.

The purpose of evaporation ponds is to collect and impound mine discharges, preventing discharge to the environment. This allows evaporation of the mine water to the atmosphere. This method is especially useful in arid regions where evaporation exceeds precipitation (U.S. EPA, 1975b, pp. 198-199).

3.3.1.2 Subaqueous Disposal (for mine tailings).

This method involves a permanent water column for disposing of mine tailings to prevent oxidation, acid generation and concomitant release of trace metals, effectively in perpetuity. The objective of this method is to prevent acid generation by preventing oxygen and bacterial action on the sulfide surfaces (See Dave and Vivyrka, 1994; Fraser and Robertson, 1994; Lapakko, 1994b, Pederson et al, 1994; Pederson and Pelletier, 1992; St. Arnaud, 1994; Watzlaf, 1992).

3.3.1.3 Underground Mine Flooding.

Mine flooding involves creating some kind of seal to prevent water from discharging from the mine. Once the mine is submerged, the rock is isolated from free air oxygen and acid generation, and metals mobilization is therefore retarded (Broman and Goransson, 1994; Mentz et al, 1991).

3.3.1.4 Deep Well Injection.

This method involves the pumping of mine drainage or its altered product into the subsurface below any useful aquifers.

3.3.1.5 Stream Flow Regulation.

This method involves containment and release of stream waters at volumes, rates, times and locations such that contaminating effects of mine discharge will be minimized (Evoy and Holland, 1989).

3.3.1.6 Controlled Release Reservoirs with Regulated Pumping.

This method entails the construction of large holding ponds or reservoirs to collect mine water discharges. Mine water is only released at opportune times, such as during wet periods when runoff volume is high and when receiving streams will be capable of accepting water without suffering contamination (Carlson and Cummings, 1993; Kalin et al, 1994; U.S. EPA, 1975b, p. 216).

3.3.1.7 Alkaline Regrading.

This method allows acidic mine discharges to come into contact with alkaline material, thereby becoming neutralized. This is only possible in certain areas, but may be especially applicable in Arizona because of the abundance of alkaline soil (Day, 1994; Skousen and Larew, 1994; U.S. EPA, 1975b, p. 211).

3.3.1.8 Slurry Trenching.

A slurry trench is a narrow, vertical excavation in unconsolidated material, with the sides maintained by a water-clay slurry (bentonite). The trench may be excavated with a backhoe, clam shell, dragline or connecting
drill holes. The clay slurry is backfilled with the previously excavated material or other material with suitable grain size distribution. As the slurry dries, an impermeable clay is formed in the trench, thus forming a groundwater dam (U.S. EPA, 1975b, pp. 200-210).

3.3.1.9 References on Managing Contaminated Water Control Through Discharge Control:

Broman and Goransson. 1994
Carlson and Cummings, 1993
Dave and Vivyurka, 1994
Day, 1994
Evoy and Holland, 1989
Fraser and Robertson, 1994
Kalin et al, 1994
Lapakko, 1994b
Mentz et al, 1991
Pederson et al, 1994
Pederson and Pelletier, 1992
Skousen and Larew, 1994
St. Arnaud, 1994
U.S. EPA, 1975b
Watzlaf, 1992

3.3.2 Decontamination

Though the problem can be greatly reduced by preventative measures, mine drainage is a persistent problem at IAM sites. There are numerous decontamination alternatives which include both active and passive methods. Again, the viability of any of these methods depends on the specifics of the mine site. Among the many alternatives are the following:

* Bioremediation
* Acid Neutralization
* Chemical Remediation
* Cyanide Destruction
* Metal Decontamination
* Alkaline Neutralization

Each of these methods has had some success and some failure. As all sites and their surrounding situations are unique, remediation often requires a number of different strategies. Below is a synopsis, with references, of the different mine drainage treatment methods.
3.3.2.1 Bioremediation.

Bioremediation of mine drainage is the process of utilizing biological organisms to decontaminate mine drainage. These organisms include both plants and animals, which alter the waste in a variety of ways.

-Wetlands. Generally, bioremediation of mine drainage is conducted in a series of existing or constructed ponds that resemble small marshes. These ponds, or wetlands, are engineered to process mine drainage by facilitating the aeration of water and the bacterial oxidation of iron. In some cases, this is followed by an anaerobic step, in which the water flows through a composted organic substrate that supports a population of sulfate-reducing bacteria. The beneficial processes that take place within the constructed wetlands include: adsorption and ion exchange, bioaccumulation, biotic and abiotic oxidation, sedimentation, neutralization, bacterial sulfate reduction and the dissolution of calcium carbonate.

As stated in Filas and Wildeman (1992):

Wetlands and bogs have long been recognized as nature's method of improving water quality. Contaminant reductions can occur through the precipitation of hydroxides, precipitation of sulfides and pH adjustments. Local conditions, oxidation state and water and soil chemistries dictate whether these natural reactions will occur under oxidizing (aerobic) or reducing (anaerobic) conditions.

Man-made or constructed wetlands employ the same principles as do natural wetlands. A thorough knowledge of the water and soil chemistries and the application of basic geochemical principles allows for the design and construction of wetland systems which can often be a cost-effective means of water treatment.

In general, wetlands have been very effective in removing iron from coal mine waste, but less effective in treating effluent from metal mines. Wetlands constructed to treat coal mine drainage are typically designed to optimize bacterial oxidative processes. This may be a useful first step in treating metal mine drainage that contains iron, but other contaminants of concern, such as copper, nickel, lead, zinc, and cadmium, cannot be removed by oxidation (Kleinmann et al, 1991).

- EMPACT and EMPACT M.I. A recently developed method called Environmental Mine Practices and Cattle Treatment (EMPACT) and EMPACT metal immobilization (M.I.) are also biological methods of remediating mine sites. EMPACT involves placing mulch over mine waste, and then introducing cattle to the site. Water sources and specially-formulated feed will be in separate locations, causing the cattle to migrate back and forth across the site. The weight and crushing actions of the cattle will aid soil development, and the cattle waste will chemically join together with heavy metals, rendering them immobile and harmless to the environment. This method has been successful at the Pinto Valley Mining Division in Arizona, and is being tested elsewhere (Rennicke, 1995).

3.3.2.2 References on Bioremediation Methods:

Altringer and Lein, 1992
Bechard et al, 1994
Bell et al, 1994
3.3.2.3 Acid Neutralization.

The oxidation of sulfide minerals in moist, aerobic conditions leads to the formation of acid and the mobilization of metals. This process is aided by bacterial action that gives rise to acid mine drainage. The purpose of this method is to neutralize the acid, and there are numerous methods for doing so including addition of lime, neutralization with aeration to oxidize iron, neutralization with sludge, and others.

3.3.2.4 References on Acid Neutralization Methods:

Ackman and Kleinmann, 1991
Cravotta et al, 1990
Day, 1994
Faulkner and Skousen, 1994
Ganse, 1993
Hedin and Watzlaf, 1994
Hedin et al., 1994
Jageman et al, 1988
Kepler and McCleary, 1994
Kleinmann, 1991
Lapakko, 1994a
Murdock et al, 1994
Narwot et al, 1994
Nevada Mining Association Symposium, 1992
Renton et al, 1988
Rich and Hutchison, 1994
Schultze et al, 1994
Skousen and Larew, 1994
U.S. Bureau of Mines, 1988a
U.S. Bureau of Mines, 1994a
U.S. Bureau of Mines, 1994b
U.S. Environmental Protection Agency, 1983
U.S. Environmental Protection Agency, 1993
Wilmoth et al, 1979

3.3.2.5 Chemical Remediation.

Chemical remediation is a broad category which encompasses numerous techniques for treating contaminated mine drainage. This category of remediation merely implies that chemical qualities of the waste or additives are utilized to promote contaminant removal or neutralization.

3.3.2.6 References on Chemical Remediation Methods:

Ahmed, 1994
Colorado Nonpoint Source Management Program, undated
Doyle, 1990
3.3.2.7 Cyanide Destruction.

Cyanide is used in the mining industry to extract precious metals from ores and to improve the efficiency of metals separation. Use of cyanide has expanded in recent years due to increased use of heap leach technologies for gold recovery. Cyanide also has the ability to form strong complexes with several metals, resulting in increased mobility of those metals.
Cyanide can also be an acute poison. This fact, combined with its increased mobility when combined with certain metals, renders it a significant environmental problem (Mine Waste Technology Pilot Program, 1994a).

Concerns about these problems have led to the development of methods of degrading cyanide and cyanide complexes in mining waste water. The following is a partial list of references which incorporate some of those different methods.

3.3.2.8 References on Cyanide Destruction:
Altringer, 1992
Comba, 1992
Comba et al, 1992
Frechette et al, 1992
Haynes, 1992
Lein et al, 1991
Milosavljevic, 1992
Mine Waste Technology Pilot Program, 1994a
Mine Waste Technology Pilot Program, 1994f
Olin, 1992

3.3.2.9 Metal Decontamination.
Metal removal from mine drainage has made much slower progress than neutralization of acid mine drainage. In recent years, however, concern for human health and environmental effects of toxic metals has been increasing. Toxic metals may be dissolved and carried away from mining sites by acidic surface runoff. Once this runoff enters streams, lakes, or reservoirs, the metal contamination becomes widespread.

3.3.2.10 References on Metal Decontamination:
The following references show a few examples of current research and applications of metal decontamination methods for mine drainage. There is considerable overlap in references between this category and bioremediation, since much of the success of metal removal from mine drainage has been biological. This list is very incomplete, but provides a starting point for further investigation.

Altringer et al, 1991
Carlson and Cummings, 1993
Colorado Nonpoint Source Management Program, 1993
Demko and Pesavento, 1988
Eger and Lapakko, 1988
Eger et al, 1994
Emerick et al, 1988
Fuerstenau and Palmer, 1980
Fyson et al, 1994
3.3.2.11 Alkaline Mine Drainage Neutralization.

A vast majority of the literature available on mine discharge remediation deals with acid and metal mine drainage. Few references specifically address the problem of alkaline mine drainage. Below is one reference which may be a helpful starting point for further investigation.

3.3.2.12 Reference on Mine Drainage Neutralization:
Hedin et al, 1994
3.4  Erosion and Sediment Control Methods

Water quality impacts from surface and underground mines are commonly exacerbated by storm water runoff and erosion. These factors can contribute significantly to the problems of mine drainage by causing greater release of pollutants to the environment, as well as by carrying the pollutants further from their source, thereby polluting a larger watershed area. Increased sedimentation to surface waters can originate from areas that are cleared for mining, roads built for access to project sites, stockpiles of topsoil, ore and waste, and stream channel alterations. These surface disturbances provide increased contact between contaminant-bearing rocks and surface water, enabling leaching to occur, resulting in water contamination. Below are some methods used to reduce the impacts of storm water runoff and erosion. These methods are closely linked to Controlling Water at the Source methods discussed above.

3.4.1 Drop Structures.

This control method involves the placement of large, hard, angular rocks in a V-shaped pattern across the width of a stream to catch sediment and slow the erosion process. Rocks must be sufficiently large that the water velocity does not dislodge them and carry them downstream (Idaho Dept. of Lands, 1992, p. 82; Oberly and Mohr, 1992).

3.4.2 Open Top Box Culverts.

This is a wooden culvert installed across a roadbed to convey surface runoff and flow from inside ditches onto the downhill slope of the road (Idaho Dept. of Lands, 1992, pp. 72-73).

3.4.3 Waterbars.

This is a berm built at a downslope angle, extending across the length of a roadway at a minesite. These waterbars reduce erosion by diverting runoff away from the road surface. These erosion control structures can be either permanent or temporary for lightly-used unimproved roads (Idaho Dept. of Lands, 1992, pp. 75-76; Oberly and Mohr, 1992, p. 51).

3.4.4 Gabions.

Gabions are rectangular wire boxes or baskets, filled with rocks and wired together. They are usually placed on steep slopes as permanent erosion control structures and are particularly useful where water seepage is anticipated. They are also useful for channel stabilization (Idaho Dept. of Lands, 1992, pp. 45-46).

3.4.5 Riprap.

Riprap is a layer of loose, hard, angular rock placed over soil to help protect against erosion. It is used below culverts, drainage outlets, along shorelines and stream banks, and as a lining in ditches and channels (Idaho Dept. of Lands, 1992 pp. 47-48).
3.4.6 Native Rock Retaining Walls.

These walls, constructed of native rock, provide an aesthetically attractive means for physically stabilizing slopes. They are usually constructed on steep slopes which are up to five feet in height and that cannot be effectively regraded or stabilized by another method (Idaho Dept. of Lands, 1992, p. 49).

3.4.7 Dispersion Terrace.

This is a terrace made with a bulldozer, graded at 1 percent, intended to disperse water without excess scour (Oberly and Mohr, 1992, p. 5).

3.4.8 Excavated Sediment Trap.

This is a pit, constructed with a backhoe, to capture sediment carried in stormwater (Oberly and Mohr, 1992, p. 5).

3.4.9 Vegetation Filter Zone.

This technique involves diverting water to a vegetated area which slows the flow velocity and allows suspended sediment to settle out as the water passes through (Oberly and Mohr, 1992, p. 5).

3.4.10 Roadside Sediment Trap.

This is a pit constructed with a backhoe, situated upstream from a culvert inlet. Its purpose is to capture sediment carried in stormwater before it reaches the culvert (Oberly and Mohr, 1992, p. 5).

3.4.11 Log Barrier Structure.

This involves placing logs in an arc shape with the ends of the arc level with the center of the arc in order to filter or contain sediment in runoff (Oberly and Mohr, 1992, p. 5).

3.4.12 Drainage Diversion.

(See above - under section 3.1)

3.4.13 Culvert.

This is a galvanized steel conduit installed with a backhoe intended to direct water without introducing sediment to draining water (Oberly and Mohr, 1992, p. 5).

3.4.14 Silt Fence.

In this method, a fine mesh fabric is suspended between fence posts in an arc shape, with ends of the arc situated upstream from the center of the arc. The fabric is embedded into ground and secured with soil or rocks. The purpose is to filter and contain sediment in runoff (Oberly and Mohr, 1992, p. 5).
3.4.15 Straw Bale Barrier.
This involves setting straw bales in shallow trenches or ditches to direct the water and retain the sediment in runoff (Oberly and Mohr, 1992, p. 5).

3.4.16 Geotextile Slope Stabilization.
This method utilizes polypropylene or biodegradable liners or blankets to stabilize slopes and control erosion (Oberly and Mohr, 1992, p. 5).

3.4.17 References on Erosion and Sediment Control Methods:
- Deely, 1977
- Idaho Department of Lands, 1992
- Oberly and Mohr, 1992
- Robinson, 1992
4. SUMMARY

Control and remediation of ground and surface water contamination related to IAM sites should begin with a full assessment of conditions at the site, including:

* type of mine
* type of waste
* mine size
* extent and method of mining
* volume of waste
* hydrology, geology, topography, and climatology of mine site
* exposure to air and water
* distribution of sulfide minerals
* accessibility of mine
* threat to human health
* threat to environment
* chemistry of native rock
* concentration of deposit in waste rock
* other site-specific factors

Consideration of these factors will dictate which control or remediation practice(s) to use. The various approaches available can be loosely classified into several groups. Sources of water entering the IAM site can be limited. Conditions necessary for toxic components in to site to become immobilized can be controlled. Contaminated water can be managed to both limit its access to the surrounding environment and to decontaminate it using chemical and biological methods before allowing it to leave the site. Erosion of potentially toxic material must be controlled to minimize the area that can be affected.

The methods described herein provide an overview of some of the technologies available with sources for further information. Neither the lists of methods, references, bibliography (Appendix A), contact list (Appendix B), nor the database list (Appendix C) are intended to be exhaustive. Rather they are intended as a starting point for further investigations.
5. APPENDICES
APPENDIX A. ANNOTATED BIBLIOGRAPHY
ANNOTATED BIBLIOGRAPHY


As part of the Bureau of Mines environmental research, a novel approach to identify and seal surface infiltration zones was tested in a stream near Frostburg, MD, that partially overlies abandoned coal mine workings. Ground electromagnetic conductivity surveys were performed within a stream channel to identify water-saturated zones at relatively shallow depths of 25 and 50 ft. Zones of increasing conductivity were found to be positively associated with areas exhibiting significant loss of flow. Conversely, zones which exhibited declining conductivity values delineated areas where there were no significant flow losses. Using this information, an experimental grouting procedure was used to place an expandable polyurethane several feet beneath the streambed over 70 ft. of the stream channel. Positive results were exhibited. Conductivity surveys present a significant cost savings in gaging work necessary for delineating stream loss zones. Grouting was also a less expensive seal option.


Water quality standards imposed on mine water discharges typically require neutralization of acidity and removal of metals in excess of established effluent limits. As an alternative to conventional neutralization and mechanical aeration, the U.S. Bureau of Mines has combined two readily-available in-line components: a jet pump aeration device and a static mixer. The combined system is referred to as the in line system, or ILS. This system is a simple and effective method of treating AMD and can reduce treatment costs. Field tests have shown the performance of the ILS to be at least equivalent and in most cases superior to conventional treatment methods.


This work was undertaken to identify conditions under which hardpan could be formed in pyrrhotite (FeS) rich tailings using surface chemical methods and to check the susceptibility of the synthetic hardpan to atmospheric oxidation and acid formation.


Surface coal mines often face operational or environmental problems which are located in close proximity to flooded, abandoned underground mines. A basic understanding of the groundwater flow systems within abandoned mine pools may help surface mine operators assess the probable hydrologic consequences of their operations or evaluate in-situ water quality improvement techniques. This paper characterizes groundwater flow systems for 2 abandoned underground coal mines. It provides little useful information on remedial methods.


This paper discusses bacterial destruction of cyanide as a means of treating cyanide-bearing waste from mining. The information appears to be relevant to abandoned mines as well as active mines. Many useful references on the same subject.


Not very useful for pollution mitigation, but contains papers and references on reclamation in CA.

Appendix A. 1
Banta, Fred, and Danni, Joe, 1993, Inactive and abandoned noncoal mines: blueprint for action: Colorado Center for Environmental Management, Conference held in Salt Lake City, UT, Nov. 15-17, 1993, 11 p. [To order copies of this report, call CCEM (303) 279-2700.]

This document provides a great deal of useful information for initiating cleanup projects at IAM sites. Its purpose is to provide decision-makers with examples of the essential elements of a state-based program to cleanup inactive and abandoned noncoal mine sites. The Blueprint identifies the significant issues, presents program ideas and principles and provides examples, where possible, to illustrate how those ideas and principles could be put into practice. Discussion includes: partnerships and stakeholder involvement; policy issues including liability and regulatory requirements; program elements including identification of geographic area, characterization of environmental quality in area, identification of pollution sources, and determination of pollution control methods and costs; identification of available cleanup programs and funds; determination of benefit derived from cleanup; establishment of a decision body for fund authorization; and eligibility of sites for IAM funds.

Bell, Alan V., Riley, Mike D., and Yanful, Ernest K., 1994, Evaluation of a composite soil cover to control acid waste rock pile drainage: Presented at the International Land Reclamation and Mine Drainage Conference and the Third International Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994, pp. 113-121.

Acid mine drainage (AMD) research under the MEND program has been ongoing since 1988 at the Heath Steel Mines waste rock piles including sulfide material, outside Newcastle, NB. In 1989 approximately 10,000 mt of waste rock was placed on a prepared sand base with an underlying impermeable membrane. The waste rock pile was heavily instrumented for oxygen concentrations and temperatures measures. A composite soil cover designed for the Heath Steel climatic conditions using local soils was placed over the pile, creating a totally enclosed system. Moisture content and oxygen probes were installed within the composite soil cover to monitor hydraulic conductivity of the cover. The waste rock has been monitored monthly since installation of the soil cover, with indications that the cover has significantly inhibited the oxidation reaction that generates the AMD.


The release of acid, copper, manganese and zinc was a major environmental problem at the abandoned Rum Jungle mine site in the Northern Territory, Australia. The main sources of pollution were the three waste rock dumps and the heap leach pile, all containing pyritic material. The site was rehabilitated between 1982 and 1986 and, as part of this program, the dumps were reshaped and covered with a three-layer cover, including a compacted clay layer. A monitoring program has been carried out to assess the effectiveness of the works on two of the dumps. Results have shown the following: 1) a significant decrease in incident rain percolation through the covers, 2) significant decrease in the rate of pyritic oxidation, and 3) decrease of the transport of oxygen through the dumps (effectively stopping thermal convection).


A laboratory investigation was conducted to determine the potential for producing low-hydraulic conductivity, amended fly-ash barriers to control sources of water which currently leach and transport products of oxidation from mine spoil and overburden materials - the result of which is acidic drainage. This surface barrier evaluation involved mixing fly ash, clay, and sand in varying amounts and analyzing the resulting mixtures' physical and engineering properties. This paper presents those results.


Constructed wetlands are often a preferred alternative to conventional methods of treating acid drainage at mine sites, coal preparation facilities, and coal-fired power stations. The TVA has designed and constructed

Appendix A. 2
wetlands and AL and TN to treat acid discharges from these sources. Between June 1985 and August 1987, 11 wetlands were constructed to treat these facilities. Treatment efficiencies have ranged from 82% - 99% removal for total iron and 9% to 98% removal for total Manganese. Wetlands systems costs from design to operation averaged $12.18/square meter of treatment area.


Many wetlands for acid drainage treatment have been constructed by the coal and utility industries with limited information on design and operating criteria. To investigate important components in wetlands treatment systems, the TVA initiated experiments at the Acid Drainage Wetlands Research Facility in Alabama, in 1986. All substrates (6) provided significant treatment of dissolved iron, suspended solids, and pH. Acid wetland soil was initially more efficient but differences between substrates became insignificant by fall. Only limited manganese removal occurred. The pronounced pattern of removal efficiency improvement, common to all substrate types, suggested that the plant-soil-microbial complex important to acid drainage treatment developed within all tested substrates within 1 yr. Treatment differences between substrates were inadequate to justify installing a specific substrate in operating systems; better performance of acid wetland soil supported protecting existing wetlands.


This workshop was a very productive one for IAM remediation issues. This document is the program for the meeting. The summary, which is more useful, is in a different volume, (see Broetzman, 1993b).


The zinc-copper deposits at Stekenjokk were discovered in 1918. Operations started in 1976 and continued until October 1988. The operation left a 110 ha tailings and clarification pond, a minor open pit, waste rock dumps and surface installations mainly comprising a head frame with ore bins and a combined concentrator, workshop and office building. The conceptual decommissioning plan for the areas was approved in 1983. The detailed planning commenced in 1986 and took 3 years to complete. The solution selected was based on a flooding concept. The decommissioning was largely completed in 1991 with minor completion works in the two following years. This paper describes the development of and the practical completion of the plan. It describes the reasons behind the selection of the method and reports practical experiences from the decommissioning work as well as the monitoring results so far.


Acid leaching from pyritic mine tailings is due to microbial oxidation of iron sulfides which provides the energy source for the organisms. The chemical reactions that take place are very inefficient and so require a good oxygen supply. Exclusion of oxygen from tailings prevents acid leaching. It is proposed that covering mine spoils with a peat blanket will actively prevent access of oxygen, as waterlogged peatlands are a reduc-
ing oxygen where organic matter or microorganisms reduce the plant cellulose to methane and CO₂. Initial experiments are reported here to establish in the range and distribution of methane in natural bogs and the conditions necessary for cultivation of methanogenic bacteria. It is postulated in this paper that pore spaces of the peat are plugged by insoluble methane which limits movement of oxygen, water, or methane itself to provide an impermeable cover.


This paper deals with subsidence abatement technology.


This volume looks very useful for mine remediation information. It includes 6 case studies of different technologies applied to mine remediation.


This book overall deals with land reclamation rather than pollution control and remediation, but there are some very useful papers.


The Golinsky Mine is within the mountainous West Shasta Mining District near Redding, CA. These mines contained massive sulfide deposits. The Golinsky Mine was not operated after 1938 and continues to emit AMD. AMD and metals from the Golinsky, along with contributions from the much larger Mammoth Mine complex and the smaller Sutro Mine, migrate to Shasta Lake where several incidents of fish kill have been noted over the years. The Forest Service has initiated studies aimed at abating metal discharges from the Golinsky mine. Due to its remoteness, the choice of remediation strategies are limited. This paper presents a matrix showing remediation choices, design and construction costs, and an evaluation of each method. A weighted average was assigned to each of the six selection criteria in order to rank remediation alternatives. Through this exercise, the preferred remediation technique was a phased program incorporating partial mine scaling as a buffer, followed by passive treatment.


This report describes a study of air pollutants emitted from coal refuse piles, abandoned mines and outcrops. The potential environmental effect of the source was evaluated using source severity (defined as the ratio of the maximum time-averaged ground-level concentration of an emission to a hazard factor. Findings are that the main principle to control emissions is to cut off the source of oxygen.


Research is being conducted on developing a clay slurry seal that will reduce or prevent acid mine drainage produced from reclaimed sites. The spoil material that is used to reclaim sites in WV is primarily shale and sandstone. When exposed to water and oxygen, the spoil produces AMD. By developing an effective phosphatic clay slurry seal, it will be possible to hydrologically isolate the acid-producing materials. An added benefit of this application is that phosphatic clay, which is a waste product of the production of fertilizer,
will be utilized, thereby reducing the need for storage of these clay wastes. An effective way to hydrologically isolate the acid-producing material is to reclaim sites using a layers system consisting of spoil material, overlain with a phosphatic clay slurry, which is, in turn, overlain by cover soil. The thickness of the slurry does not seem to significantly alter the permeability of the spoil-slurry system.


This paper addresses some new techniques for reclaiming tailing and acid-forming mine wastes in the western U.S. These methods include: 1) the use of adapted plant species which are now becoming commercially available; 2) the use of lime and selective bactericides for controlling acid; and 3) the use of organic amendments such as manure or sewage sludge.


This extremely useful paper reports the findings of a brief study done to ascertain whether mining and mineral processing technologies could be applied to the remediation of hazardous waste sites and, if so, which methods showed particular promise. The conclusions of the study were: 1) there may be an opportunity for technology transfer; 2) 2 categories show special promise: high temperature metal recovery and metal recovery through leaching; 3) currently, the greatest limitations to wide applications of both methods are cost and lack of data; 4) there are concerns that institutional barriers (e.g. CERCLA Feasibility Study requirements) will prevent development and use of promising technologies. This paper is an excellent overview of the utilization of mining technologies for IAM site remediation.


This useful fact sheet contains short discussions of remediation projects in mining nonpoint source controls which were funded in part by the U.S. EPA. The sites include: Pennsylvania Mine, which has Zn, Cd, Fe and Pb in drainage from the mine; South Mosquite Creek, which received Zn and Cd-contaminated drainage from the Alma Betts Mill tailings site; St. Elmo, in which the Chalk Creek is heavily polluted by drainage and metals from Golf Tunnel; East Willow Creek, involving AMD and metals coming from actively eroding waste piles; and Gamble Gulch, involving AMD. The fact sheet contains short synopses of the remediation efforts for each project, with comments on levels of success. Abbreviated, but very useful document. More detailed discussion has been written up by CO School of Mines.


This paper discusses different methods for treating cyanide-bearing waste from mining. The information appears to be relevant to abandoned mines as well as active mines. Many useful references on the same subject.


An average of 108,000 gallons per day of AMD originating from the underground coal mine known as the Union Coal Mine No. 2 is adversely affecting water quality in Pittsburgh and Latimer Counties of southeastern OK and has brought about a multitude of citizens complaints. An attempt to reduce AMD flow by raising the water level in the mines was not successful. In 1992 a new effort was begun. A list of 5 reclamation alternatives was presented. A partial mine seal with a passive shallow wetland was selected and implemented in the summer of 1993. One significant early finding was that the mine water pH was raised from 3.4 to 5.8 by channelizing the acid mine drainage away from the original seep location. This is the result of moving the flow away from the acid forming deposits which catalyzed reactions driving the pH down.
The results of the partial seal installed in June 1993 were less exciting, but this was not unexpected since they were experimenting and pioneering a new method for AMD.


The addition of alkaline materials to supplement deficient "neutralization potential" of mine spoil, and thus to prevent or abate AMD, has not been successful at most surface coal mines in PA. A basic problem may have been improper accounting for acid-production potential and thus inadequate addition rates of calcium carbonate, calcium oxide, or calcium hydroxide at many mines. This paper reviews some geochemical reactions involving FeS₂ and various alkaline additives that support the argument that the acid-base accounting method for computing "maximum potential acidity" from overburden analysis should be revised.


This 350-page compendium contains detailed background on 53 Canadian companies, and lists 120 technologies, products, and services, with their track record. The intent is to identify solutions to air, water and land pollution caused by mining and mineral processing. The initial target audience is developing countries, but it is intended to be useful to anyone in mining or mineral processing industry.


This study was designed to assist individuals involved with problem of abandoned mines that are subsiding. The study analyzed the practicality and desirability of using blasting to stabilize subsiding abandoned underground mines. Application of blasting to subsidence problems could provide a valuable alternative technology to classical methods of injecting fill material into abandoned mines to fill voids and prevent subsidence. By blasting, subsidence can be induced in a controlled manner, completed, and the site returned to its desired usage. Subsidence control can help control water infiltration to the subsurface, so this paper is relevant to pollution control methodology.


Under the Mine Environmental Neutral Drainage (MEND) program, a joint research project between CANMET, Elliot Lake Laboratory and Rio Algom Limited, Elliot Lake, Ontario, was established to investigate the feasibility of establishing a shallow water cover on pyritic uranium tailings as a close-out option for controlling acid generation and release of contaminants. The results of the program indicated that acid generation could effectively be controlled using a shallow water cover 90.5-1.0 m in depth).


Mixing acid generating and acid consuming rocks is an attractive and potentially low cost alternative for in situ prevention of acid generation in waste rock piles at some mine sites. In addition to the practicalities of day to day management of mixed waste piles, the success of the mixing will probably depend on the proportion of acid-consuming material, the availability of the acid-consuming material, and the intimacy of mixing. This paper shows a case history from British Columbia. The conclusions were that limestone addition was highly effective in delaying acid release but was less effective in delaying zinc release.


This is an extremely useful information source on mine-related pollution control. It includes discussions of the following: 1) a water quality management program for mine-related sources; 2) existing pollution source identification and assessment; 3) current technology and programs for source pollution control; 4) mine-related best management practices; 5) abandoned mine pollution source abatement; 6) new source pollution control planning; and 7) continuing mine-related water quality management and planning. The document
dates to 1977, so some of the information is dated. However, there is a great deal of useful information that is still effective.


The use of man-made wetland ecosystems to renovate mine discharges has mainly been limited to low to moderate concentrations of iron, manganese, and aluminum. In order to study such a system under more adverse conditions, a wetland ecosystem complex has been constructed to treat a mine discharge in PA which is characterized by high concentrations of Fe, Mn, Al and sulfate and a low pH. The flow rate varies seasonally and reacts quickly to precipitation and snow melt events, but averages 12 gal/min. The wetland ecosystem complex was designed to remove high metal loadings by three mechanisms or groups of mechanisms: 1) the staged, bio-catalyzed oxidation/precipitation of the metal ions and complexes in solution; 2) co-precipitation adsorption, chelation, ion-exchange) of metal ions and complexes by iron, manganese and aluminum oxides and hydroxides; and 3) inorganic chemical precipitation. Preliminary results show considerable decrease in acidity and Fe concentration.


Artificial (constructed) wetland systems have attracted considerable attention in connection with the treatment of acidic mine waters. A study was undertaken to examine the effects of *Sphagnum spp.* and decomposed peat on pH, and iron and sulfate concentrations, in laboratory-scale reactors receiving synthetic mine water. Effluent was monitored for pH, iron, and sulfate. Depth profiles were examined for iron, sulfate, sulfide, pH, Eh, and sulfate-reducing bacteria. Addition of iron in the ferric state to the experimental units resulted in fluxing of highly visible oxidized iron which, according to profile and effluent data, underwent transformation to ferrous iron under reducing conditions. The addition of sulfate to the system correlated well with parameters of sulfate reduction, i.e., level of sulfate-reducing bacteria enriched in the peat, reducing Eh, sulfate loss, and concentrations of sulfide obtained.


The PA Dept. of Environmental Res. has identified wetland treatment as an appropriate technology to reduce impacts of AMD on surface waters. Several Wetland Treatment Systems (WTS's) were constructed to reduce AMD impacts on receiving streams, evaluate treatment effectiveness, biological and chemical processes, and design criteria for future WTS construction. This paper contains the results of that study.


This paper discusses the role of surficial land configuration in the formation and dissemination of water pollution.


An excellent overview of the Wyoming AML Program with specific information on the laws, the AML process, and remediation technology. Some of the remediation technology is very applicable to AZ AMLs.

This proceedings volume includes sections on Regulations and Permitting, Chemical Characteristics and Behavior of Wastes, Environmental Impact of Mining Wastes, Case Studies on Waste Management Practices, Innovative Waste Impoundment Strategies, and Innovative Chemical Treatment Methods. It appears to be a very useful resource.


This is an extremely useful paper which identifies and characterizes water quality sources at abandoned hardrock mine sites and best management practices (BMPs) used to control polluted runoff. It discusses the need to clearly define the best approach for controlling nonpoint pollution sources at abandoned mines. These are issues that could be addressed in reauthorization of the Clean Water Act.


Recently a considerable amount of attention has been focused on the use of wetlands, both natural and constructed, for the treatment of acid coal mine drainage. Wetlands also may have a significant capacity for removing trace metals from other types of mine drainage. Minnesota has many peatlands near existing and potential mining developments, and the use of peatlands for the control of drainage quality is an attractive alternative to chemical treatment. A study has been conducted on a white cedar peatland receiving stockpile drainage which had an average concentration of 17.9 mg/L nickel and 0.62 mg/L copper. Surface and groundwater, vegetation, and peat were all analyzed for trace metal content. Based on mass balance calculations and water quality data, essentially all of the copper and 80% of the nickel were removed by the peatland. Removal by peat accounted for 90% of the overall metal reduction.


Wetland treatment has successfully removed nickel, copper, cobalt and zinc from neutral mine drainage in northeastern Minnesota. Pilot and full-scale overland flow wetlands have removed up to 90% of incoming nickel and 50%-90% of the other metals. This paper presents the results of a wetland study in which the fate of the metals and the removal mechanisms were determined by studying the vegetation and peat in the wetland.


During the summer of 1986, discharge from the Pennsylvania Mine was diverted into a natural sedge wetland in an experiment to assess the metal removal capability of a wetland type common to the higher elevations of the Rocky Mountains. The Pennsylvania mine is an abandoned metal mine located at an elevation of 3355 m in the Peru Creek basin of Central Colorado. Surface discharge from the mine averages 380 L/min with a mean pH of 3.6 and high metal concentrations. During the course of the investigation it was determined that the wetland was heavily contaminated with metals prior to the experiment, apparently coming from metal-laden surface and colluvial waters. The experiment was therefore terminated. However, the study demonstrated that the plant species present (mainly Carex aquatilis) have a high tolerance for metals and low pH and thus have good potential for use in constructed wetland treatments systems in the Rocky Mountains.


A novel coating methodology was developed to prevent pyrite oxidation in mining "waste." The mechanism of this coating technology involves leaching mining "waste" with a phosphate solution containing hydrogen. Appendix A. 8
peroxide (H$_2$O$_2$): when this solution reaches pyrite surfaces, H$_2$O$_2$ oxidizes the surface portion of pyrite and releases Fe$^{3+}$ so that iron phosphate precipitates and forms a passive coating on pyritic surfaces. This study demonstrated that iron phosphate coatings on pyrite surfaces could be established with a solution containing as low as 10$^{-4}$ mol/L phosphate and 0.027 mol/L H$_2$O$_2$ and that iron phosphate coating could effectively protect pyrite from oxidizing further. This method could mean solution to production of AMD from certain types of mine waste.


This publication pertains to wholesale reclamation, but contains useful information for mitigating water contamination. Chapter 3 contains BMPs for controlling leachate waste problems, unwanted chemicals, example contaminant control approaches, removal of groundwater to keep water table low beneath site, runoff control, damming, erosion and sedimentation control.


Passive AMD treatment constructed on sites in WV treat flows ranging from 4 to 98 L/min and acidity concentrations from 170 to 2,400 mg/L. Five wetland systems reduce acidity by 3% to 76%, and Fe concentrations by 62% to 80%. These wetlands are generally much smaller than that recommended by earlier formulas based on iron loads, but they still show good amelioration of acid and iron loads. In 2 of the 5 wetlands, limestone was not incorporated into the substrate. Iron and acid reductions were similar between wetlands with and without limestone revealing that limestone may not be important for metal removal in wetlands. Anoxic limestone drains (ALDs) reduce acidity by 11 to 100%. Based on our successes and failures in building and monitoring ALDs, several conclusions have been reached, and are reported in this paper.


The control of acidic drainage from uranium mine wastes in Germany is a significant component of mine site rehabilitation that began in 1992. Uranium was mined on a very large scale in the States of Thuringen and Sachsen from 1946 to 1991. Sulfide oxidation creates acidic drainage from waste rock piles at several mine sites and may occur in the future at two tailings impoundments. The extent of the problem of acidic drainage and methods to control acid production are reviewed from an international perspective. A central component of the rehabilitation plans in Germany is a proposal to fill a large open pit with acid-producing waste rock, allowing it to flood, and treating the overflow. This plan is assessed using a regional geological model in a probabilistic framework. The modeling has proven to be a useful tool in assessing management alternatives.


This paper discusses the utility of wetlands and bogs for reducing water contaminant levels by precipitating hydroxides and sulfides, and adjusting pH. Useful article with useful references on same subject.


A study of subaqueous disposal of reactive tailings started in 1988 with an initial overview of all known Canadian sites. A work plan was developed in 1989, which consisted of evaluating 4 lakes over 2-year periods. The initial year consisted of evaluating the biophysical features of each lake as a preliminary exercise in preparation for the second year of work. The second year consisted of performing detailed geochemical work on interstitial water at 2-3 sites in each lake. At the request of MEND, a scientific and technical peer review of all work was done in 1992. This and presentations made to regulatory agencies provided feedback on the merits of use of subaqueous disposal to control reactive materials. Information deficiencies were also

Appendix A. 9
documented. Additional research work was undertaken to address these and support application of this method. A program was outlined in 1993 to incorporate review recommendations, and 2 lakes were selected for further study. This paper is an overview.


This volume contains the proceedings of the "First Western Regional Conference on Gold, Silver, Uranium and Coal," held in South Dakota Sept, 18-20, 1980. The papers include discussions of many aspects of gold, silver, uranium and coal exploration, mining, processing techniques and resource characterization. The environmental discussions are less comprehensive and focus more on identifying potential environmental hazards than on control or remediation methods.


Lab experiments were carried out to test the capacity of sediments from muskeg ponds to treat waste rock seepages with mean concentrations of As and Ni 35 mg/L and 79 mg/L, respectively. Seepage water was added to column reactors containing muskeg sediment, and additions of organic matter were made to the sediments to stimulate microbial activity. Concentrations of As and Ni were very significantly reduced. These experiments have shown that muskeg sediments have the capacity to remove As and Ni from waste rock seepage water through providing conditions that facilitate precipitation and adsorption with or without the addition of organic amendments.


Mostly about reclamation, and an old reference, but has some valuable information about practices which would be useful for pollution control.


A large rehabilitation project has been carried out on an abandoned uranium mine at Rum Jungle in the Northern Territory of Australia where oxidation of pyritic mine wastes has led to substantial water pollution. This pyritic oxidation has been halted by the exclusion of air and water from two rock heaps by contouring and installing a clay cap. Ground water levels and quality have been monitored for acidity and dissolved metals over the four years since the project began. Although the contaminant input to the local river has dropped markedly, there has been no significant change in ground water quality. The purpose of this work is to estimate the time scale over which an improvement might be expected to occur. A model in
which the main store of pollutant is assumed to be the contaminated water below the heap leads to the very low estimate of less than four years. A more complex model which accounts for contaminants stored in pore water held in the dump produces an estimate of 20 years.


This document is available through NTIS. Though dated, this is a useful bibliography pertaining to reclamation of coal-mine land. Some of the technologies discussed are relevant to mining processes in AZ.


Though this concentrates largely on issues related to current mining practices, some of the information is transferable to inactive and abandoned mine land.


Though this concentrates largely on current mining issues, many of the ideas are transferable to inactive and abandoned mines.


Report presents a multi-media (air, liquid, and solid wastes) environmental assessment of the domestic mineral mining industry. Primary objective was to identify the major pollution problems associated with the industry. Second objective was to define research and development needs for adequate control of air pollutants and liquid and solid wastes connected with mineral mining. Useful background, but does not address specific abatement practices.


Batch tests were conducted to determine if biogenic \( H_2S \) could be used to selectively recover \( Cu \) and \( Zn \) from extremely acidic and metal-contaminated drainage from the Iron Mountain Mine near Redding, CA. Two methods were attempted, both having some success.


Hydrogen sulfide generated by the anaerobic respiration of sulfate-reducing bacteria was used to treat samples of pH 2.2 water from the abandoned Rio Tinto copper mine in NV. The untreated water contained 550 mg/L Fe, 140 mg/L Al, 92 mg/L Cu, 76 mg/L Mn, 60 mg/L ZN, 4 mg/L Co, and 2 mg/L Ni. \( H_2S \) was generated in a bench-scale bioreactor and bubbled into mine water in 3 precipitator-clarifier units, where metal-sulfide precipitation and recovery took place. The treatment system reduced the concentrations of all metals except Mn to less than 0.1 mg/L. Mn concentrations were reduced by 96% to 3.3 mg/L. A CuS-SO\(_4\) concentrate (33% Cu) and ZnS-SO\(_4\) concentrate (28% Zn) were produced that may be suitable for metal recovery at existing smelters.


Experiments were done to determine if a compost-based sulfate-reduction system could be used to treat nickel-contaminated mine waters. Sulfate-reduction systems were established in columns containing acid-washed mushroom compost. Simulated mine waters containing 2000 mg sulfate/l and 50-1000 mg nickel/l were adjusted to pH 4.5 and pumped through the columns at flow rates between 15 and 25 ml/h. Initially, almost all of the influent nickel was removed in the columns by sorptive and ion exchange mechanisms. The nickel removal rate then dropped to 18-30 mg nickel/kg compost day (7.8 to 12.8 mmol/g compost day), where it remained relatively constant. The mechanisms responsible for the low and sustained rates of Ni
removal on unamended compost are unclear. When sodium lactate was added to the inflow, sulfate reduction rates between 250 and 650 nmol day/ cm³ compost were obtained and a sevenfold increase in the nickel removal rates was observed. The maximum nickel removal rate observed was 540 mg Ni/kg compost day (92 nmol Ni/g compost day) for columns receiving 1000 mg Ni/l.

The oxygen dependence of abiotic and biotic pyrite oxidation was examined on 3 scales: 1) pyrite surfaces to a depth of 20 Ångstroms; 2) 5 g quantities of pyrite in small columns; and 3) 175 kg quantities of pyritic shale in large columns. Results of these studies indicated that the initial abiotic oxidation of fresh pyrite surfaces was independent of oxygen partial pressures above 10% (0-order reaction) as was proportional to oxygen partial pressures from below 10% (first-order reaction). However, the rates of abiotic oxidation measured in small columns were proportional to oxygen partial pressures between atmospheric (21%) and 5%. Small column and large column results indicated that with bacteria present, the rate of pyrite oxidation was independent of oxygen partial pressures down to 1%. The oxygen-permeable and oxygen-consumptive barriers other than water that are economically feasible at present are not capable of maintaining oxygen levels below 1%.

This volume is one of the prime references on wetland treatment. It includes discussions of wetland treatment for a variety of wastes, including mining waste and sewage.

Very useful report. It discusses the mission and objectives of the environmental technology research program. Technologies discussed include treatments for acidic and metal contaminated water (bio-fix beads, bacterial assisted contaminate removal [sulfate reduction and selenium removal]), cyanide removal and treatment, and reclamation.

Construction and water quality characteristics of 21 anoxic limestone drains (ALDs) were studied in order to identify and evaluate key factors responsible for the variable performance of these passive treatment systems. 19 of these ALDs discharged water that contained bicarbonate alkalinity ranging from 69 to 469 mg/L as CaCO₃. In addition to adding alkalinity to the mine water, some ALDs decreased the mineral acidity of the mine water. Acidity removal ranged from 0 to 5,901 mg/L. Large changes in acidity were primarily associated with retention of ferric iron and aluminum.

Passive methods of treating mine water use chemical and biological processes that decrease metal concentrations and neutralize acidity. Compared with conventional chemical treatment, passive methods generally require more land area, but use less costly reagents and require less operational attention and maintenance. Currently, three types of passive technologies exist: aerobic wetlands, organic substrate wetlands, and anoxic limestone drains, all of which operate differently. Rates of metal and acidity removal for passive systems have been developed empirically by the U.S. Bureau of Mines. A model for the design and sizing of passive treatment systems is presented in this report.

This paper involves the performance of a "best professional judgment" (BPJ) analysis to determine the treatment of post-mining ground water seeps from surface coal mining operations. Acidity, Fe, and Mn.
were selected as the pollutants of primary interest to be removed. Data from 73 constructed wetlands were
applied to data from 794 post-mining seeps in coal mining country. Based on the analyses, wetland treat-
ment was found to be the best available technology economically achievable for treatment of post-mining
ground water seeps, particularly for mildly acidic and alkaline seeps.

Hiel, Michael T., and Kerins, Francis J., Jr., 1988, The Tracy Wetlands: a case study of two passive mine drain-
age treatment systems in Montana, in Mine Drainage and Surface Mine Reclamation, Proceedings of a con-
ference sponsored by the American Society for Surface Mining and Reclamation, Bureau of Mines, and The
Office of Surface Mining Reclamation and Enforcement. Volume I: Mine Water and Mine Waste: U.S. Bu-

Two man-made wetland systems were constructed in MT to experiment with and assess applicability of
Passive Mine Drainage Treatment technologies to the state. The wetland systems, designated the Large
Tracy Wetland and the Small Tracy Wetland treat flows of .95 and .15 liters per second, respectively. Both
wetlands were constructed during the summer of 1986 and utilize a peat substrate planted predominantly
with Typha Latifolia for metals removal and limestone gravel and aeration structures for pH buffering. The
large wetland has approx. 418 sq. meters of surface area. Inflow to system has metals concentrations > 280
mg/L Al and 1.5 mg/L Mn. The small wetland has approximately 111 sq. meters of surface area. Inflow to
this system has metals concentrations > 143 mg/L Fe, 46 mg/L Al and mg/L Mn. Construction costs for the
large and small wetlands were $67/sq. m and $140/sq. m, respectively. Both wetlands were ineffective in
improving water quality of AMD. Reasons for this are discussed.

sorbents for the selective recovery of toxic heavy metals from acid mine drainage: Presented at the Interna-
tional Land Reclamation and Mine Drainage Conference and Third International Conference on the Abate-
ment of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994, U.S. Bureau of Mines Special Publication SP

By a new synthetic technique, macroporous crosslinked polystyrene resin was functionalized with ligands
containing sulfur, nitrogen, and/or oxygen atoms. Preliminary studies indicate that when added to a syn-
thetic AMD solution, some of these functional polymers were capable of selectively binding zinc without
becoming "fouled" by iron. Elution of the loaded resins with acid to recover the zinc was also possible. The
greatest selectivity for zinc was obtained with functional groups that contained only electronically "soft"
nucleophilic centers such as sulfur and nitrogen, and not oxygen atoms, which are electronically "hard" (and
prefer "hard" electrophiles as magnesium, aluminum, or iron cations). The performance of some of these
new materials exceeded that of the commercial ion-exchange resins tested with respect to capacity and se-
lectivity.

Hustwit, C.C., Ackman, T.E., and Erickson, P.M., 1992, Role of oxygen transfer in acid mine drainage abate-

The U.S. Bureau of Mines formulated a new mathematical model to characterize iron oxidation. The new
model is intended to replace the currently used model, recommended by the EPA for most acid mine drain-
age treatment applications. This paper is an evaluation of that model. The paper is more theoretical than
applied - and probably will not be of much use for determining remediation or control methods.

Hustwit, Craig C., and Sykes, Richard G., 1994, Pipeline treatment of a metal mine drainage containing copper
and zinc: Presented at the International Reclamation and Mine Drainage Conference and the Third Interna-
tional Conference on the Abatement of Acidic Drainage, Pittsburgh, PA, April 24-29, 1994, U.S. Bureau of

A pipeline treatment system, previously used to treat coal mine drainage, was tested at pilot- and full-scale
to determine its effectiveness in treating a copper-zinc bearing metal mine drainage in northern CA. Based
on these studies, it was concluded that 1) pipeline treatment is a viable approach to metal mine drainage
treatment, 2) establishing a treatment pH in the 9.0 to 10.0 standard unit range was critical for metals re-
moval, and 3) treatment in the In-Line System (ILS) may involve coprecipitation mechanisms.

Idaho Department of Lands, 1992, Best Management Practices for Mining in Idaho: Idaho Department of Lands,
Boise Idaho (208) 344-0247, 12 p., 4 appendices.

This handbook is a reference guide which contains standardized practices and procedures designed to miti-
gate the impacts of surface disturbing activities. It contains numerous BMP's that are intended to mitigate
the impacts to water quality resulting from mining. They are geared for active mines more than inactive and
abandoned mines, but some of the recommendations are directly transferable to abandoned mines. The sec-

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tion on BMP's includes these categories: soil stabilization, seeding and revegetation, runoff collection, run-off dispersion, and sediment collection.


AMD pumped from an underground mine can contain dissolved carbonates. When hydrated lime is added in the treatment process to neutralize the AMD, the dissolved carbonates react with lime to form insoluble calcium carbonate. The presence of dissolved carbonates in the untreated water increases both the amount of lime required to neutralize the AMD and the amount of sludge formed during the treatment process. Laboratory tests show that dissolved carbonates can be removed as gaseous CO₂ by aerating the AMD prior to the addition of lime (pre-aeration). Field tests were conducted at three AMD treatment plants. The tests demonstrated that pre-aeration is an effective method of reducing treatment costs for an AMD containing dissolved carbonates. Pre-aeration has been permanently applied at each of the sites, and treatment costs have been substantially reduced, while strict compliance with environmental permits has been maintained.


This paper presents the methodology and considerations utilized to design the impoundments associated with the wetlands for AML Project 14B, located in the Big Horn Basin of WY. 18 bentonite disturbances were reclaimed as part of this project. Many of the disturbances had pit bottom areas or blocked drainages where wetlands had formed. To replace the wetlands which were backfilled or compacted during reclamation, 24 new or enhanced impoundments were constructed. Due to the number or sites and varying location a standard procedure for sizing the impoundments was required which could be utilized for all of the sites. This included pond sizing guidelines, weather data, runoff, evaporation, etc. A pond size was developed which would balance the runoff volume with the pond evaporation. The impoundments were sized to spill during precipitation seasons with average rainfall or slightly above average rainfall.


A research program supported by both Resources and the Canada-British Columbia Mineral Development Agency has evaluated the use of cementitious dry surface covers for the prevention of water and oxygen infiltration into acid-generating waste-rock piles. This paper presents the results of a field trial of a dry cover over a large test area on a waste rock pile at the Westmin Myra Falls site near Campbell River, BC, Canada. The objectives of this study were to apply the cementitious cover in the most cost effective manner and to evaluate the material properties and the long-term efficacy of the cover system. This technique looks interesting; the test area, however, is very different from AZ because of the large amount of rainfall.


This document includes copies of documents submitted to WGA in response to the May 26, 1994 letter requesting information from State and Federal contacts about specific IAM inventory issues. The 4 items requested were: 1) IAM inventory definitions; 2) IAM site priority ranking systems; 3) QA/QC systems; and 4) Field training protocols. The documents do not specifically address remedial methods. However, it is a useful document for finding contacts in different states, and finding out more about the above issues.

Seepages from a coal waste dump in Nova Scotia contain a considerable amount of iron and acidity. Upon exposure to air, ferrous iron oxidizes, hydrolyzes, and precipitates, reducing pH to 2.7. An experimental passive treatment system was developed to remove iron and acidity from the seepage water. A trench system, providing sufficient retention time for iron removal through precipitation of ferric hydroxides, was constructed. Berms of phosphate rock were constructed to intercept seepage water, to enhance iron removal from water. Early results show some reduction in acidity and iron concentration. Water leaving the trench system enters a chemical reducing zone where, through microbial activity, alkalinity is generated and the pH is increased. An experimental enclosure, amended with potato waste and covered with floating cattails, was set up with encouraging results. Overall, the results show that an oxidation/reduction passive system has promise for treatment of coal waste AMD.


High mountain wetland plant communities can be used to effectively mitigate copper mine discharge. Several plant and soil micro-fungi species were discovered that tolerate and accumulate copper and other heavy metals from enriched flows. The importance of an aquasolic soil and a flat gradient for the optimization of metal sequestration was also documented. pH effected solubility of Cu, but temperature change did not seem to cause release of Cu from the plants of soil. No appreciable release of Cu was noted from the senescent Cu-laden plants into Cu-spiked water. Most of the species studied showed no toxicity symptoms in relation to an excess of Cu.


This booklet provide information on how to use RECLAIM, the reclamation reference system. The database is an extensive database of mine reclamation methods. Includes some useful methods for remediating Arizona mined land problems.


Preliminary studies utilizing the digestion and ashing of freshwater algae of several phyla, samples from AMD sources, indicate relatively high concentrations of iron and manganese associated with the algae. A wetland treatment system was constructed in 1987 at an abandoned drift mine in PA, associated with a coal seam. Specifically designed and planted "algae ponds" are integrated with the emergent marsh sections of the system in an effort to examine the role of algae in treating AMD. The site of mineral accumulation in the algae and the forms in which the minerals are found in the algae are of primary interest. The relationship between mineral uptake and water quality, the effects of mineral toxicity to the algae, and the potential ability of algae to modulate effluent pH values on a diel basis will also be investigated. An overview of methods and their rationale along with results to date at the study with are presented.


Constructed wetland treatment system effectiveness has been limited by the alkalinity-producing, or acidity-neutralizing, capabilities of the systems. Anoxic limestone drains (ALDs) have allowed for the treatment of approximately 300 mg/L net acidic mine drainage, but current design guidance precludes using successive ALDs to generate alkalinity required in excess of 300 mg/L because of concerns with dissolved oxygen. "Compost" wetlands designed to promote bacterially mediated sulfate reduction are suggested as a means of generating alkalinity required in excess of that produced by ALDs. Compost wetlands created two basic needs of sulfate reducing bacteria: anoxic conditions resulting from the inherent oxygen demand of the organic substrate, and quasi-circumneutral pH values resulting from the dissolution of the carbonate fraction of the compost. However, sulfate reduction treatment area needs are generally in excess of area availability or cost-effectiveness.
Acid drainage from underground coal mines and coal refuse piles is one of the most persistent industrial pollution problems in the United States. This Bureau of Mines report reviews the acid mine drainage problem generally and describes research currently underway to combat it.

A bacterium, *Thiobacillus ferrooxidans*, is of prime importance in the formation of acid drainage from pyritic material. Above pH 4.5, *T. ferrooxidans* increases initial acidification; below pH 4.5, it allows acidification to continue by oxidizing Fe$^{2+}$. Below a pH of approximately 2.5, the activity of Fe$^{3+}$ is significant and results in steady-state cycling between oxidation of pyrite by Fe$^{3+}$ and bacterial oxidation of Fe$^{2+}$. Laboratory and field tests demonstrate that inhibition of *T. ferrooxidans* by controlled release of anionic detergents can inexpensively reduce pyrite oxidation and acid formation.

Biological treatment of coal mine drainage is typically conducted in a series of excavated ponds that resemble small marshes. The ponds are engineered to facilitate the aeration of water and the bacterial oxidation of iron. In some systems, this is followed by an anaerobic step, in which the water flows through a composted organic substrate that supports a population of sulfate-reducing bacteria. The anaerobic bacterial sulfate reduction process can raise the pH. During the past 4 years, over 400 wetland water treatment systems have been built on mined lands. In general, mine operators have found that the wetlands reduce chemical treatment costs enough to repay the cost of wetland construction in less than a year. Biological treatment of metal mine drainage to date has been limited to pilot-scale experiments. Two basic approaches are currently being examined: wetland systems modified to enhance bacterial sulfate reduction and enclosed sulfate reduction reactors.

Passive treatment of mine water can be a low-cost alternative to conventional chemical treatment or can be used to reduce chemical costs by eliminating most of the pollutant load. Water quality, flow data and site characteristics determine whether passive treatment should be used at a specific site. However, based on its rapid adoption by the coal mining industry, it should be clear that at many sites, the cost of construction is recouped rapidly by reduced chemical treatment requirements. In addition, passive treatment technologies now are being used at many long-abandoned mine sites, where the water otherwise simply would flow into the nearest stream.
Batch reactor tests were conducted to determine the ability of peat to remove trace metals (Cu, Ni, Co, Zn) from one acidic and two near neutral mining stockpile drainages. In all three drainages, Ni contributed 70–90% of the trace metal burden. Laboratory experiments were conducted to examine the effect of 3 different subaqueous disposal techniques on the oxidation of sulfide minerals present in Virginia Formation hornfels rock containing 14 wt % pyrrhotite. The subaqueous techniques were unmodified subaqueous disposal, subaqueous disposal with alkaline addition, and pretreatment (rinsing and neutralization) of rock prior to subaqueous disposal and subsequent alkaline addition. This paper presents the results of the laboratory investigation. The rates observed in the laboratory were used, in conjunction with existing knowledge on oxygen transport, to determine rates of acid production for subaqueous disposal of similar mine waste in an open pit.

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85% of the trace metal concentration. The sum of the trace metal concentrations in the acidic drainage was 580 mg/L at pH 3.15. At a loading of 50 g dry peat/L, 60% of the trace metals were removed from this drainage after 1 hr. of reaction, with no subsequent removal. The trace metal concentrations in the near neutral drainages totaled 1.2 mg/L at pH 7.4 and 9.2 mg/L at pH 7.9. Kinetic studies on these 2 drainages indicated that the majority of metal removal occurred in the first 20 hours of reaction and that equilibrium was approached after about 70 hours. Metal release increased as solution pH decreased and was greater yet when peat was exposed to bog water.

Lein, R.H., Dinsdale, B.E., and Altringer, P.B., 1991, Biological and chemical cyanide destruction from heap leachates and residues, in Environmental Management for the 1990's, Lootens, D.J., Greenslade, W.M., and Barker, J.M., eds.: Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, pp. 135-142. The U.S. Bureau of Mines is investigating biological and chemical decontamination of cyanide-containing leachates and residues. Biological cyanide oxidation, using bacteria isolated from a precious metals tailing pond, destroyed >85% of the cyanide in several processing solutions containing up to 280 ppm CN. Reaction time varied from about 4.5 hr in a trickling reactor using quartz as a bacterial substrate to 2 months in unagitated, covered flasks. Chemical techniques were used to destroy the remaining complexed cyanide down to 1 ppm. Exploratory tests were also conducted using spent ore from heap leach operations as the bacterial substrate to determine if biological cyanide oxidation could be used to destroy the residual cyanide in spent heaps.

Lewis, Michael A., and Burraychak, Ronald, 1979, Impact of copper mining on a desert intermittent stream in central Arizona: a summary: Journal of the Arizona-Nevada Academy of Science, vol. 14, pp. 22-29. Open pit copper mining in Arizona requires approximately 380,000 liters of water to process 1 ton of copper from ore. Liquid wastes resulting from ore refinement are eventually discharged into streams, having significant impacts on water quality and biotic diversity and density. This paper discusses the findings of a study on an open pit copper mine and its impact on biotic survival in a small desert stream, Pinto Creek. Results show that stream water quality was greatly reduced, with a very direct impact on the biota. Sedimentation, the primary detrimental effect, eliminated much of the biota, reduced primary production, and altered a normal habitat by reducing water depth and filling the interstices with sediment. Heavy metals entering the stream were diluted by stream water, unlike the suspended solids, so that levels were generally non-toxic to most of the biota, though there were occasional fish kills from toxic metals. Primary production was, and continues to be, impacted.

Lucido, S.P., and Iwasaki, I., 1991, The removal of Cu++ from mine effluents using a fresh water green alga, Cyanidium Caldarium, in Environmental Management for the 1990's, Lootens, D.J., Greenslade, W.M., and Barker, J.M., eds.: Society for Mining, Metallurgy, and Exploration, Inc., Littleton, CO, pp. 143-149. The potential of controlling heavy metal ions in effluents from discontinued mining operation and waste rock piles has been investigated. A fresh water green alga, Cyanidium Caldarium, was found to have the potential to remove Cu++ from solutions while exhibiting high tolerance to acid conditions which are commonly encountered in copper-nickel mine drainage. The process has the potential for application as a low maintenance metal decontamination system. The growth requirements and copper removal characteristics of this microorganism are described.

Martin, Harry W., 1976, Water Pollution Caused by Inactive Ore and Mineral Mines: U.S. Environmental Protection Agency Document No. EPA/600/2-76-298, December, 1976. Though dated, this source may have some very useful information on water pollution from inactive and abandoned mines.

Appendix A. 18

Surface coal mining was conducted in a potentially acid producing region of central West Virginia between 1979 and 1986. Seven different surface mining operations were conducted at the complex with different acid preventative techniques employed at six of the operations. No acid control techniques were utilized on the first operation that serves as the control for this evaluation. Water quality, treatment reagents and acid preventive costs were closely monitored from the time the operations were started to several years after reclamation. The evaluation indicates that 50% to 70% of the control acidity was prevented by the techniques employed at the facility. The economics of the evaluation indicates that the preventative techniques employed at the facility were more expensive than treating the drainage from the sites with no preventative techniques employed.


This study concentrated on the analyses of two potential means of partially inundating abandoned segments of active underground mines to reduce acid formation. Seal construction techniques were taken through five logical steps and the design details of both low-wall dams and section seals were discussed. The study showed that both concepts are feasible only in certain mines where the geologic-hydrologic physical makeup is suitable to contain a mine pool.


This paper presents a case study of permitting and issues associated with hard rock gold mine closure. A mine closure design for Cyprus Cornerstone Mine In Arizona was prepared and submitted to State and Federal agencies for review and comment. Issues addressed as part of the mine closure design included: open pit stability; heap leach pad detoxification; tailings impoundment closure; and waste rock disposal area closure. The mine closure was designed to minimize long-term environmental impacts, reduce physical hazards, and return the area to the pre-mining land uses.


This paper has two parts. The first part covers the accepted nomenclature of the cyanide containing species, as well as some of the species derived from cyanide. The second part is a short overview of some of the analytical methods available for assaying these species.


This volume contains the proceedings of the conference on abatement of acidic drainage.

Mine Waste Technology Pilot Program, 1993a, Berkeley Pit Water Treatment Research Project [Fact Sheet]: Implemented by MSE, Inc., Butte, MT.

This fact sheet describes an innovative technology for treating mine water which is highly acidic and oxidized, contains high levels of metals and sulfate, and is at or near saturation with several solids. Precipitation of the solids and adsorption of trace metals are occurring in the water. This study involves bench-scale tests using chemical precipitation with or without aeration to neutralize the acid waters and precipitate contaminants from water. Project was scheduled to begin June 1, 1993. Reference gives contacts for further information.


This fact sheet describes an innovative technology for treating mine water which involves stabilizing sludges generated from mining operations. 3 treatment systems will be used to generate sludge: base-initiated precipitation of hydroxides and oxides of the metals, inorganic sulfide-initiated precipitation of metals, and removal of metals via sulfide-reducing bacteria. Chemical characterization studies will then be
conducted. Based on the chemical properties, various storage environments will be evaluated. The results of this sludge characterization and stability study will identify techniques and procedures that may be transferable to other sludges. Project was scheduled to begin June 14, 1993. Reference gives contacts for further information.

Mine Waste Technology Pilot Program, 1994a, Biocyanide Demonstration Project [Fact Sheet]: Implemented by MSE, Inc., Butte, MT.

This fact sheet describes an innovative technology for biological degradation of cyanide compounds and metal-cyanide complexes in mine waste. They will utilize a strain of the bacteria *Pseudomonas (P.) Putida* that degrades cyanide. They will use the bacteria in a precious metal mining operation with 2 project goals: 1) develop a reactor design that will best use the cyanide-degrading effects of this bacteria in calcium alginate beads. The design will be incorporated into a complete system design that may include suspended solids separation, addition and exchange of process heat, and addition of a supplemental carbon source; 2) to develop a method for using the bacteria for *in situ* remediation of cyanide-contaminated solid mining wastes. The project was scheduled to begin in late summer, 1994 at the Paradise Peak Mine in Gabbs, NV. Reference gives contacts for further information.

Mine Waste Technology Pilot Program, 1994b, Clay-based grouting demonstration project [Fact Sheet]: Implemented by MSE, Inc., Butte, MT.

At sulfide mine sites where natural acid generation is typical, clay grouting has the potential to eliminate the water component of acid generation, thus slowing or stopping the problem. The grouting process inhibits or eliminates the flow by injecting fine-grained slurries or solutions into pathways. This clay grouting technique involves 3 phases: integrating the knowledge gained from extensive geologic studies of a mine site, developing the grout formulation, and applying the grout. This application is expected to improve surface and groundwater chemistry in areas of contamination. Demonstration projects will be performed at applicable mine or waste sites (as of date of publication, no site had been selected). Reference gives contacts for further information.


This Annual Report describes the development and mission of the MWTPP, and provides statistics for several western states on the number of IAM sites and amount of water affected by pollution from IAMs. It also provides contacts for further information on MWTPP activities.


This fact sheet describes a project to design chelating polymer systems for laboratory study and for theoretical study (molecular modeling). The validated modeling procedure will be used to design and test a variety of neutral chelating systems for their capability to remove metal ions and associated anions from acid mine wastewater. This research project is currently underway. Reference gives contacts for further information.

Mine Waste Technology Pilot Program, 1994e, Nitrate Removal Demonstration Project [Fact Sheet]: Implemented by MSE, Inc., Butte, MT.

This fact sheet describes an innovative technology for removing nitrate from mine waste. 3 technologies are being considered in various combinations: 1) ion exchange with nitrate-selective resin, 2) biological denitrification, and 3) electrochemical ion exchange. MSE, Inc. is currently developing a demonstration project for these technologies. Reference gives contacts for further information.


This fact sheet describes a project to remediate toxic anions while minimizing treatment byproducts. They are utilizing dissolved and solid photocatalysts for the removal of cyanide and nitrate anions from mine wastewaters. This research project is currently underway at Montana Tech University. Reference gives contacts for further information.

Mine Waste Technology Pilot Program, 1994g, Remote Mine Site Demonstration Project [Fact Sheet]: Implemented by MSE, Inc., Butte, MT.

Acidic metal-laden water draining from remote abandoned mine workings has been identified by EPA as a significant environmental hazard to surface waterways in the western U.S. The EPA selected one of these sites to develop a treatment. Reference gives contacts for further information.

Appendix A. 20

This fact sheet describes the Science and Technology Information Retrieval System (STIRS) which allows immediate and centralized access to many existing data bases and facilitates efficient and comprehensive searches of literature and data for appropriate remediation science, technologies, and processes. The Montana Tech Library in Butte, MT houses STIRS. This is an invaluable resource to any person investigating mine waste remediation and pollution control. Reference Librarian Jean Bishop is contact at Montana Tech.

Mine Waste Technology Pilot Program, 1994i, Sulfate-reducing bacteria demonstration project [Fact Sheet]: Implemented by MSE, Inc., Butte, MT.

This fact sheet describes the technology of biological sulfate reduction to be demonstrated at an abandoned hard rock mine site where acid production and associated metal mobility is known to be occurring. This demonstration project began at the Lilly/Orphan Boy Mine near Elliston, MT in early September, 1994 and will continue for 1 year. Reference gives contacts for further information.


This fact sheet describes the Resource Recovery Project (RRP), established in 1992 by the Office of Technology Development, U.S. DOE, which evaluates and demonstrates multiple technologies for recovering water, metals, and other industrial resources from contaminated surface and groundwaters. The RRP is operated by MSE, Inc., at DOE's Western Environmental Technology Office in Butte, MT. Fact sheet describes what RRP is doing and key contacts.


This abstract discusses a stabilization process used on active mine tailings at Magma Copper Company's Pinto Valley operations. The process involves feeding cattle in high density paddocks situated on mine tailings to till and fertilize the sterile tailings into a viable growing medium. The project proved to be beneficial in stabilizing the tailings and bringing in indigenous plants from surrounding areas.


The control of AMD offers significant opportunities to explore the principles of ecotechnology. A general framework of the use of natural ecosystems for the "treatment" of water is presented, based on several years of wetland research in KY and OH, followed by specifics of a case study in eastern OH. The case study involves a constructed wetland sized into 3 cells of Typha latifolia, which is being used as an alternative control of AMD. Changing water quality and vegetation characteristics have provided a measure of the effectiveness of the wetland in removing dissolved Fe from the mine effluent. Total reduction of Fe from mine water has averaged 57% within the system, with the largest proportion occurring in the third and final cell, where vegetation density is greatest. Distribution of vegetation appears to be independent of distance from mine effluent; it is controlled by depth of standing water in wetland. Growth does not appear to be affected by mine water.


This is a listing of 39 available databases which contain information on mine remediation. Listing includes description of database, format, information type, cost to user, strengths and weaknesses, and the relevance to the Mine Waste Technology Pilot Program. Extremely valuable resource.


This is in a very large volume dealing with all aspects of metals in the environment - including microbial interactions and metal availability, water treatment, metal removal, plant uptake of metals, pathways and cycling of metals, reclamation, and other aspects of metals in the environment. This conference is one of

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several on metals in the environment. This particular paper suggests a method of reclaiming metalliferous mine waste.


The oxidation of sulfide minerals in moist, aerobic conditions leads to the formation of acid and the mobilization of metals. This process is aided by bacterial action and gives rise to acid mine drainage. The most commonly applied technology for chemical neutralization of acid mine drainage is the use of lime which not only neutralizes the acid but also precipitates metals as their oxides and hydroxides. The processes which have been used to date for lime neutralization include simple neutralization, neutralization with aeration to oxidize Fe, and neutralization with aeration and sludge recycle. A refinement of the third method, based on aeration and sludge recycle, can produce a dense sludge of 20% + solids with free drainage properties, which rapidly achieves 40% to 50% solids in the impoundment area. Because of these advantages, this method has been selected for treatment of acid mine drainage at several mining operations in Canada and U.S.


In May, 1986, the Wyoming AML Division began work on reclamation of 5 large open pit uranium mines in Shirley Basin, WY. The project, known as AML Project 13, is the single largest surface reclamation project undertaken by the Wyoming AML Division. Completed in June 1993, the AML site is spread over 7.5 sq. miles and includes 5 large water-filled pits, 72 million cubic yards (cu yds) of mine waste material, and 2,000 acres of disturbance. Some of the major project accomplishments include: 1) 31,200 ft. of highwall reduction and stabilization; 2) 16,500 ft of river channel relocation-Little Medicine Bow River; 3) 44,500 feet (8.4 miles) of ephemeral drainage channel construction; 4) 46,100 cu yds of riprap drainage protection; 33,000,000 cu yds total earth movement; 6) County bridge replacement; 7) 196,540 ft of Erosion Control Drainage construction; 8) 1,800 acres of reclaimed disturbance; 9) total cost = $30,000,000.00.


During construction of a taxiway at Halifax International Airport in 1982, 225,000 cu. metres of fractured waste pyritic slate material was disposed in a pile covering 7 hectares on airport property. As a result of air and water infiltration and presence of Thiobacillus ferrooxidans, this waste rock pile has been seeping a heavy metal- laden acidic drainage similar to AMD. Because sufficient quantities of a relatively impermeable clay overburden were present on site, it was decided to apply a compacted clay cap to the pile to reduce air and water infiltration. From previous experience it was known that concentrations of greater than 1% NaCl in aqueous phase are inhibitory to T. ferrooxidans. Lab studies confirmed that addition of clay layer of highway salt beneath clay not only inhibits production of acid drainage, but enhances the sealing capacity of clay. Placement of salt supplemented clay cap was undertaken in 1986 - 1987. Early observations indicate a reduction in volume and improvement in water quality.


Mine drainage contaminated with heavy metals requires proper treatment to avoid pollution of surface waters. The aim of this work was to improve on known biological methods and to develop an economic, cost-effective pilot plant-scale process for removal of metal in mine drainage. Good results were obtained with a continuous-flow fluidized bed-type anaerobic reactor, with a working volume of 180 L, in a continuous flow system using Desulfovibric vulgaris as the principal sulfate-reducing bacteria.

Concentrated alkaline recharge pools have been constructed above previously soil covered acid gob at the Peabody Will Scarlet Mine to abate acid seeps. Preliminary monitoring results (1989-1994) from a concentrated alkaline recharge pool demonstration project in the Pit 4 area have documented a 45% to 90% reduction in acidity in the principal recharge pool groundwater zone. A 23% reduction in acidity has occurred in the primary seep located downslope from the alkaline recharge pools. The initial improvements in water quality are seen as a positive indication that groundwater acidity will decrease further and amelioration of the acid seep will continue.

Nevada Department of Minerals, 1990, Reclaim - The Nevada Department of Minerals' Reclamation Reference System: Nevada Department of Minerals.

This is an extensive database of mine reclamation methods. Includes some useful methods for remediating Arizona mined land problems.


This proceedings volume includes information on environmental issues/regulations, successful reclamation examples, innovative reclamation practices, reclamation research needs, revegetation, cyanide detoxification, reclamation permitting and bonding, and acid mine drainage.


This may be useful paper since much of the mining land in Arizona is carbonate-rich.


Discusses very useful BMP's for storm water control and erosion stabilization. The success of these activities is based on implementing control measures that dissect drainage patterns, reduce flow velocities, and disperse runoff toward sediment control sites.


This paper discusses the method of tailing pond detoxification for treating cyanide-bearing waste from mining. The information appears to be relevant to abandoned mines as well as active mines. Many useful references on the same subject.


Anionic surfactants are effective in controlling acid production from sulfidic materials such as overburden, coal, refuse, ores, waste rock, and tailings. Their use in practical mining and reclamation applications, however, is only being recently documented since longer term field data are only now becoming available. This paper describes three applications of bacterial inhibitors: 1) at a surface coal mine where special handling and bacterial inhibition have prevented acid drainage from highly pyritic dark shale overburden; 2) an active refuse disposal area where alkaline addition at more than three times that indicated by acid-base accounting failed to control acid production in refuse with 13% pyritic sulfur. Bacterial inhibitors were successful in reducing acidity and metals in site underdrain effluent by 88% to 90%; 3) at a silver mine where waste rock with up to 0.37% pyrite was treated with bactericides to reduce leach acid by 70%.

This paper discusses disposal of sulfide-bearing mine tailings under a permanent water column, a promising method for preventing oxidation, acid generation, and concomitant release of trace metals. To assess the potential efficacy of this method over both the short and long terms, high resolution studies of the chemistry of dissolved metals in interstitial waters extracted from tailings submerged in lakes and coastal marine waters have been carried out at a number of locations in Canada. These results have been used in support of the now-licensed subaqueous disposal operation which will be used to prevent acid generation from tailings from a mine in British Columbia.


Sulfide-rich Zn-, Cu-, and Pb-bearing tailings have been deposited via floating pipeline into shallow Anderson Lake in Manitoba since 1979. The lake water contains elevated levels of dissolved metals which are derived mainly from an acid-generating roadway along the north shore. Water-column sampling and sediment coring were carried out through the ice on Anderson Lake in April 1993. 2 sites were occupied: 1 proximal to the tailings discharge (Station B) and the other about 2 km away (Station A). Interstitial water were extracted from cores at both locations, exhibiting 4 layers at Station A (2 of which were dysaerobic or anoxic) and 2 layers at Station B, the lower being dysaerobic. High concentrations of dissolved Fe in shallow pore waters indicated that the sediments at both locations were anoxic at shallow depths. Concentrations of Zn, Cu, Pb, and Cd were very low. There was no evidence of these metals being released from tailings. Metals were removed from pore waters below 10 cm.


At the TVA's Fabius Coal Mine, Alabama, manganese was more effectively removed from a pond containing an algae mat consortium and limestone substrate than from ponds containing only limestone or pea gravel substrates. The algae mat resulted from the integration of a microbial mat and volunteer filamentous green algae. The microbial mat consisted of blue-green algae and bacteria isolated from the site, cultured in the laboratory, and returned to the site. System operation ran from August 1992 through March 1993. Manganese and Iron were consistently removed more efficiently in the Algae mat pond (mean flow of 4.2 L/min) than through gravel-only ponds even as water temperatures dropped to less than 5 degrees C in the winter. A green algae and microbial mat consortium may be a cost-effective treatment technique for permanently removing metals from mine drainage.


While organic amendments have been well documented for revegetation of acid-generating tailing and waste rock, it is recognized that they do not prevent tailing oxidation and therefore are not a permanent solution to the acidic drainage problem. Laboratory research presented here compared three compost cover layer models that employed fresh and mature municipal solid waste compost. Fresh compost covers on tailing established low redox potential under anaerobic conditions that not only prevented further tailing oxidation, but also reversed the processes that generate acidic mine drainage. Reductive dissolution of previously oxidized and precipitated trace metals was seen, but this may be a transient phenomenon. Further lab studies and preparations for a field research program are ongoing.


Experimental investigations were conducted to determine the process of recovering valuable metals from acid mine drainage from a Canadian source. In particular, potential for the recovery of zinc as sulfide for recycling to zinc roaster has been examined. The findings were very promising, though economical and tech-
nical constraints of this process are restrictive. Acceptability of zinc hydroxide for recycling is uncertain. Alternative approaches for metal recovery based on these findings are suggested.

Rennicke, Dennis, 1995, Cows will reclaim old Tiger tailings, Magma Update:, V. 11, No. 1: Magma Copper Company, p. 9.

This short article discusses the Environmental Mine Practices and Cattle Treatment (EMPACT) and EMPACT metal immobilization (M.I.) alternatives for mine reclamation. This method involves placing mulch, comprised of grass clippings, tree limbs and other plant materials, over mine tailings. Cattle are then introduced to the site. Water sources and specially formulated feed are in separate locations causing cattle to migrate back and forth across the site. It is hoped that the weight of the cattle and the crushing action of their hooves will assist in the production of soil while the microorganisms contained in their waste will not only promote soil building, but also chemically join with heavy metals, rendering them harmless to the environment. This method has been successful at the Pinto Valley Mining Division of Magma, and is now being tested at the old Tiger Mine tailings at San Manuel.


Research has shown that limestone, when used as an acid ameliorant in surface mine reclamation, may result in an increase in both the acid production rate and the total acid load. Rock phosphate has been shown to be an effective acid ameliorant based upon its ability to sequester the major oxidizing agent of the iron disulfide minerals, Fe$^{3+}$, as an insoluble phosphate. A series of coordinated bench scale and small field scale experiments were conducted to evaluate the response of rock phosphate intermixed with toxic rock materials upon exposure to laboratory and real weathering conditions. Experiments showed that rock phosphate effectiveness as an ameliorant increased with decreasing particle size and application rate. Most effective was a clay slurry spiked with -325 mesh apatite and hydraulically applied.


High Power Mountain is a large surface mine located in central WV. The majority of production is by mountaintop removal; however contour combined with highwall mining occurs in a lower seam. Combined (coarse and fine) refuse disposal is planned as part of the mining reclamation process by use of "refuse Cells". These engineering structures are designed to encapsulate and isolate the refuse from the environment. In addition, lime kiln dust is used to control acid mine drainage and stabilize the combined refuse. The benefits of the lime kiln dust amendment include increased pH and alkalinity, elimination of bacterial growth, limiting the formation of acid water, decreasing metal mobilization, increasing the workability of combined refuse, and stabilizing the refuse. This paper demonstrates that the combined technique of engineering design concepts and lime chemistry can control AMD.


This document includes information on the following subjects: mine hydrology and drainage; unusual, unique reclamation projects; shaft and adit closure; and a transcript of a panel discussion between several different state AML program managers. The included papers offer useful information on control/remediation methods for mine drainage problems.


Discusses what the Geologic Division has done organizationally to address environmental issues related to mineral investigations.

Excellent reference. Contains an introduction and orientation on AML program, program and project management, remediation methods, cost estimates, and information on underground safety. Document is available through the National Park Service, Land Resources Division, Mining and Minerals Branch, 12795 West Alameda Parkway, Rm. 221, Lakewood, CO 80228.


The need for an economically viable treatment alternative to lime neutralization of acid mine drainage (AMD) has led to the investigation of many processes, including those utilizing biological sulfate reduction. This paper focuses on the Biosulfide process.


This report contains digital data files compiled from databases maintained by the U.S.G.S. and the U.S. BOM. The data presented comprise selected information for each of four databases related to active and inactive mine locations in the state of Arizona. The U.S.G.S. databases are RASS, PLUTO, and MRDS, and the U.S. BOM database is MILS. These U.S.G.S. databases include geochemical and mineral deposit information; the U.S. BOM database includes information on locations of mines, their operational status, and minerals found at those locations.


Mining projects which contain sulfide mineralization face increasing regulatory hurdles due to environmental concerns over acid rock drainage (ARD) and the ability of long-term reclamation to protect water quality. Among regulatory agencies, much of the perception about sulfide projects has been based on conditions at historic mining sites at which little or no effort was made to control ARD. With proper design measure, ARD production can be greatly reduced or eliminated. The science of ARD prediction can control must be expanded to enable mine planners to anticipate the effect of various facility design options on ARD potential. Some common-sense examples of geochemical prediction techniques and mitigation measures for waste rock dumps, spent ore heaps, and mine pits are described. This appears to be a useful overview of environmental management of ARD.


Effective abatement of acid mine drainage can be achieved by isolating the pyritic sources of the AMD from water and oxygen. Early experimental field tests relied upon the use of ordinary portland cement, which was injected into discrete buried piles in an attempt to "cement" these pyrite-containing piles to the point that flowing ground waters would be diverted from the pile, thus minimizing the formation of AMD. Portland cement, however, constitutes a significant expense to this type of an abatement procedure. Fly ashes derived from the combustion of coal in utility power plants or in fluidized bed combustors contain latent pozzolanic behaviour which can be activated by alkaline materials. The activation process results in hydration reactions which possesses cementitious behaviour. This can be used in abating AMD. It can also be used in applications which as pavement base course, landfill covers, embankments, or subgrade stabilization, relieving a burden from landfills.

Buried pyrite-rich tipple refuse and pit cleanings on a reclaimed 37 acre surface coal mine site in PA were found to be producing severe acid mine drainage. The pyritic material is located in discrete piles or pods in the backfill. A grout, made from fluidized combustion ash mixed with water, was used in 2 approaches that attempted pyrite isolation. 1) Pressure injecting grout directly into buried pods, in order to fill void space within pods and coat pyritic materials with a cementitious layer. 2) Using grout in 3 different applications to divert water from targeted zones. Pods that would not accept grout because of a clay matrix were isolated from percolating water with a cap and trench seal of the grout. The grout was also used in certain areas to pave the pit floor to prevent dissolution of clays. The initial post-grouting water quality data have been encouraging. More data are needed.


The U.S. Bureau of Mines is investigating the use of natural zeolites to remove metals from AMD. The loading characteristics of Al^{3+}, Ca^{2+}, Cu^{2+}, Fe^{2+}, H^+, Mg^{2+}, and Zn^{2+} were studied for samples of clinoptilolite from Barstow, CA, Buckhorn, NM, and Hector, CA. The relative order of cation selectivity was Zn^{2+}>Ca^{2+}>Cu^{2+}>Fe^{2+}>H^+>Mg^{2+}>Al^{3+}. The order of exchange capacity for the three zeolites was Hector>Barstow>Buckhorn, which corresponds to the Na content of the three zeolite samples. An AMD sample from Rio Tinto Mine, an abandoned copper mine in northeastern NV, was used to measure the zeolites' cleanup potential. At an approximate flow rate of 4 mL/min (5 bed vol/h), 75% as much zeolite was required to clean the water to drinking water standards when the Hector Material was used as compared with zeolites from Buckhorn or Barstow. Zeolites were generated using 25% NaCl solutions. Loading and regeneration studies show no degradation in loading ability through 18 cycles.


Natural and constructed wetlands have been shown to ameliorate AMD, but mechanisms for metal removal in wetland treatment systems are not well understood. Therefore, 12 natural cattail wetlands in WV, which received drainage from surface coal mines, were selected for study. Aboveground plant biomass in each wetland was estimated and plant samples were collected in June and September 1986 to evaluate bioconcentration of Fe and Mn. Calculations show that cattails in these wetlands removed less than 1% of the total Fe added to the wetlands by mine drainage. The Fe (oxidation state) + pH values of the sediment where cattails were growing were less than the values for areas with no cattails, indicating that cattails may lower the redox potential of the wetland enough to precipitate Fe and Mn.


In 1976, RCRA aroused concern in the mining community about the regulation of mine waste streams under RCRA. In response, the Bureau of Mines (BOM) initiated research in the late 1970's that addressed mine and minerals processing waste. Research included investigating improved environmental technology for metal, coal, non-metal, and emerging industries such as oil shale, tar sands, peat, and lignite. Environmental issues escalated in the 1980's. Proposed regulations addressing control technology for mining and mineral processing wastes prompted the BOM to become involved in 1985 in an advisory capacity to the EPA. In 1985 the BOM initiated a program to provide mineral industries with cost-effective solutions for ameliorating environmental effects of mining. BOM research has led to advances in numerous abatement technologies. The BOM also researches new methods to remediate IAM land. A discussion of mine waste issues is presented, followed by a summary of research conducted by BOM.
A series of laboratory experiments were conducted to evaluate the effectiveness of an electrochemical approach to ameliorate AMD. An electrochemical cell was constructed using a block of massive sulfide-graphite rock from the Sherman Iron Ore Mine of Canada as the cathode, scrap iron as the sacrificial anode, and acidic leachate collected from the mine site as the electrolyte. The cell raised the pH of 41.0 L of leachate from 3.0 to a maintenance value of 5.5. This result was accompanied by a significant decrease in redox potential from >550 to 300 mv. Furthermore, iron sulfate precipitate formed, with a concomitant lowering of Al, Ca, and Mg solution concentrations. The study clearly demonstrated the electrochemical approach to be a technically feasible and practical method of ameliorating AMD.

Peat was investigated as a potential source of indigenous microflora capable of: (1) providing a suitable carbon source for sulfate-reducing bacterial (SRB) through the anaerobic degradation of black spruce and trembling aspen wood chips, (2) complexing metals to form relatively insoluble sulfide minerals through the reduction of sulfate to sulfide, and (3) surviving exposures to extremely acidic conditions. Enumeration studies, combined with measurements of dissolved organic carbon, indicated sufficient available carbon was generated by anaerobic degradation of cellulose to support a viable population of SRB. The bacterial systems showed signs of recovery within 2 to 3 weeks following acidification to pH 3.0. The re-establishment of active microbial systems was indicated by the formation of a black iron sulfide precipitate.

Alkaline addition to acid-producing overburdens during surface mining and reclamation has shown variable results in improving postmining water quality. This paper describes a mining operation where acid mine drainage from an abandoned deep mine was eliminated by surface remining the deep mine workings and adding alkaline material during reclamation. About 15,000 mt/ha (6,600 st/ac) of alkaline shale were hauled to the remined site and placed on the pit floor and also on top of toxic material placed "high and dry" in the backfill. No acid mine drainage has come from the site during the past 2 years since reclamation. The cost of hauling the alkaline material to the site was about $9,880/ha ($4,000/ac). Chemical treatment costs of acid mine drainage previously coming from the site before remining were projected to be $8,000 to $15,000/yr depending on the chemical reagent.

Increasing interest in the use of Sphagnum wetland to treat AMD has prompted study of the tolerance of Sphagnum spp. to the various constituents of AMD waters. In this study, S. fallax and S. henryense plants
were grown in the laboratory for 33 days in synthetic bog water to which FeCl₂ was added to achieve Fe²⁺ concentration ranging from 0 to 10,000 mg/L. Observations and estimates reinforce the conclusion that Fe uptake by growing Sphagnum plants can play only a relatively minor role in Fe retention in wetland systems constructed for mine drainage treatment. Results of this study also indicate that the viability of Sphagnum wetlands constructed for AMD treatment will be dependent on the species composition.


Covering sulfidic mine tailings with water effectively reduces oxygen influx to the tailings and the resulting acid generation. However, metals present in porewater solutions or in soluble mineral phases may still be released from the flooded tailings impoundment. Several laboratory leach tests are performed to evaluate metal release rates and times. This paper discusses results over different time periods and construction costs for containment structures.


A porous envelope effect may occur in ground water systems when mine tailings of low permeability are placed within high-permeability soils. If the permeability contrast between the tailings and the natural soil is large, ground water will flow around the tailings mass rather than through it, and metal leaching will be minimal. This paper involves a case study at Falconbridge Fault Lake tailings site. It appears that conditions for porous envelope containment may be occurring. This is more of a theoretical/modeling paper than an applied study, but the concept is a useful one for mine waste remediation.


In 1985, a 3,000 sq. meter, 3-celled wetland was installed at the Peabody Coal-American Electric Power Simco #4 deep coal mine site in OH. The wetland included a limestone/ compost substrate planted with Typha Latifolia L. (cattail). The deep mine seepage pH is near 6.0, total iron 80-241 mg/L, and acidity 15-389 mg/L. The percent reduction in iron concentration in effluent water relative to influent water of wetland significantly exceeded pre-wetland percent reduction, improving from 28% during the first winter after construction to 62% in the summer of 1987. Further site modifications in 1987 elevated the percent Fe re-duction of the wetland to 70-85%. Iron reduction corresponds to a greater wetland area, higher cattail density and increased plant coverage. Prominent plants in the wetland besides cattail are cutgrass and algal species. Cattail and cutgrass coverage increased from 1986 to 1987. Roots of cattail accumulated up to 5 times the iron content of roots from a control site.


The Simco constructed wetland near Coshocton, OH, has received mine water containing an average of 89 mg/L at a loading of approximately 15 g Fe/m²/d since 1985. Its capacity to remove iron is evaluated by analyses of 1) inlet and outlet water chemistry, 2) concentration treatment efficiency over time, and 3) area-adjusted iron retention over time. Since 1990, the wetland system outlet has not required any chemical treatment, meeting federal compliance levels for iron and pH. This paper discusses the efficacy of this wetland treatment.

Appendix A. 29

A Typha-dominated wetland was constructed in September, 1986 to remove Fe and Mn from a surface mine seep characterized by an average flow of 10 gpm, pH of 5.5, and maximum concentrations of 40, 50, and 2700 ppm Fe, Mn, and SO\(_4\)\(^{2-}\), respectively. Sample analysis revealed that 74% of the 186 kg of iron introduced to the system was removed between October 1986 and July 1987. Mn removal was less successful; only 8% of the 368 kg influx was removed during this same period. Periods of increased waterflows corresponded with smallest percent reduction of influent mass concentrations. The wetland's ability to remove Fe and Mn varied with time and location within the basin. Inlet flow volume, basin length, and water flow through the substrate were important factors affecting the retention of influent iron and manganese.


This paper discusses coal mine reclamation in Arizona.


This volume is out of print, but looks very useful and worth trying to borrow through a library.


This paper discusses an Acid Mine Drainage Control technique used on the East Sullivan Mine. In order to stop AMD from being generated, plans have been made to cover the entire tailings pond with an organic blanket comprised of two meters of softwood and hardwood bark. This type of covering has proven effective in preventing oxygen from reaching the tailings. In fact, oxygen concentrations drop from 16.1% near the surface to less than 1.5% some 70 cm below surface, while CO\(_2\) concentrations at the same depth rise from 8.2% to 50.8% A grass cover is planted on top of the bark to reduce seepage. Sludge from a municipal waters treatment plant is incorporated into the first 30 cm of organic material as a conditioner and then seeded.


This Bureau of Mines document discusses monitoring systems, seepage prediction and control technologies, and mine waste disposal.


Contains useful information specific to water pollution mitigation in abandoned mines (even though overall the volume addresses mine reclamation).


This proceedings volume deals largely with reclamation issues. There are some papers, however, which deal specifically with mitigating problems associated with abandoned mines. They are more concerned with the physical hazards of abandoned mines, though some of the information is useful for environmental hazards.

This book describes how to develop and conduct an AML inventory and assessment using a 4-step process. The focus is on hardrock sites. This includes: 1) things to consider during a reconnaissance of an AML site and the data required to adequately assess a site; 2) environmental and physical hazards at each site on the AML inventory are initially assessed and ranked according to potential risk to the environment and human health; 3) instructions for a site investigation using a standard data form; and 4) assignment of a priority ranking on which to base site characterization or hazard mitigation. Major hazards discussed fall into two categories: 1) physical or 2) environmental hazards.


This publication and its companion three volumes are the proceedings of a conference held in Pittsburgh, PA. There were 12 sessions (69 papers) that dealt with mine drainage, including modeling, geochemistry, prediction, treatment, control strategies, characterization, hydrology, and case studies. These sessions comprise volumes 1 and 2. The six sessions (34 papers) that dealt with reclamation and revegetation of disturbed lands are included in volume 3. Volume 4 includes the six sessions (34 papers) that dealt with such topical issues as fires at abandoned mine sites, subsidence, hydrology, mine wastes, and policy. (Volumes 1 and 2 are very useful for purposes of pollution abatement).


This publication and its companion 3 volumes are the proceedings of a conference held in Pittsburgh, PA. The 12 sessions dealt with mine drainage, including modeling, geochemistry, prediction, treatment, control strategies, characterization, hydrology, and case studies. (Volumes 1 & 2). Six sessions dealt with reclamation and revegetation of disturbed land (Volume 3). Vol. 4 includes the 6 sessions (34 papers) that dealt with such topical issues as fires at abandoned mine sites, subsidence, hydrology, mine wastes, and policy. Very useful document for drainage control and remediation issues.


This article provides the National Park Service with the guidelines it needs for closing abandoned mine openings such as shafts and adits. These guidelines are more for the physical hazards associated with mines than the environmental hazards, but they provide useful descriptions, applications and construction information for implementation of the guidelines.


A very useful report which includes information on the nature and extent of the noncoal IAM problem, existing noncoal reclamation laws and regulations, noncoal IAM reclamation programs, and noncoal IAM reclamation costs. Remedial activities are not discussed in length, but this paper gives a perspective on what programs are available for funding remediation, and what the different phases are which precede remediation (i.e. inventory, physical safety concerns, prioritization, etc.).


This very useful document provides information on processes, procedures, and methods to control pollution resulting from mining activities. The control methods included are identified and described by way of a brief text, generalized illustrations, and unit cost indications where possible. References are cited for each pollution control method. Topics include, for surface mining: pollution control planning, controlled mining procedures, water infiltration control, handling pollution-forming materials, waste water control, regrading, erosion control, revegetation; and, for underground mining: controlled mining procedures, water infiltration control, waste water control, mine sealing; various neutralization treatments, sludge disposal treatment.
evaporation processes, reverse osmosis, electrodialysis, ion exchange processes, freezing, and iron oxidation.


This volume describes organizational, financial, and legal considerations involved in implementing a water pollution abatement program for abandoned sources. It also discusses technical approaches to collecting mine-related water quality data, conducting mine source inventories, and identifying control needs and priorities. It includes discussion of environmental impacts of different types of mining techniques and materials, as well as the benefits from reclamation. It does not, however, discuss specific abatement techniques.


This is an extremely useful document for remediation methods. It dates from 1975, and therefore does not contain new technologies; but it is a thorough treatment of some of the older, tested technologies. Includes water infiltration control, mine sealing, mine modification methods, water handling, and discharge quality control.


Objective was to assess existing antimony removal technologies and evaluate their potential for reducing antimony levels in mining industry wastewaters. It was found that neither sulfide precipitation technology nor lime precipitation technology is suitable for achieving minimum desired antimony levels. Five other techniques were investigated, two of which are promising candidates for antimony removal. This paper deals more with active mining practices, but may have some relevance for abandoned mines in which antimony contamination is a problem.

U.S. Environmental Protection Agency, 1979b, Environmental Effects of Western Coal Surface Mining, Part IV - Chemical and Microbiological Investigation of a Surface Coal Mine Settling Pond: U.S. EPA, Environmental Research Laboratory, Duluth, MN EPA-600/3-79-125.

Discusses chemical and microbiological investigations of the settling pond system of a coal mine in SE Montana from 1975-1977. Though surface waters were impacted, it was concluded that ground water would not be impacted. Based on this study, some recommendations were made regarding the use of coal mine settling ponds for pollution remediation.


This document was prepared to assist mine drainage treatment programs to identify and select appropriate processes, equipment, and procedures for the particular wastes that are produced. A review is provided of neutralizing agents and the methods used to handle, prepare, and feed these alkalis. Sludge dewatering and disposal are explained and two sample treatment facility designs are provided. Constructed wetlands have proven to be quite effective in lessening the adverse impact of mine drainage on the environment.


This draft document is useful for understanding the regulatory aspect of managing mine waste. Though it does not specifically apply to abandoned mines, it provides useful regulatory background information.


Very general article. Good for the public - it discusses different types of mine waste, but has no specific abatement strategies.


A very general article, good for the public, but offers no specific abatement information.

Appendix A. 32
A series of laboratory tests and an on-site pilot scale demonstration of Bio-Recovery Systems' AlgaSORB® technology for the removal and recovery of mercury-contaminated groundwaters were conducted under EPA's Superfund Innovative Technology Evaluation program. AlgaSORB®, a non-living, immobilized algal bio-mass, was packed into columns through which the mercury-contaminated groundwaters were pumped. Optimum conditions were determined for mercury binding to AlgaSORB®. Conditions under which mercury could be stripped from AlgaSORB® were also developed. On-site, pilot scale demonstrations with a portable waste treatment system incorporating columns containing two different AlgaSORB® preparations confirmed laboratory tests. Over 500 bed volumes of mercury-contaminated groundwater could be successfully treated before regeneration of the system was required. Mercury was removed to levels below the discharge limit of 10 µg/L.

A very general article which directs the reader to other EPA documents which may be useful for defining the need for management, as well as for prevention, treatment and disposal of waste.

This manual provides industrial facilities with comprehensive guidance on the development of storm water pollution prevention plans and identification of appropriate BMP's. It provides technical assistance and support to all facilities subject to pollution prevention requirements established under NPDES permits for storm water point source discharges. EPA's storm water program significantly expands the scope and application of the existing NPDES permit system for municipal and industrial process wastewater discharges. It emphasizes pollution prevention and reflects a heavy reliance on BMPs to reduce pollutant loadings and improve water quality. This manual provides essential guidance in both of these areas.

Appears to be a very useful document with sections on: 1) Overview - What are alternative and innovative treatment technologies, sources of information, definitions; 2) Superfund remedial actions (frequency of technology selection, status of implementation, contaminants addressed by innovative technologies, quantity treatable); 3) Superfund removal actions (frequency of technology selection, status of implementation, contaminants addressed by innovative technology); and 4) actions under other federal programs. [Preceding and subsequent Annual Reports are probably also very useful.]

Very useful document with information specific to inactive and abandoned mines. This publication includes information on site characterization, new environmental applications of existing technologies, and six case studies of specific remediation methods. Very useful. Available from EPA publications office in Washington, D.C.

This document, and others in the same series, appear to be very useful.

This is a report on the protection and restoration of the Nation's land and water resources under Titles IV and V of the Surface Mining Control and Reclamation Act of 1977. This act regulates surface coal mining and reclamation operations and regulates the reclamation of abandoned coal mines on a national scale. The report discusses the Surface Mining Control and Reclamation Act (Titles IV and V), program implementa-
tion, mining and reclamation today, milestones achieved in improved environmental protection—under both
titles IV and V.

U.S. Office of Technology Assessment, 1986, Western Surface Mine Permitting and Reclamation, OTA-E-279:
This document includes some very useful guidance on site characterization and monitoring. Specifically see
pp. 126, 139, 152, and 190.

University of California, 1990, Proceedings of the Western Regional Symposium on Mining and Mineral Proc-
This volume is a proceedings of the Western Regional Symposium on Mining and Mineral Processing
Wastes. It includes discussions on: regulations and permitting; chemical characteristics and behavior of
wastes; environmental impact of mining wastes; case studies on waste management practices; innovative
waste impoundment strategies; and innovative chemical treatment methods. It is a very useful document for
information on pollution control and abatement from mine waste.

Wali, Mohan K., ed., 1975, Practices and Problems of Land Reclamation in Western North America: The Uni-
An old resources, primarily about reclamation, but may be useful for pollution abatement in Arizona since it
focuses on the western states.

Watzlaf, George R., 1988a, Chemical inhibition of iron-oxidizing bacteria in waste rock and sulfide tailings and
effect of water quality, in Mine Drainage and Surface Mine Reclamation, Proceedings of a conference spon-
sored by the American Society for Surface Mining and Reclamation, Bureau of Mines, and The Office of
Surface Mining Reclamation and Enforcement. Volume 1: Mine Water and Mine Waste: U.S. Bureau of
The effectiveness of sodium lauryl sulfate (SLS), potassium benzoate, and potassium sorbate in controlling
the population of iron-oxidizing bacteria, thereby reducing acid production, was tested on sulfide tailings
and waste rock, common waste products of metal mining. Several different samples of waste rock and tail-
ings, of different sizes, were treated, and some samples were left as untreated control samples. Results
showed that, in the waste rock, a single treatment of SLS and potassium benzoate completely inhibited iron-
oxidizing bacteria repopulation for up to 231 days. Acidity in the leachate from these same samples re-
mained below the untreated control for up to 343 days. In an extensively weathered sample of sulfide tail-
ings, none of the treatments inhibited the iron-oxidizing bacteria or reduced acidity levels in the leachate. In
the slightly weathered sulfide tailings, all treatments inhibited the bacterial populations, but did not signifi-
cantly reduce acid production.

Watzlaf, George R., 1988b, Chemical stability of manganese and other metals in acid mine drainage sludge, in
Mine Drainage and Surface Mine Reclamation, Proceedings of a conference sponsored by the American So-
Federal regulations require mine operators to reduce the average concentration of manganese in the effi-
uent to 2 mg/L. To meet this standard, the majority of mine operators add an alkaline material, typically lime or
sodium hydroxide, to raise the pH to about 10.0. Our laboratory tests using actual AMD containing Fe, Mn,
Ni, Cu, Zn, and Cr, have indicated that the high-pH precipitation method is effective at removing these
metals. However, Mn, Ni, Zn and Cu in the precipitated sludge were susceptible to dissolution upon subse-
quent depression of pH. Up to 30% of original Mn in the high-pH precipitated sludge dissolved at pH 7.5.
At pH 6.0, this figure increased to 78%. Cu, Zn and Ni also redissolved at lowering pH levels. The problem
of Mn redissolution can be avoided by using an oxidizer such as sodium hypochlorite or potassium permanganate (which also increase treatment costs); however, these chemicals were ineffective at removing Cu, Ni
and Zn.

Watzlaf, George R., 1992, Pyrite oxidation in saturated and unsaturated coal waste, in Achieving Land Use Po-
tential through Reclamation: Proceedings of the 9th Annual National Meeting of the American Society for
Surface Mining and Reclamation, Duluth, MN, June 14-18, 1992: American Society for Surface Mining and
Reclamation, Princeton, WV, pp. 199-305.
Currently the main strategy used to limit acid mine drainage (AMD) from pyritic coal waste materials is to
minimize the contact of these materials with water. An alternative approach, not generally practiced in the

Appendix A. 34
coal industry, is to keep the pyritic material inundated with water. Concerns about this latter technique include the potential detrimental effects of dissolved oxygen and ferric iron on pyrite oxidation, as well as the ability to maintain complete and continuous water saturation. This paper discusses laboratory tests which were conducted to determine the effects of dissolved oxygen and ferric iron on pyrite oxidation. Results from this and other studies, theoretical calculations, and experience from the metal mining industry show that the disposal under saturated conditions can significantly reduce contaminant concentration from pyritic material.


An electromagnetic induction (EMI) method of measuring earth conductivity was applied at several back-filled surface coal mines to determine the utility of this method for acid mine drainage assessments. The method was found to be a quick, useful tool for effective at-source AMD abatement strategies. Survey results and interpretations along with the results of confirmatory drilling are presented.


Very useful document - including short section on remediation technologies, inventory methods, policy options, regulatory constraints, remediation incentives, etc.


This report contains reports from each of the 18 participatory states in the WGA Mine Waste Task Force. It is useful because it contains a description of mining history, the key state agencies involved, inventories for each state, useful contacts, synopses of reclamation histories and associated costs, and references.


This volume contains reports from states which are participants in the Interstate Mining Compact Commission, Interstate Coalition on Mine Waste States. This includes 16 states which are not a part of the WGA Mine Waste Task Force States. None of these are western states, so this document may not be useful for addressing IAM problems in western states.


This volume is an appendix to the other 3 volumes. It is a report on the scope of the environmental, public health and safety problems presented by inactive and abandoned mines in 17 additional states not covered in the first 3 volumes. Probably not too useful since it doesn't specifically address remediation issues.


Lake acidification from AMD is an important environmental problem. AMD can be ameliorated by the production of the minerals FeS and FeS2 in impacted lake sediments. The authigenic formation of FeS and FeS2 is hypothesized to occur when ferrous iron reacts with dissolved sulfide which is produced by microbially mediated sulfate reduction. The result is that iron, sulfate, and acidity concentrations are decreased, while bicarbonate alkalinity is increased. If the reaction occurs in sediments that receive abundant sulfate ions and organic matter, then iron will be the limiting reactant. As the iron concentration increases, the dry weight percent of FeS or FeS2 in the sediments should increase. The objective of this study was to determine if porewater iron concentration could be used as an indicator of FeS and FeS2 concentration in the sediments.

Within the past several years, there has been a tremendous increase in the use of man-made wetland systems for the treatment of acid coal mine drainage. However, quantitative estimates of the long-term capacity of a wetland for metal retention are lacking. In this paper, an upper limit for Fe retention in *Sphagnum* wetlands is estimated by individually considering the biological and chemical processes contributing to metal retention in wetland ecosystems. Also, different field monitoring schemes are discussed in terms of their potential for assessing the effectiveness of metal retention in man-made wetland systems and their potential for extrapolating the long-term capacity for effective treatment of mine drainage. Although it has been suggested that man-made wetlands may offer a low-cost approach to mine drainage treatment, cost/benefit analyses cannot be carried out without being able to reliably estimate long-term capacity for metal retention in a given man-made wetland system.


The book provides some very useful information on the use of wetlands for remediating mine drainage.


At the Big Five Tunnel in Idaho Springs, CO, an EPA Superfund Site, a model wetlands ecosystem has been built. The project is sponsored by Camp, Dresser and McKee under a contract to the CO School of Mines. Three 200 sq. ft. pilot plants have been constructed so the fates of all entering chemicals can be established. The objective of the project is to determine in one yr. whether wetlands can be used as a cost-effective first step in the treatment of metal mine drainages. So far, the following conclusions have been made: 1) the design was simple and the construction was straightforward; 2) an area of 200 sq. ft. was adequate to maintain a complete ecosystem; 3) selection of plants from local environments was possible, but transplanting was difficult; 4) the mechanical proportions of the system have been operated well through a more severe winter than normal; 5) the chemical and bacteriological removal of pollutants has been occurring through the winter, even with plant dormancy.


AMD from a closed gold-mining operation in northern California was studied first in the laboratory and then on the pilot scale to determine the technical feasibility of passive treatment. The lab studies concentrated on the question of whether local organic and soil materials could be used to support sulfate reduction in a passive treatment. Samples were incubated at laboratory temperatures for 4 weeks. Soil and wood wastes from immediate vicinity proved to be too acidic to maintain a large population of sulfate producers. The most reasonable material for sulfate reduction was a mixture of cow manure, planter mix soil, and limestone chips. The pH was significantly increased, and metal concentrations were significantly reduced. A larger scale pilot system was then constructed using the same substrate mixture as that used in the lab mix. Over the course of 9 months, the pilot system achieved removal of Cu and Ni below the effluent standards, and mixed results for Fe and Zn.


Laboratory investigations were conducted to determine "in-principle," whether passive treatment is a reasonable option for two water types produced by a surface and gold operation in NV. The results of the laboratory tests were used to design a settling pond-anaerobic-aerobic passive system for the acid rock drainage and an aerobic passive system for the underdrainage and seepage.

Appendix A. 36

Lime neutralization, reverse osmosis, and ion exchange were studied for their effectiveness in removing mg/l levels of 10 specific trace elements from spiked acid mine drainage under typical operating conditions. All three methods proved to be effective in some of the 10 trace elements.


Deals more with reclamation than with controlling water pollution. There were no specific papers of critical importance for pollution abatement practices, but it may be a useful resource because it deals with the unique problems of arid lands.


These proceedings include information on: subsidence analysis and monitoring; toxic and radioactive wastes; mine and refuse fires; revegetation technologies; subsidence mitigation; water quality issues; reclamation for wildlife; geomorphology and erosion control; and shaft closures cultural issues.


The Waite Amulet Covers Project was initiated in 1990 under the Mine Environmental Neutral Drainage program to evaluate the effectiveness of engineered soil covers in reducing acid generation in reactive tailings. Two 3-layer soil covers (60 cm compacted clay placed between two 30 cm sand layers) with gravel crusts were designed and installed on the partially oxidized sulfidic tailings at the decommissioned site. Another test plot was installed in which a 2 mm thick, high density polyethylene replaced the compacted clay. The 3 covered test plots and a control plot without a cover were instrumented to measure gaseous oxygen concentrations, water contents, pressure heads, temperature, and water quality. Lab experiments were also installed to simulate the soil-covered test plots. This paper presents the results of these studies.
APPENDIX B. ONGOING RESEARCH AND CONTACTS INVOLVED IN COMPILING BEST MANAGEMENT PRACTICES
In the course of the research for this project, several groups were identified which are actively researching IAM pollution control issues. Some groups are compiling similar compendiums, some are research groups testing innovative remediation methods, some are inventorying IAM sites, and some are performing other activities. These parties may be very useful resources for further investigation of water pollution prevention, control, and remediation efforts for inactive and abandoned mines. The following is a partial list, not intended to be all-inclusive, but rather an informal listing of groups or individuals who might have valuable information on mine waste hazard mitigation. Contacts are current as of March, 1995.

**Mine Waste Technology Pilot Program.** The Mine Waste Technology Pilot Program (MWTPP) is a federally-funded research program whose mission is to prioritize and select innovative treatment technologies for mine waste, and implement demonstration projects that show cost-effective results. The MWTPP was established under the 1991 fiscal year Department of Veterans Affairs and Housing and Urban Development, and Independent Agencies Appropriation Bill, which allocated $3.5 million to establish a pilot program for treating mine wastes in Butte, MT.

As stated in the Mine Waste Technology Pilot Project 1993 Annual Report (Mine Waste Technology Pilot Project, 1994c), an Interagency Agreement was signed between the EPA and United States Department of Energy in June, 1991, that made these funds available to the Western Environmental Technology Office's (WETO, formerly CDIF) operating contractor, MSE, Inc., and Montana Tech for the development of MWTPP. Under the terms of the agreement, the combined responsibilities for MSE, Inc. and Montana Tech include the following:

* identifying and prioritizing treatment technologies as candidates for demonstration projects.
* developing a generic Quality Assurance Project Plan to ensure comparability and credibility of the results in the pilot program.
* proposing and conducting large pilot-/field-scale demonstration projects of several innovative technologies that show promise for cost-effectively remediating local, regional, and national mine waste problems.
* preparing and distributing program reports and developing and conducting a series of symposia/workshops to convey the continuing and final results of the pilot program to user communities and to publicize information concerning mine waste treatment technologies developed under the pilot program to facilitate early commercialization of those technologies.
* developing and implementing a plan to establish training/educational programs directed toward current and future personnel interested in mine waste treatment technologies.

Operation of the pilot program includes:

- identifying mine waste problems that are most severely affecting human health and the environment at local, regional, and national levels;
- evaluating engineering and economic factors for selected technologies;
- prioritizing the most promising mine waste treatment technologies based on their engineering and economic value;
- planning and documenting the demonstration, testing, and evaluation of the most promising mine waste treatment technologies;
- accelerating the commercialization of selected mine waste treatment technologies that are developed, tested, and evaluated; and
- planning the transfer of knowledge gained from the above through systematic training of user communities.

The resources used in this pilot program are restricted to practical applications for solving mine waste problems. The MWTPP is managed through an interagency committee with input from two separate committees: a technical integration committee comprised of waste experts from the throughout the nation and an industrial integration committee comprised of major companies with expertise in the mining industry (Mine Waste Technology Pilot Project, 1994c).

FOR FURTHER INFORMATION, CONTACT:

Roger Wilmoth  
U.S. EPA/Office of Research and Development  
Risk Reduction Engineering Laboratory  
26 W. Martin Luther King Drive  
Cincinnati, OH 45268  
(513) 569-7839  
Fax: (513) 569-7787

Gary Staats  
U.S. Department of Energy  
Pittsburgh Energy Technology Center  
P.O. Box 10940, MS 922-316B  
Pittsburgh, PA 15236-0940  
(412) 892-5741  
Fax: (412) 892-4134

Mel Shupe  
Office of Technology Development  
Trevion II/ EM-54  
U.S. Department of Energy  
Washington, D.C. 20545  
(301) 903-9742  
Fax (301) 903-7457

Appendix B.2
Science and Technology Information Referral Service. As part of the MWTTP, the Science and Technology Information Retrieval System (STIRS) was established. This system allows immediate and centralized access to many existing databases and facilitates efficient and comprehensive searches of literature and data from appropriate remediation science, technologies, and processes. The Montana Tech Library houses the STIRS and allows electronic access to many of the STIRS databases (MWTPP, 1994g). Many of these databases are available through other libraries as well. A partial list of the databases compiled by STIRS, is included in APPENDIX C.

Contact: Jean Bishop, Reference Librarian
Montana Tech
1300 West Park Street
Butte, MT 59701-8997
(406) 496-4282

The U.S. Bureau of Mines. The U.S. Bureau of Mines (USBM) compiles information and conducts research on materials to help protect the health and safety of workers in the minerals and materials industries and on the development of new materials and processes that provide for sustainable development and resource conservation. The USBM solves problems in water contamination, waste production, and management and develops clean technologies in mining and processing. USBM information is used by land managing, defense, and environmental protection agencies, State authorities, and the private sector. USBM contacts involved in IAM site remediation include:

Robert Kleinmann (active in passive mine remediation research)
U.S.B.M.
Pittsburgh Research Center
Environmental Technology
P.O. Box 18070
Pittsburgh, PA 15236
(412) 892-6555

Appendix B.3
Michael J. Gobla (Environmental Engineer involved in compiling Best Management Practices for mine remediation)
U.S.B.M.
P.O. Box 25068
Bldg. 20, Denver Federal Center
Denver, CO 80225
(303) 236-0428

Galen Knudsen (Actively researching mine remediation practices)
U.S.B.M.
P.O. Box 25068
Building, 20, Denver Federal Center
Denver, CO 80225
(303) 246-0321

Colorado School of Mines (CSM). There is a group at CSM involved in compiling: 1) information on remediation technologies for IAM remediation; and 2) a flow chart for decision-making on mine contamination problems.
Contact: Tom Wildeman (303) 273-3642
Colorado School of Mines
Department of Chemistry and Geochemistry
Golden, CO 80401

The U.S. Forest Service. The U.S. Forest Service has been involved in identifying IAM sites.
Contact: David Fredley
U.S. Forest Service/USDA
201 14th St., SW and Independence
(4th floor Central), Washington, D.C 20250
(202) 205-1234

The Colorado Nonpoint Source Management Program. This program provides the guidance for developing mining nonpoint source projects. The program’s objective is to improve water quality and restore its beneficial uses.
Contact: Jim Herron
Department of Natural Resources
Colorado Division of Mines and Geology
215 Centennial Bldg.
1313 Sherman St.
Denver, CO 80203
(303) 866-3567

Appendix B.4
Colorado Center for Environmental Management. The Colorado Center for Environmental Management (CCEM) is a nonprofit consortium of business, government, public and educational institutions. Created in 1991 by Governor Roy Romer, the Center focuses on developing more cooperative and effective approaches to the cleanup of hazardous materials and other environmental problems.

Contact: Cha Snyder
999 18th St., Ste. 2750
Denver, CO 80202
(303) 297-0180

U.S. Geological Survey (USGS). There are several programs within the USGS that have useful information pertaining to pollution abatement at mines. The two programs below provide a useful starting point for obtaining information:

- Center for Environmental Geochemistry and Geophysics (CEGG). This center coordinates and supports research on the natural and human-induced environmental effects associated with geologic sources, especially those related to mineral resources and their development.

  CEGG
  U.S. Geological Survey
  Denver Federal Center, MS-973
  Denver, Colorado 80225
  (303) 236-3301

- Mineral Resource Surveys Program. Within this program, USGS has started a Mitigation Studies Program in which USGS scientists work cooperatively or in partnership with biologists, botanists, soil scientists, hydrologists and other researchers at State and Federal (e.g. USFS, BLM, and EPA) agencies. They collectively conduct studies that determine geochemical baselines and backgrounds, document human-induced processes resulting in environmental problems, and suggest methods for mitigating or remediating these mineral-resource-related problems.

  Contact: Chief, Office of Mineral Resources
  U.S. Geological Survey
  913 National Center
  Reston, VA 22092
  (703) 648-6100
  or

Appendix B.5
Mine Environment Neutral Drainage (MEND). This is a cooperative research program sponsored, financed and administered by 3 partners: the Canadian mining industry, the Government of Canada and the governments of the provinces of British Columbia, Manitoba, Ontario, Quebec, New Brunswick, and more recently Saskatchewan, Nova Scotia and Newfoundland. Their objectives are to:

1) provide a comprehensive, scientific, and technical and economic basis for the mining industry and government agencies, to predict with confidence the long term management requirements for reactive tailings and waste rock; and

2) establish techniques that will enable the operation and closure of acid-generating tailings and waste rock disposal areas in a predictable, timely, affordable, and environmentally acceptable manner.

Contact: T.J. Patell, Library and Documentation Services
CANMET
562 Booth Street
Ottawa, Ontario K1A OGl
(613) 996-9758

Western Governors' Association. The WGA has established a State/Federal Ad Hoc Inventory Group for Inactive and Abandoned Mine (IAM) Inventory Information. Though the advisory group does not specifically address control methods and remediation technologies, the committee is comprised of numerous individuals from State departments which are involved with environmental quality and contamination control. A contact person for the WGA is:

Dick Juntenen
Resource Management Associates
258 McClellan Creek Rd.
Clancy, Montana 59634
(406) 442-3048.

Office of Surface Mining Reclamation and Enforcement (OSM)
Public Affairs
Office of Surface Mining
1951 Constitution Ave., NW
Washington, D.C. 20240
(202) 208-2553

Appendix B.6
Conferences. There are several conferences held periodically which directly address problems of water pollution control at IAM sites. They include:

- International Conference on the Abatement of Acidic Mine Drainage
- International Land Reclamation and Mine Drainage Conference
- American Society for Surface Mining and Reclamation
- Canadian Land Reclamation Association
- Mining and Reclamation Conference and Exhibition
- The Association of Abandoned Mine Land Programs.
- Abandoned Mine Land Programs in individual states and tribes (see Office of Surface Mining Reclamation and Enforcement, 1994)
- International Conference on Metals in the Environment
- Western Regional Symposium on Mining and Mineral Processing Wastes
- Society of Mining, Metallurgy and Exploration, Inc.
- American Institute for Mining, Metallurgical, and Petroleum Engineers
APPENDIX C. LIST OF DATABASES PERTINENT TO THE
CONTROL AND REMEDIATION OF SURFACE AND
GROUNDWATER CONTAMINATION FROM INACTIVE AND
ABANDONED MINES
STIRS DATABASES

The Mine Waste Technology Pilot Program (MWTPP) created the Science and Technology Information Retrieval System (STIRS), as discussed in Appendix B. This system uses numerous databases to facilitate comprehensive data and literature searches on mine-remediation science and technology. The STIRS personnel at Montana Tech Library have compiled a list of numerous mining-related databases with useful information for remediation. A draft copy of the database list includes the following information for each of 39 databases: description, format, information type, cost to user, assessment of strengths, assessment of weaknesses, and relevance to MWTPP (Montana Tech Library, 1994).

The final version of the database list is part of a mine-remediation manual in preparation by MWTPP. The following is a small subset of the databases available through STIRS, as identified in a STIRS factsheet (Mine Waste Technology Pilot Program, 1994h).

DATABASE LIST


* Vendor Information System for Innovative Treatment Technologies (VISITT). An EPA database developed to aid in the selection of appropriate technologies for remediating contaminated sites.

* STIRS Mine Waste. This database contains abstracted bibliographies of local Superfund documents and mine waste cleanup and technology publications.

* STIRS Technology. Contains descriptions of mine waste cleanup technology and vendor information.

* CLU-IN. An electronic bulletin-board which provides access to databases dealing with cleanup methods and technologies.

* Alternative Treatment Technology Information Center (ATTIC). An on-line system providing information on alternative treatment systems for remediation of contaminated sites.

* EPA’s On-Line System (OLS). A bibliographic system that contains numerous databases.

* QuickLaw (QL). A Canadian database that provides access to two additional databases: MINTEC (mining technology) and MINPROC (mineral processing technology).

* DIALOG. An on-line database that combines bibliographic listings from databases around the world.

* IMMAGE. A database containing information on nonferrous metals and industrial minerals.

* WILSONDISC. A database containing general applied science and technology information.

* MARCIVE. The database for government-published documents.

* LaserCAT. A listing of books and government documents contained in many western libraries.

* Water Resource Abstracts. This database includes abstracts from thousands of water-related publications and is provided by the U.S. Geological Survey.

Information on these or additional databases used by STIRS is available from Montana Tech Library, Contact: Jean Bishop, Reference Librarian (406) 496-4282.
U.S. GEOLOGICAL SURVEY AND U.S. BUREAU OF MINES DATABASES

There are four additional databases on mining which may be of great value for determining appropriate mine-remediation methods. Though these databases cover much of the United States, a 1995 U.S. Geological Survey (USGS) Open-File Report, No. 95-0578 Diskette, presents data exclusively for Arizona (Ryder, 1995).

The National Geochemical Database is a collection of geochemical information maintained by USGS, Branch of Geochemistry, and consists of three separate databases: Rock Analysis Storage System (RASS), PLUTO, and Mineral Resource Data System (MRDS).

The RASS and PLUTO data date as far back as 1960’s, and the 1930’s, respectively. The data indicate sample source (i.e. open pit mine, prospect pit, underground mine, etc.), the analytical method used to produce the data, and some qualifying remarks (i.e. Not analyzed, Trace, etc.).

The MRDS data originate from USGS studies as well as other federal and state agencies and primarily pertain to mineral commodities. The Arizona data set includes information on 4,441 sites and includes mine names, locations, deposit types, mineral age, commodities, products, and tectonic information.

In addition, the U.S. Bureau of Mines database, the Minerals Availability System (MAS) Database, is a non-proprietary data set. The Minerals Industry Location System (MILS) data is a subset of the MAS database and provides information on locations of mines, their operational status, and information about the minerals at those locations. The Arizona MILS data set contains 10,632 sites. These data are also included in U.S.G.S. Open-File Report 95-0578 Diskette (Ryder, 1995).

Contact: Associate Branch Chief
Branch of Geochemistry
U.S. Geological Survey
Denver Federal Center
Building 20, Mail Stop 973
Denver, CO 80225
(303) 236-1800

Appendix C.2
APPENDIX D. ACRONYMS
ACRONYMS USED IN REPORT

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<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
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<tbody>
<tr>
<td>ABA</td>
<td>Acid-Base Accounting</td>
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<tr>
<td>ADEQ</td>
<td>Arizona Department of Environmental Quality</td>
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<tr>
<td>ADMR</td>
<td>Arizona Department of Mines and Mineral Resources</td>
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<td>ALD(s)</td>
<td>Anoxic Lime Drains</td>
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<td>AMD</td>
<td>Acid Mine Drainage</td>
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<td>AML(s)</td>
<td>Abandoned Mine Land(s)</td>
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<tr>
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<td>Acid Rock Drainage</td>
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<td>AZGS</td>
<td>Arizona Geological Survey</td>
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<td>Best Management Practice(s)</td>
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<td>Bureau of National Affairs</td>
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<td>BOM</td>
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<td>BPJ</td>
<td>Best Professional Judgment</td>
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<td>CCEM</td>
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<td>CERCLA</td>
<td>Comprehensive Environmental Regulatory Compensation Liability Act</td>
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<td>COD</td>
<td>Chemical Oxygen Demand</td>
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<td>Colorado School Of Mines</td>
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<td>SRB</td>
<td>Sulfate-Reducing Bacteria</td>
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<td>STIRS</td>
<td>Science and Technology Information Retrieval System</td>
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<td>TVA</td>
<td>Tennessee Valley Authority</td>
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Appendix D. 1
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<td>Western Interstate Energy Board</td>
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<td>Wetland Treatment System</td>
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