



**White Paper**

# **Mine Waste Issues in the United States: A White Paper**

**January 2008**

**Prepared by  
The Interstate Technology & Regulatory Council  
Mining Waste Team**

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## **EXECUTIVE SUMMARY**

Mining is essential to the economy of the United States, but historical mining practices and the absence of routine mined-land reclamation, remediation, and restoration have led to legacy sites with significant environmental and human health impacts. Typical remedial solutions are often lengthy, expensive, and unacceptable to the regulated and regulatory communities, as well as to the public. Nevertheless, gaining acceptance of new and more cost-effective remedial methods appears protracted and sluggish and is in need of stimulation. This white paper is an attempt to communicate some of these new innovative ideas and remedial practices to the industries, regulatory agencies, and communities that continue to embrace economic prosperity along with a dynamic environment.

Although traditional mining practices and regulations have changed, new mining operations continue to have severe waste issues that must be addressed during and after the actual mining operation. Some new operations occur in areas with legacy environmental sites where the actual material contains sufficient residual mineralization such that further development, re-mining, and subsequent reclamation of the waste is economically viable. Some current operations even have the infrastructure in place to co-manage the cleanup of legacy waste while in operation. This being said, current regulations, poor communication, and often combative relationships create barriers to these innovative approaches.

New mining operations see tremendous benefits by incorporating the idea of “sustainable development” into their business plan. Industry in general has found that by reducing long-term maintenance and overall wastes, their impact to the environment is minimized, thereby reducing overall operational costs. Pollution prevention and waste management are critical operational components in the mining industry, and innovative techniques and technologies (i.e., remediation, reclamation, restoration, and reuse) are the key elements for long-term environmental protection.

Since there are many issues related to mine waste, the Interstate Technology & Regulatory Council (ITRC) Mining Waste Team produced this white paper to describe the current situation and highlight four areas that participating states and industries felt are most important. The paper conveys an understanding of the mining industry’s issues and introduces some of the innovative solutions to historical and current industry environmental problems. It is intended to build a solid foundation for future work by the team.

Four programmatic areas were identified:

- pollution prevention
- waste management
- remediation, reclamation, and restoration and reuse
- legacy management at mining sites

Over the past year the team has met, and each member state has presented its issues (see Appendix B). As a result, two general problem areas have been identified:

- Mining-impacted waters are difficult to treat cost-effectively to levels protective of human health and the environment.
- Solid mining waste is not a specifically regulated waste and involves huge volumes of material. The volume of material alone makes some of the techniques for minimizing the risk unreasonably costly. On the other hand, the exposure posed by direct and indirect ingestion of some of this waste is a major health and ecological concern.

Although standard approaches exist, the high costs of implementation and long-term maintenance are often prohibitive. At Superfund sites, the U.S. Environmental Protection Agency (EPA) provides 90% of the funding for remedial activities. The states must provide 10% of the cleanup costs and 100% of the funding for operations and maintenance (O&M) after the remedy is completed. The cost and resources issues for long-term O&M by the states is significant, with hundreds of years of legacy and active mining. According to a report issued to the Government Accounting Office by the EPA Region VII, it will cost approximately \$1.345 billion to clean up the solid waste lead mining and smelter sites in Missouri alone. Mining-impacted water, occurring from mine drainage, can last for tens to hundreds of years. Undoubtedly, the potential liability for states on any of these properties is a major issue.

Based on the issues identified by the states (Appendix B) and the input received from the Mining Waste Team, this white paper concludes that the team should pursue the following activities:

- Identify and evaluate emerging and innovative technologies that can cost-effectively and successfully be used to characterize, remove, treat, reuse, or stabilize mining, milling, processing, and smelting wastes and mining-impacted water.
- Identify state or federal regulatory obstacles to deployment of conventional or innovative environmental technologies at mine-impacted properties.
- Identify approaches and/or solutions to overcome regulatory barriers.
- Identify innovative environmental solutions to solve legacy mine waste issues.

When addressing a mining waste environmental problem, it is important to understand the relationships between mining-impacted water and mining solid waste. Mitigation, remediation, or waste management decisions must consider the source and the pathway within the chemical and physical conditions of the site. Improved environmental management at active mining operations can prevent legacy issues from developing. The ITRC Mining Waste Team will pursue a partnership with the Society of Mining Engineers to provide the state perspective to its draft Environmental Management System.

The ITRC Mining Waste Team will use case studies and literature searches to provide data and evaluate technologies for treating, stabilizing, reclaiming, and reusing solid mine waste and mining-impacted water and evaluate their performance. For technologies that may contribute solutions to the problems, the team will develop a guidance document that will assist the user to properly evaluate and apply each technology. The ITRC Mining Waste team will also identify regulatory barriers or impediments and recommend specific flexibility when there is a net environmental benefit.



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## **1. INTRODUCTION**

Mining is essential to the economy of the United States. However, mining practices and the lack of mine land reclamation and restoration have led to properties with environmental and human health problems. Historical and current practices have resulted in many of the operating sites having mine waste problems that must be addressed when operations cease. Often insufficient resources are available to fully address these problems. Remedial solutions are often lengthy, expensive, and unacceptable to the mining community, the regulatory community, and the public. Some sites where mining has occurred contain enough residual mineralization that further development, re-mining, and subsequent reclamation may be economically feasible. Some current operations may even have the infrastructure in place to co-manage the cleanup of legacy waste while in operation. However, current regulations often provide barriers to these approaches. Innovative approaches and technologies that will solve environmental issues and remove existing regulatory barriers are needed at current and former mining projects.

### **1.1 Purpose**

Interstate Technology & Regulatory Council (ITRC) teams identify problems within the environmental industry which can be improved by development, testing, and acceptance of new technologies. These problems are sometimes immense and, if not well-delineated or defined in manageable pieces, can overwhelm the best intentions of ITRC teams. The ITRC Mining Waste team realized immediately that the immense nature, volume, and potential cost associated with environmental problems within the mining industry could pose an unmanageable situation.

Ultimately, ITRC teams develop guidance for state regulators and industry and actively pursue acceptance from ITRC states. These guidance documents help users ask the unique questions about new and emerging technologies that will help them understand the proper application and likely performance of technologies otherwise unfamiliar to them. Understanding is accelerated by Internet-based training (offered on the U.S. Environmental Protection Agency [EPA]-hosted Web site CLU-IN) on the guidance itself.

### **1.2 Problem**

Appendix B summarizes specific examples of pending issues surrounding mining-impacted water and mine solid waste from 11 state team members. Over the course of 2006 and 2007, other team members from industry, academia, and community have expressed parallel concerns. As a result, two general problems have been identified:

- Solid mining waste is not a specifically regulated waste and involves huge volumes of material. The volume of material alone makes some of the techniques for minimizing the risk unreasonably costly. On the other hand, the exposure posed by direct and indirect ingestion of some of this waste is a major health and ecological concern.
- Mining-impacted waters are difficult to treat cost-effectively to levels protective of human health and the environment.

Each has unique features and requires adequate characterization and development of the conceptual site model (CSM) to fully understand the appropriate design of a remedial solution. However, there are relationships between mining-impacted waters and solid mining waste. They are integral, and it is important when addressing an environmental problem to understand the relationships between mining-impacted waters and mining solid waste. Waste mitigation, remediation, or management decisions must consider the source and the pathway within the chemical and physical conditions of the site.

### **1.3 Solution**

The Mining Waste Team has spent two years identifying team members; documenting issues of states, academia, industry, and community stakeholders; defining manageable problem definitions; and establishing a common understanding of the problems and potential new and emerging technologies being tested. The team is now ready to begin a multiyear process of collecting reliable information and data on new and emerging technologies; evaluating the reliability, performance, maturity, and proper application of these technologies; and preparing guidance that state regulators and industry can use to expedite the appropriate deployment of these new technologies. When the guidance is complete, the Mining Waste Team will pursue state acceptance of the guidance from all ITRC member states in a formal concurrence process. The team will also develop free Internet-based training to familiarize all users with the proper application of the guidance.

This white paper documents the Mining Waste Team's current understanding of mine waste problems and provides direction for the future work of the team as described in the 2007 project proposal to ITRC.

## **2. SOLID MINING WASTE**

### **2.1 Background**

Ore deposits are typically part of large-scale, ore-forming systems. Many elements, including those of economic interest, are present in the ore-forming system. Accessing the ore often requires removing large volumes of soil and rock. Generally, the elements of economic interest, such as lead, copper, molybdenum, gold or zinc, compose only a small percentage (less than 10%) of the materials extracted during the mining process. Those elements are separated from the host materials during mineral processing. Thus, a large portion of the mined material is set aside on the surface in large waste piles and/or impoundments. These waste materials often have mineral concentrations that are elevated but cannot be extracted economically at the time and can leach metals and other contaminants to surface soil surface water and sediment and groundwater.

Once above ground, minerals present in mine and mill wastes are exposed to atmospheric conditions that affect their fate and transport. Milling the ore decreases particle size, increases surface area, and generally increases bioavailability, solubility, and mobility of metals. Oxidation of the minerals can further increase bioavailability and solubility. Particles may be transported and redeposited by wind, water, or human activity. Through erosion these oxidized materials are transported to areas where human or ecological exposure is more likely to occur.

Removal or treatment technologies are used to minimize exposure to these solid materials by eliminating or minimizing the source, interrupting the pathway, or reducing the toxicity of the contaminants of concern (COCs). Additionally, these solid waste piles are exposed to precipitation that can dissolve and transport contaminants to surface or groundwater. A number of treatment technologies can be used to minimize exposure to solid mine waste material and prevent the formation and transport of mining-impacted waters from mine/mill waste.

## 2.2 Treatment Technologies

Solid mining waste must be characterized to determine toxicity and potential for environmental impact. Wastes at older operations typically have not been properly characterized, leading to large problem areas of sediment, water, and air contamination. Proper waste characterization in more recent mining operations allows the owners opportunities to avoid contaminant transport by designing effective pollution prevention procedures within their production stream.

Before a treatment technology can be selected or a remedial system designed, a thorough understanding of the surface and subsurface geological and hydrogeological characteristics; the source and extent of COCs and their fate, transport, and chemical stability in the environment; and the risk they pose is critical. Ongoing optimization of a treatment technology is achieved only when the site characterization is thorough, accurate, and well-documented and then incorporated into the final CSM.

A well-documented CSM provides a comprehensive summary of what is known about the site and identifies what other information is needed to clearly delineate the chemical and physical characteristics containing and controlling contaminants. This understanding is necessary to design a remedial system to achieve predetermined cleanup goals. The CSM is site specific and details the contamination problem through graphical and narrative elements (EPA 1988). The CSM examines the contamination problem and data gaps, describes the necessary sampling to overcome these gaps, and provides future decision-making guidance. The CSM is not static but evolves as new information becomes available. A robust CSM synthesizes what is known about the site while evaluating the uncertainty associated with the site that influences decision making.

A wide variety of site characterization tools and approaches exists. A comprehensive discussion of the various tools available to investigate and characterize mine waste, contaminated soils, and surface and groundwater is beyond the scope of this document. An example of a CSM, developed by Atlantic Richfield and its contractors for the Yerington Mine Site (Atlantic Richfield Company 2002), can be found at [http://ndep.nv.gov/yerington/wp\\_CSM\\_fnl\\_report.pdf](http://ndep.nv.gov/yerington/wp_CSM_fnl_report.pdf). In addition, general discussions on CSM development can be found in various EPA documents, including those focused on Triad investigations; the Triad Resource Center ([www.triadcentral.org](http://www.triadcentral.org)); ITRC 2003d; and ASTM 2003.

Technologies to address contaminants from solid mining waste range from relocation and encapsulation to industrial reuse. Table 2-1 identifies many of them along with possible case studies the team will assess in future work. The technologies are briefly summarized in the

sections that follow. The ITRC Mining Waste Team's future products will not be limited to those technologies identified in the table. As the team continues its investigations, it will identify and evaluate other and new technologies.

### 2.2.1 Reuse

The coarse-grained fraction of the mine and mill waste can be used for a number of industrial uses (e.g., aggregate for asphalt roads, road fill, commercial sand-blasting, and antiskid surfacing of bridges). Larger rock has been used for breakwaters and for landscaping. Chemical composition of the material must be taken into account in determining appropriate use. For example, Clark, Jambeck, and Townsend (2006) estimated that approximately 1.6 billion metric tons of waste material generated annually could be utilized as a resource.

In many historic mining areas, mine and mill waste has been widely used by nearby communities in a variety of ways, including as fill under roads, gravel for driveways, fill in sewer lines, etc. Many of these unregulated and unrestricted uses have and still do cause exposures to the public. However, there have been regulatory mechanisms developed that help ensure appropriate use and tracking of the used waste in ways that do not create additional exposure to the public (see EPA 2006 and 40 CFR Part 278).

### 2.2.2 Capping

Mine and mill waste piles are capped to isolate the waste from direct exposure to atmospheric conditions such as wind and water. A variety of capping options exists, ranging from clean soil and vegetation to more engineered solutions, including synthetic membranes and evapotranspiration final covers (ITRC 2003c).

Conventional covers are designed to reduce moisture from contacting the waste and isolate the waste from humans and animals (and in some cases plants). Conventional covers are made from material with variable hydraulic conductivities, depending upon the requirements of the cover, and include native material as well as compacted clay, geosynthetic materials, or geomembranes, either alone or in combination. The basic types of conventional covers are as follows:

#### *Earthen Barrier*

- soil laid directly over waste
- compacted clay laid over the waste then overlain by soil

#### *Geocomposite Liner (GCL)*

- a sandwich of fabric and bentonite over the waste then overlain by soil

#### *Composite Barrier*

- similar to an earthen barrier but with a geomembrane (thin layer of plastic material) separating the compacted clay or GCL from the soil

**Table 2-1. Solid Mining Waste Treatment Technologies**

<b>Technology</b>	<b>Contact</b>	<b>Case Study 1</b>	<b>Case Study 2</b>	<b>Case Study 3</b>
Capping/covering/grading	John Carter, Doe Run; Bob Hinkson, Missouri Department of Natural Resources	Big River Mine Tailings, Desloge Pile		
Excavation and relocation, on land disposal in engineered facility	Mike Bishop, EPA Region 8 (Montana Office); David Swanson, CDM, Helena, Montana.	Montana		
Excavation and disposal/subaqueous	Dave Mosby, U.S. Fish and Wildlife Service; Mark Doolan, EPA Region 7; Dave Hinrichs, Newfields	Waco Pits, Jasper County site	Webb City Shaft Closure	
Reuse <sup>a</sup>	Mark Doolan, EPA Region 7; Steve Hoffman, EPA	Jasper County Site Development	Bob Narin, University of Oklahoma, road base use study at Tar Creek	Dennis Datin, Oklahoma, chat use studies
Remining				
Chemical stabilization				
Cyanide heap leach detoxification	Diane Jordan, MSE; Diana Bless, National Risk Management Research Laboratory			
In situ treatment: bioavailability reduction, phosphate, biosolids	Dave Mosby, U.S. Fish and Wildlife Service; Sally Brown, University of Washington, John Carter, Doe Run	Joplin Phosphate Treatment	Jasper County Site Biosolids Application on Upper Arkansas River	Viburnum Trend residential yards
Passivation of sulfide materials	Rick Glover, University of Nevada–Reno (UNR); Felipe Vasquez, UNR; Glenn C. Miller, Ph.D., UNR; Dirk van Zyle, P.E., Ph.D., Mackay School of Earth Science and Engineering; K. Altman, UNR	Gilt Edge Mine, S.D.; Ken Wangerud		

<sup>a</sup> EPA published the final rule on chat use in asphalt and cement (40 CFR Part 278, EPA-HQ-RCRA-2006-0097, FRL-RIN 2050-AG-27). [www.epa.gov/epaoswer/other/mining/chat/chat-fnl507.pdf](http://www.epa.gov/epaoswer/other/mining/chat/chat-fnl507.pdf)

### *Alternative Cover*

- evapotranspiration cover
- water balance or field water balance cover
- store and release cover
- water harvesting cover

These alternative covers work particularly well in areas where evapotranspiration exceeds precipitation; however, this is not a firm limitation to the cover design. The cost of this type of cover is typically less than that of conventional subtitle D (municipal solid waste) landfill covers.

### 2.2.3 Excavation and Disposal

Excavating mine waste and relocating it to a designed containment area is effective but extremely costly. Montana has developed a repository where waste from several sites has been consolidated into a single disposal facility (EPA 2003).

### 2.2.4 Backfilling

Backfilling mine and mill waste means placing waste material into abandoned mine workings or subsidence features. Backfilling techniques can include injection, slurring, truck haul, and/or dozing. Material can be placed into workings that may be wet or dry. Advantages of backfilling include removal of mine waste from the surface where exposure is more likely to occur and reduction of the rate of oxidation. However, subaqueous disposal of mine and mill waste may initially affect the groundwater quality as contaminants dissolve from the waste.

Amendments have been added with backfill material to improve strength and/or ground water quality. Cement is typically added to tailings used to backfill underground mine workings. Lime and limestone are often added to neutralize acid mine water, and some organic amendments have been tested to stimulate sulfate reduction. For an example of backfilling, see <http://yosemite.epa.gov/R10/CLEANUP.NSF/sites/formosa>.

### 2.2.5 Remining

“Remining” refers to mining areas formerly mined and abandoned. It can include mine, mill, or processing waste. Remining has been an important tool in reclaiming abandoned mine lands. A mine operator who engages in remining must reclaim the area. Abandoned mine reclamation through remining has received a great deal of attention, and most coal-producing states are developing ways to advance their remining and reclamation programs.

### 2.2.6 Chemical Stabilization

A variety of chemicals can be added to solids to change chemical form, solubility, and/or bioavailability. Chemical application of phosphate and other stabilizing agents has been used in the hazardous waste management industry for decades. Chemical-based stabilization has been most widely used to treat wastes that fail the Toxicity Characteristic Leaching Procedure for heavy metals. More recent research has focused on in situ treatment of soils contaminated with lead and other heavy metals from mining or smelting activities to reduce heavy metal



bioavailability. Similar treatment approaches have been used to address lead in soils at small arms firing ranges (see ITRC 2003a, 2005). Examples of this technology include inorganic phosphate-based chemical treatment and biosolids application. Silica and permanganate compounds as well as a variety of biocides are being tested.

Sodium lauryl sulfate (SLS), an anionic surfactant, has been used in coal mining applications in both liquid and slow-release solid forms. Alkyl benzene sulfonate was also effective and less expensive than SLS but required higher concentrations. The compound affects the permeability of the cell wall of the iron-oxidizing bacteria *Thiobacillus ferrooxidans*. The membrane becomes permeable to acid, and the bacteria can no longer survive in the environment they help create. In general, the application tended to reduce the overall acid load, but the effect appears temporary.

Recently, another product that uses thiocyanate has been developed, and data on its effectiveness are being generated (Olson, et al, 2005).

#### 2.2.6.1 *In Situ Inorganic Treatment*

Chemical treatment includes phosphoric acid and other inorganic phosphate amendments added to contaminated waste to change the species of metal to a less mobile and less toxic form. The goal is to transform more bioavailable forms of Pb (Pb carbonate, Pb oxides, etc.) to various forms of pyromorphite, a Pb phosphate compound molecule with very low solubility. Other amendments (e.g., KCl and lime) have also been added to either accelerate the reaction to a pyromorphite compound (e.g., chloropyromorphite) or stabilize acid conditions created in the soil or mine waste. In addition to Pb, other heavy metals tend to be tightly bound to phosphate, including Fe, Al, Cd, and Zn. A patented compound, Bauxsol, has been used to treat acid rock drainage (ARD) in Pennsylvania (Albrecht et al. 2006).

#### 2.2.6.2 *Biosolids Application*

A variety of amendments, including composted municipal sewage sludge, composted yard waste, and composted cattle and poultry waste, have been added to create suitable growing conditions on formally barren mine waste and to reduce the bioavailability of heavy metals. Organic matter increases the water-holding capacity and nutrient content of the mine/mill waste, improving conditions for plant growth. In addition, it is suspected that heavy metals are bound to organic forms of phosphate and complex organic molecules present in the biosolids, which tend to reduce mobility and bioavailability of metals. This also promotes plant growth in low pH and/or high metal concentration conditions by reducing the phytotoxic effects of the metals.

#### 2.2.7 Cyanide Heap Leach Detoxification

Several biological treatment technologies have been compared with a conventional cyanide heap leach detoxification method. The conventional method of detoxifying heap leach material is by simply rinsing the spent heap leach material with fresh or treated water until it meets the current regulatory standards. However, metals often remain after cyanide removal. Biological processes improve on this result by using bacteria to detoxify a spent heap leach pad by destroying the cyanide, nitrates, and sulfates and removing the metals (Joyce 2004). This technology, referred

to as “biocyanide technology,” is capable of detoxifying cyanide and nitrates and immobilizing metals in wastewater from cyanide heap leach operations (Nordwick et al. 1999).

### 2.2.8 Passivation

Preventing oxidation of sulfides in situ by controlling the environmental conditions for oxidation is potentially a viable alternative to treatment in perpetuity. Techniques for halting metal sulfide oxidation involve deoxygenation, dewatering, surface coating, bacterial inhibition, or raising pH. Plastics, polymers, or cementation can be used to seal sulfidic surfaces (Moncrieff 2006). Passivation of acid-generating material involves oxidizing or protecting the sulfide surface from water and oxygen. Surface passivation is analogous to galvanizing a nail; the outer layer resists oxidation. Passivated materials will generally not oxidize even if oxidation is an energetically preferential reaction.

Oxidation of the surface under controlled conditions can create a passivated layer that is resistant to further oxidation. For these passivation treatments to work properly, metal oxides must come into contact with metal sulfides at a sufficiently high pH and at a high Eh. This combination can be found by treatment of acid-generating rock with permanganate and magnesium oxides at a high pH (>12). Maintaining the high pH prevents the permanganate from disproportionating to a weaker oxidant and lowering Eh (DeVries 1996). The iron-manganese-magnesium surface film has been shown to be remarkably stable to further oxidation. Although preliminary tests have shown this treatment to work, more experimentation needs to be performed to assess the long-term viability of passivated coating.

Phosphate treatments react with  $\text{Fe}^{3+}$  in solution to create a ferric phosphate coating on the surface of the sulfides. Pretreatment of pyrite surfaces with hydrogen peroxide or other oxidant will generate more  $\text{Fe}^{3+}$  in solution for phosphates to react with (Evangelou 1995). A drawback of all oxidation treatments is an initial release of sulfate into solution. To prevent biotic oxidation from occurring and undermining the phosphate treatment, a water-soluble biocide, commonly sodium thiocyanate, can be added. Although sodium thiocyanate works to inhibit sulfur-oxidizing bacteria, adsorption to the rock, rinsing by precipitation, or degradation by iron oxidation all reduce its effectiveness over time; thus, bacterial treatment must be repeated on a regular basis (Olson et al. 2006).

In an analogous fashion to ionic phosphate treatment, phospholipids or other lipids with hydrophilic heads can form films, preventing water from reaching the pyrite surfaces. Two tailed lipids have been shown effective at preventing oxidation by forming this film (Elsetinow et al. 2003). There is some evidence to suggest formation of a lipid bi-layer, given the correct conditions (Elsetinow et al. 2003). Application of these lipids requires high temperatures or coinjection of a solvent to carry the lipids to the surface layer and allow them to be deposited with polar heads toward sulfide surfaces.

Treatment of surfaces with high pH aluminum waste also offers certain benefits that can neutralize acidic wastes but also provide a passivation layer to the remaining rock. In this treatment, waste from aluminum smelters, which generally exists at a high pH, is mixed with

either the waste rock or an acid drainage solution. The resulting precipitate on the rock surface serves to limit further oxidation of reactive surfaces.

All passivated surfaces still have reactive rock below the surface, and oxidations will return once that passivation layer is removed. Thus, whether passivation is a viable option depends on time, other environmental conditions, and treatment efficiency requirement.

### **3. MINING-IMPACTED WATER**

“Mining-impacted water” is a general term used to describe any waters that have been impacted by any part of the mining and/or processing portion of the operation. Water quality impacts vary from elevated suspended solids to acid mine drainage. Elevated suspended solids generally occur through erosion of mine wastes, causing increased turbidity and potential aquatic impacts following deposition. Acid mine waters occur in mined rock masses or mining/milling waste piles containing sulfide minerals with insufficient neutralizing capacity. Oxidation of these sulfide minerals produces acid and releases metals into solution. These problems can persist for tens to hundreds of years. Over 10,000 miles of receiving waters in the United States are affected by mining-impacted water, primarily acid drainage.

Pit lakes and mine pools can be found across the United States. Mine pools occur when groundwater is intercepted and collects within underground mine workings. In some cases the water is able to reach the surface and potentially have a negative impact on surface water bodies. Pit lakes are a surface feature left over from open-pit mining and a collapse feature from underground mining activities that have intercepted surface and/or groundwater and allowed the water to accumulate over time within the confines of the pit. Often a pit can fill to a point where water enters local groundwater, overflows the confining walls, or creates a head pressure above bedrock fracture zones. The fracture zones can allow the captured pit water to flow into the surrounding aquifer(s) and potentially to surface outlets downgradient. Discharges from mine pools or pit lakes can potentially lead to exceedance of water quality standards.

Standard water treatment processes exist for most constituents of mining-impacted water. However, due to the volume and persistent nature of mining-impacted water, standard treatment process can require considerable maintenance and financial resources. More cost-effective and sustainable treatment systems are needed. The following sections summarize technologies or techniques used to treat mining-impacted waters.

#### **3.1 Mining-Impacted Water Treatment Technologies**

A variety of chemical treatment processes exist for mining-impacted water treatment. Some of these require large treatment plants, which have high initial construction costs and extensive operation and maintenance costs. These treatment operations require maintenance and staff (e.g., power input for pumps, controls, or chemical input). Therefore, if power is lost to the operation, treatment typically ceases.

At the other end of the technology spectrum, there are treatment systems that use natural processes to treat mining-impacted water. These systems are generally designed to work without

power and are designed to have low operation and maintenance requirements. There is no completely passive system; however, it is a goal we continue to pursue. Although treatment is provided, strict compliance with all water quality standards may not always be achieved.

Table 3-1 provides list (not necessarily complete) of treatment technologies for mining-impacted waters. More labor-intensive treatment technologies are listed first, and techniques typically requiring less maintenance are listed last. At least one constructed treatment wetland appears to be self-sustaining and may provide long-term treatment with minimal maintenance (Eger and Wagner 2002). A brief discussion of each technology is provided in the following section. Additional information is available in publications by EPA and the Acid Drainage Technology Initiative ([www.unr.edu/mines/adti/workbooks.asp](http://www.unr.edu/mines/adti/workbooks.asp)).

### 3.1.1 Chemical Precipitation

The most common treatment technology is chemical precipitation. For acid mine drainage, pH must be neutralized and metals reduced or removed. A choice of neutralizing chemicals and a wide range of polymers are available. The choice of the neutralizing chemical and proper plant design drives metal removal efficiencies and economics in precipitation systems. Lime [ $\text{Ca}(\text{OH})_2$ ] and caustic soda (NaOH) are the most commonly used means of adjusting pH. The principal advantage of hydroxide precipitation is that it is simple and uses inexpensive reagents. These systems do produce sludge which require disposal.

Treatment plants have also been built that precipitate metals as metal sulfides. Sulfide can be added either chemically or generated biologically. Metals precipitated as sulfides can sometimes be recovered and recycled.

### 3.1.2 Ion Exchange

Ion exchange is the process of exchanging unwanted ions in the mine water (generally trace metals) for an ion on a solid resin. A variety of resins are available and test work with the specific mine water is required prior to designing a treatment system. Although these systems can be quite effective, the resin only contains a fixed amount of exchangeable ions and therefore a limited treatment capacity. When the capacity is exceeded, the resin must be replaced or regenerated. Resins can be regenerated through contact with a solution that will remove the metals from the resin and replace them with the exchangeable ion. The resulting metal rich solution must be either disposed or recycled.

**Table 3-1 Mine-Impacted Water Treatment Technologies**

<b>Technology</b>	<b>Contact</b>	<b>Case Study 1</b>	<b>Case Study 2</b>	<b>Case Study 3</b>
Chemical precipitation	Mike Bishop, EPA Region 2	Luttrell, Basin Creek Mine, Mont.	Copper Hill, Tenn., State of Tennessee, John Chermak	Flambeau Mine, Dunka Mine
Ion exchange		Soudan Mine		
Reverse osmosis	Mike Bishop	Luttrell		
Electrolytic • Electrocoriolysis, ELCOR™	• Joseph J. Hanak, Ph.D., Apogee Corporation			
Pulsed limestone bed treatment  • Rotating cylinder treatment system  • Aqua Fix	P.L. Sibrell, U.S. Geological Survey; T. Wildeman, CSM; David Reisman, EPA/ORD  • Timothy K. Tsukamoto, Ph.D., Ionic Water Treatment Technologies	Argo Tunnel, Idaho Springs, Colorado, published EPA/ORD		
Bioreactors  • Ethanol or solid-phase, organic-based, sulfate-reducing bioreactors • Limestone-buffered organic substrate • Sulfate-reducing bioreactors (compost)	David Reisman, EPA/ORD  • Figueroa, Ph.D. CSM; Holmes, EPA Region 8  • James Gusek, Golder and Associates	Elizabeth Mine, South Strafford, Vt., Clear Creek/Central City Superfund Site  • Black Hawk Colorado  • Peerless Jenny King Mine, 10-mile superfund Site Montana,	Elizabeth Mine, South Strafford, Vt.  • Leviathan Mine, Markleeville, Ca  • Luttrell Mine, Timothy Tsukamoto and Ed Bates (published)	

Technology	Contact	Case Study 1	Case Study 2	Case Study 3
<ul style="list-style-type: none"> <li>• Alcohol amended</li> <li>• Biosolids waste fluid as an inexpensive carbon source for bioreactors treating acid mine drainage</li> <li>• Biochemical</li> </ul>	<ul style="list-style-type: none"> <li>• Dave Reisman, EPA/ORD</li> <li>• Marek Zaluska, MSE</li>   <li>• Melody Madden, Phelps/Dodge</li> </ul>	<ul style="list-style-type: none"> <li>• Iron King Mine, Ariz.</li> </ul>		
Anoxic limestone drain				
Groundwater treatment <ul style="list-style-type: none"> <li>• Permeable reactive barrier walls</li> <li>• Chemical treatment (selenium PPT under reducing environment)</li> </ul>	<ul style="list-style-type: none"> <li>• Kennecott Utah, dissolved selenium, Doug Bacon, Utah</li> </ul>			
Source treatment <ul style="list-style-type: none"> <li>• Milk waste</li> <li>• Soybean oil (emulsified oil substrate), patented</li> </ul>	Jeff Morris, Ph.D., Western Research Institute, Laramie, Wyo. <ul style="list-style-type: none"> <li>• Robert Borden Solutions, IES</li> </ul>	Sequatchie Valley Coal Mine near Dunlap, Tenn.		
Constructed microbial mats				
Constructed treatment wetlands <ul style="list-style-type: none"> <li>• Reduced-alkalinity-producing systems</li> </ul>	David Reisman, EPA/ORD	Peerless, King, 10 mile, Mont.		

### 3.1.3 Reverse Osmosis

Mining-impacted water with elevated metals and total dissolved solids (TDS) can also be treated via membrane filtration (reverse osmosis, nanofiltration), which has front-end costs associated with the energy expenditure to push the feed water through the membranes. Additional expenditures can arise because of the need to dispose of the inevitable wastewater (or concentrate) from the treatment plant, which may or may not require secondary treatment. Long-term disposal of the concentrate can add to the expenditures because of the disposal facility's operation, management, and replacement over time. Chemical treatments have similar energy, operation, management, replacement, and long-term disposal costs.

### 3.1.4 Electrolytic Methods

Some metals can be removed from solution via electrochemical processes. Steel cans have been used to remove copper from mine drainage or from leached stockpiles, and copper can also be recovered in electrolytic cells. Water has also been treated with electrocoagulation to remove sediment and heavy metals. The technology removes metals, colloidal solids and particles, and soluble inorganic pollutants from aqueous media by introducing highly charged polymeric metal hydroxide species.

#### *3.1.4.1 Electrocoriolysis*

Electrocoriolysis is a patented apparatus for separating and removing ionizable components dissolved in water by separating ionizable substances into fractions by the action of electric current and of Coriolis force.<sup>1</sup> Liquid containing ionizable components is continuously fed in the apparatus, and the purified solvent and the solute in a concentrated solution are continuously removed while the liquid is rotated. Compound centrifugal force (Coriolis force) causes the concentrated solution to move to a location where it can be effectively and continuously removed as well as causes the depleted liquid to move to a separate location where it also can be effectively and continuously removed (see [www.wipo.int/pctdb/en/wo.jsp?wo=2000009451](http://www.wipo.int/pctdb/en/wo.jsp?wo=2000009451)). The Mining Waste Team does not currently have case studies or examples where electrocoriolysis has been tested but will continue to search for demonstration or case examples.

### 3.1.5 Pulsed Limestone Bed Treatment

Although limestone can neutralize acidic drainage, it loses effectiveness if significant amounts of ferric iron are present in the solution. As the solution pH increases, the iron precipitates out of solution and coats or “armors” the limestone, thereby reducing its effectiveness. In this approach the limestone is periodically “pulsed” or fluidized to remove the precipitate and maintain treatment efficiency.

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<sup>1</sup> The Coriolis effect is the apparent deflection of objects from a straight path if the objects are viewed from a rotating frame of reference.

### 3.1.5.1 Rotating-Cylinder Treatment System

The rotating-cylinder treatment system is a variation on lime treatment. The system is portable and uses shallow troughlike cells to contain the water being treated and rotating cylinders to transfer oxygen and agitate the air/water/lime mixture.

### 3.1.5.2 Aqua Fix

This system is also a variation on lime treatment. The system includes a hopper that contains pebble lime and a drive mechanism powered by a water wheel. No external power is required as the flow of the mine water powers the drive mechanism. The dispensing system is calibrated based on the acidity and flow of the drainage. The faster the flow, the more lime is added. A downstream settling pond is needed to allow the metal hydroxides to settle. This system has been used in coal mine areas in the eastern United States.

### 3.1.6 Bioreactors

Bioreactors use biochemical remediation processes to treat mining-impacted water. The most common bioreactors currently employed use sulfate-reducing bacteria to raise pH and remove metals. Sulfate-reducing bacteria are anaerobic and typically use small chain organic molecules and sulfate as part of their metabolic processes. Sulfate is reduced to sulfide, which can react with metals to form relatively insoluble metal sulfide precipitates. The organic carbon can be supplied either in the form of liquid (e.g., ethanol) or from a solid phase (e.g., manure, wood chips). Recently other substrates are being tried, such as fish bones, chitin (crab shells), biosolids waste fluid, and sources of liquid carbon (biosolids) waste.

In the past, the best substrate was generally one that was locally available and inexpensive. Recently, research has been conducted to help better understand the reactivity of various substrates (Figueroa, Sevler, and Wildeman 2004).

A limestone-buffered organic substrate (LBOS) is a modified design of the traditional bioreactor that achieves in situ mineral acidity neutralization. The main components of the modified design are replacement of the coarse limestone in reducing and alkalinity-producing systems (Section 3.1.12) with fine-grained limestone incorporated into the organic layer, creation of a thicker organic layer, and replacement of the limestone drain with one composed of inert material. This new type of passive system design, termed a “limestone-buffered organic substrate,” is capable of completely neutralizing net acidic ( $738\text{--}2320\text{ mg}\cdot\text{L}^{-1}\text{ CaCO}_3$  equivalents), low pH (1.6–3.0), ferric iron-dominated ( $92\text{--}237\text{ mg}\cdot\text{L}^{-1}\text{ Fe}^{3+}$ ), and aluminum-bearing ( $39\text{--}274\text{ mg}\cdot\text{L}^{-1}\text{ Al}^{3+}$ ) ARD while avoiding armoring. In field test and full-scale applications, the LBOS consistently produced circum-neutral pH (6.4) water that is always net alkaline ( $619\text{ mg}\cdot\text{L}^{-1}$  as  $\text{CaCO}_3$  equivalents) with greater than 97% of the influent acidity neutralized within the LBOS (Thomas and Romanek 2002).

### 3.1.7 Anoxic Limestone Drain

Anoxic limestone drains (ALDs) are buried cells or trenches of limestone into which anoxic (oxygen-free) water is introduced. The limestone dissolves in the mine water and adds alkalinity.



Under anoxic conditions, the limestone does not coat or armor with Fe hydroxides because ferrous iron ( $\text{Fe}^{+2}$ ) does not precipitate as  $\text{Fe}(\text{OH})_2$  at  $\text{pH} < 8.0$ . The effluent pH of ALDs is typically 6–7.5. The sole function of an ALD is to convert net acidic mine water to net alkaline water by adding bicarbonate alkalinity. The removal of metals within an ALD is not intended and has the potential to significantly reduce the permeability of the drain resulting in premature failure. Once the drainage has been converted to net alkaline, it is typically treated with a settling pond and a surface flow wetland.

Anoxic limestone drains can be very effective in raising the alkalinity of some mining-impacted waters. They have been used primarily in the coal-mining areas of the eastern United States, where they have been used to treat drainage from abandoned mines. To be successfully treated, the water must have low dissolved oxygen and low aluminum. Typical designs have an estimated lifetime on the order of 15 years, after which most of the limestone has dissolved. The drain would then need to be opened and new limestone added.

More information on the anoxic limestone drain can be found in Skousen 1998 and Watzlaf, Schroeder, and Kairies 2000.

### 3.1.8 Groundwater Treatment

#### *3.1.8.1 Permeable Reactive Barriers*

Permeable reactive barriers have been widely used to treat groundwater containing chlorinated organic compounds but have also been successful in treating groundwater influenced by mining (Nickel Rim). Reactive media have been similar to those used for substrate-based sulfate reducing bioreactors. See ITRC 1999 for more information about PRB treatment of inorganics and radionuclides.

#### *3.1.8.2 Chemical Treatment*

Chemical treatment involves a chemical reagent introduced to the aquifer as a carbon source (fuel) for the native microbial population. As the organic carbon is consumed, the electrons produced from the oxidation activity are transferred to the naturally occurring terminal electron acceptors, such as oxygen, nitrate, manganese, iron, and sulfate. Metals such as selenium, uranium, and chromium can be electrochemically reduced to less toxic and immobile forms. The formation of reduced iron and sulfide minerals can cause the coprecipitation of toxic metals such as arsenic and chromium, as well as provide oxidation protection of the solid-phase metals to prevent dissolution once aquifer conditions become oxidizing again. Kennecott Copper Utah is using a patented process proposed by ARCADIS (reportedly used at over 200 sites). The process calls for the creation of a chemically reducing area within the groundwater (patently termed the “in situ reactive zone”). As part of a pilot study, Kennecott and ARCADIS are investigating the benefit of adding iron sulfide minerals to the introduced reagent (carbon source) to provide access sorption sites for arsenic and selenium.

### 3.1.9 Source Treatment

Groundwater has also been treated by injecting various organic substrates into areas influenced by mining. The goal is to promote sulfate reduction and achieve in situ treatment. Jeff Morris of the Western Research Institute in Laramie, Wyoming reported that after identifying acid generating areas using electromagnetic surveys, waste milk substrate was injected and an inoculum (municipal wastewater effluent solids) at or upgradient from problem areas (personal communication, 2007). Treatment performance was monitored through injection and monitoring wells using electromagnetic surveys. Results from laboratory and field experiments show increased pH and good longevity of the system in two years and counting. Laboratory work is currently under review and field data review will begin soon.

### 3.1.10 Constructed Microbial Mats

Constructed microbial mats are naturally occurring living organisms composed primarily of cyanobacteria (formerly known as “blue-green algae”). Microbial mats are completely nontoxic and do not produce offensive odors. They are called “constructed” mats because they are grown using a standard technique that is very inexpensive and can be accomplished with minimal training. Microbial mats have few growth requirements and will flourish even under harsh environmental conditions. Although mats are not classified as plants, they are photosynthetic and can be grown like plants, harvested, and dried until needed. Another effective technique is to grow mats onto a low-cost silica bead. This technique increases the surface area of the mat and results in a low biological oxygen demand (BOD) and low dissolved organic carbon levels in the water being treated.

Previous research has shown that mats will adsorb and sequester a variety of metals, including As, Mn, Fe, Pb, and Cu, and they have been successfully tested on waste streams generated at mine sites, including acid mine drainage. The silica bead mats have been used to remove a suite of metals including radionuclides, plutonium, and uranium from waste streams.

Mats can remove metals, metalloids, radionuclides, and oxyanions from water through several different mechanisms:

- *Ion exchange/sorption*—Mats provide huge, negatively charged surface area for binding positively charged metals. Surface binding and ion exchange mechanisms are involved in the metal removal process. Once all the binding sites are filled with metals, a period of regrowth is needed to rejuvenate the mats.
- *Reduction*—Many metals (e.g.,  $U^{6+}$ ,  $Cr^{6+}$ , and  $Se^{6+}$ ) must be reduced for removal to occur. Metals are reduced in the anoxic reducing zones created in mats at night or in mats maintained in dark or low-light conditions. Once these metals are reduced, they precipitate as oxides, hydroxides, or sulfides.
- *Oxidation*—Some metals (e.g., manganese) are oxidized and precipitated. Mats are photosynthetic and can saturate the water with oxygen during daylight hours.
- *Bioflocculants*—Mats produce negatively charged carbohydrate molecules that act as bioflocculants to bind metals and cause them to precipitate out of the water column.

### 3.1.11 Constructed Treatment Wetlands

The type of wetland constructed to treat mine drainage is determined by the quality of the input water (see Figure 6-3, ITRC 2003b). Although net acidity and alkalinity are used to select the general type of wetland, the details of the design are determined by the initial concentrations of iron, aluminum, sulfate, and trace metals and the removal needed to meet effluent levels.

Surface-flow wetlands can be used to treat water that is net alkaline. These wetlands are also called “aerobic wetlands” since most of the treatment occurs in the oxygenated, or aerobic, portion of the wetland. Aerobic constructed wetlands used to treat mine drainage typically consist of shallow excavations filled with flooded gravel, soil, and organic matter to support wetland plants, primarily *Typha*, but other species including *Juncus* and *Scirpus* have also been used (Skousen 1998). These systems also contain oxidizing bacteria such as *Thiobacillus ferrooxidans*, *Leptothrix discophora*, and *Ulothrix* (Robbins, Brant, and Ziemkiewicz 1999). The cells are typically on the order of 30 cm (12 inches) deep or less, lined with relatively impermeable sediments composed of soil, clay or nonreactive mine waste.

Biogeochemical interactions provide treatment as contaminated water travels through the constructed wetland, typically across the surface or near surface. Aerobic wetlands promote oxidation and hydrolysis in the surface water of the wetland, which is the primary removal mechanism for iron. Areal removal rates for iron in these systems generally vary between 10 and 20 g/m<sup>2</sup> per day (Hedin, Narin, and Kleinmann 1994).

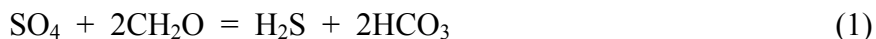
Often a net acid drainage can be converted to net alkaline by using either an anoxic limestone drain or sequential alkalinity producing wetlands (also called “reducing and alkalinity-producing wetlands”).

Subsurface-flow wetlands are often called “anaerobic wetlands” since treatment occurs in the deeper layers of the wetland where no oxygen is present. Constructed anaerobic (both vertical and horizontal flow) wetlands rely on various bacteria to remove iron, aluminum, manganese, trace metals (e.g., copper, lead, zinc, cadmium, chromium, cobalt, uranium), sulfate, selenium, cyanide, and nitrate. Subsurface-flow wetlands are often constructed of a mixture of organic/nonorganic materials and may include woody waste, compost, manure, hay, limestone, and a bacterial starter culture or inoculum, which is typically a suite of indigenous bacteria rather than a specific bacterial strain that was nurtured in a laboratory environment. The consortium of bacteria and the degree of reductive environment are dependent on the amount and type of carbon available and the electron donors. If these systems are built without plants, they are generally called “bioreactors” (discussed in Section 3.1.6).

In anaerobic constructed wetlands designed for heavy metal removal, the metabolic products of sulfate-reducing bacteria, in conjunction with the dissolution of limestone, which is generally included as part of the matrix of the wetland, are responsible for raising the pH and precipitating metals as sulfides, hydroxides, and/or carbonates.

Certain bacteria, *Desulfovibrio* and *Desulfotomaculum*, can use reactions between organic substrate (CH<sub>2</sub>O, a generic symbol for organic carbon) and sulfate as a source of energy for their

metabolism. The bacteria require relatively simple organic compounds, so only part of the organic matter is normally usable by them or they require action by fermenting or other bacteria to degrade complex compounds. The bacteria convert sulfate to sulfide, which can react with the metals in the drainage to form metal sulfide precipitates.



If there is an excess of sulfate reduction, bicarbonate alkalinity will be produced, and the pH will increase.

Surface-flow wetlands can also be used to polish the effluent from anaerobic sulfate-reducing cells (bioreactors), which is typically low in dissolved oxygen and can contain elevated concentrations of dissolved sulfide. During system startup, BOD, fecal coliform bacteria, and color are also usually elevated. Aerobic cells can also contain cyanide-degrading bacteria that include *Actinomyces*, *Alcaligenes*, *Arthrobacter*, *Bacillus*, *Micrococcus*, *Pseudomonas*, and *Thiobacillus* (Canty 2000).

### 3.1.12 Reducing and Alkalinity-Producing System

The reducing and alkalinity-producing systems (RAPS) are alkalinity-generating systems of particular interest because they can treat highly acidic, oxygenated, ARD containing elevated concentrations of iron and aluminum. A RAPS is a type of constructed treatment wetland with a layer of organic matter (generally compost, 0.1–0.5 m) that overlies a layer of limestone (0.5–1.0 m). A perforated-pipe drainage system is placed at the bottom of the limestone layer to regulate water depth and ensure that the organic and limestone layers remain submerged. The RAPS design directs water to flow downward through the organic matter and limestone layers. As water flows through the organic layer, oxygen is removed, and the iron remains in the ferrous form. Ferrous iron will not precipitate in the limestone layer, so that the limestone will not be coated and lose reactivity. The RAPS discharges to either a settling pond or surface-flow wetland, where the iron is converted to the ferric form and precipitates. Depending on the quality of the initial input water, this process can be repeated with additional cells. These systems are generally referred to as “sequential alkalinity-producing systems.” Excess aluminum can reduce permeability of these systems, and they require periodic flushing to maintain flow.

More information on sequential or reducing alkalinity-producing systems can be found in Skousen 1998 and Watzlaf, Schroeder, and Kairies 2000.

## **3.2 Mine Pool and Pit Lakes Treatment**

Mine pools can be treated with conventional pump-and-treat technology, but recently there has been some success with in situ treatment. In situ treatment involves the addition of material directly into the pit lake or mine pool to treat the water either chemically or biologically. Typical chemical additions are lime and/or limestone, while for biological processes various types of organic material are added.

### 3.2.1 In Situ Neutralization and Bioreduction

In situ neutralization and bioreduction of nitrates and metals has shown effectiveness at treating the 30 million gallons of ARD pit water at Gilt Edge Mine, South Dakota. This treatment alternative has been successful at reducing contaminants to nontoxic levels and allowing the water in the pit to be discharged. This same process might be effective to address water quality at mine pools as long as sufficient “static” residence time for bioreaction phases can be accomplished. However, the implementation of and benefits from the neutralization/bioreduction process needs to be investigated.

### 3.2.2 Mine Pool and Pit Lake Summary

Direct surface release to downgradient receptors, percolation to the surface and migration to receiving surface waters or wetlands, or direct contact/use by migratory species or the public through recreational activities are concerns that drive the need to address the quality of mining-impacted waters at sites with pit lakes and/or a mine pool. Standard treatment technologies call for piping the water to a traditional treatment plant and treating the water to numeric water quality standards, but costs are rising.

## **4. REGULATORY ISSUES**

The ITRC Mining Waste Team intends to identify any and all statutes, regulations, or policies that impede or slow the use of new technologies in the reduction of threats to human health and the environment related to mining waste. During the investigative process, the team has searched and will continue to search for a variety of solutions to these barriers and recommend ways to overcome them. ITRC’s experience in past projects suggests that statutory and regulatory barriers often do not exist since exception, variances, or technical impracticality waivers are available. Even so, these are time-consuming, costly, uncertain, and biased toward existing or conventional technologies. This bias is part of what we are trying to overcome—to allow new technologies to be tested, demonstrated, and earn an appropriate place in the toolbox of environmental professionals. The Mining Waste Team has identified the following issues while preparing this white paper.

### **4.1 Water Quality Standards—What Should They Be?**

One of the barriers to the use of innovative technology is the ability to consistently meet all ambient water quality standards. For example, wetland treatment systems almost always provide treatment but may not always consistently meet strict water quality standards. By neutralizing the drainage and removing most of the metals from the discharge, environmental conditions in the receiving streams can be markedly improved, returning biological activity to a previously “dead” section.

The Clean Water Act (CWA), first passed in 1972, is the cornerstone of the surface water protection in the United States. Its stated objective is “...to restore and maintain the chemical, physical and biological integrity of the Nation’s water. The act works towards achieving this

objective by reducing direct pollutant discharges, financing treatment facilities, and managing polluted runoff.

Water quality standards are the foundation of the water quality–based control program mandated by the CWA. The act and associated regulations required states to define and specify appropriate water uses to be achieved and protected, set criteria to protect those uses, and establish provisions to protect water quality from contaminants. A water quality standard consists of three basic elements:

- designated uses of the water body (e.g., water supply, aquatic life, recreation, agriculture)
- water quality criteria to protect designated uses (specific numeric pollution concentrations and narrative requirements)
- an antidegradation policy to maintain and protect existing uses and high-quality waters

#### 4.1.1 Designated Uses

When specifying designated uses, states are required to consider the use and value of water for public water supplies; protection and propagation of fish, shellfish, and wildlife; recreation in and on the water; and agricultural, industrial, and other purposes, including navigation. Most states use a classification system based on those requirements. Due to the large number of waters for which states are required to designate uses and in keeping with the antidegradation policy of the CWA, states typically designate the most protective use possible, even when monitoring data do not confirm that such a use is being achieved.

#### 4.1.2 Water Quality Criteria

Water quality criteria include both narrative and numeric criteria. Narrative criteria are general protective statements that usually specify that water be free from specific conditions, such as concentrations of pollutants that impair aquatic life. Narrative criteria are always supplemented by numerical criteria for specific physical, chemical, and radiological characteristics of the water. These criteria are estimations of concentrations of chemicals and degree of aquatic life toxicity allowable in a water body without adversely impacting its designated uses. States and the EPA determine both acute and chronic water quality criteria in fresh and salt waters.

Most numeric criteria are derived from toxicity test data compiled by EPA in a national database. In toxicity test studies, fish and benthic macroinvertebrates are exposed to known concentrations of a chemical. The short-term (acute) and long-term (chronic) effects of the exposure are measured, and the results are used to set water quality criteria protective of the most sensitive species.

#### 4.1.3 The Role of Water Quality Standards at Mining Impacted Sites

Mining sites typically contain both traditional and nontraditional pollution sources. Discharge of AMD from adits, shafts, and abandoned waste piles provides point sources of contaminants to receiving surface waters, while waste piles and mining-impacted groundwater contribute nonpoint source pollution to receiving streams.

As with other industries, active mining operations must comply with the CWA. Active mines with a point source discharge are required to obtain a permit under the National Pollutant Discharge Elimination System (NPDES) program. A NPDES permit sets limits on the amount of various pollutants that a source can discharge in a given time and are usually set to allow achievement of water quality standards in the receiving stream. Storm-water discharge permits and best management practices are common methods of addressing nonpoint sources at active mining operations.

Unfortunately, many streams are impacted by both point and nonpoint sources of pollution from historic and abandoned mining operations. In cases where mining impacts are severe or widespread, reclamation of such sites is accomplished under federal or state environmental programs such as Superfund. However, due to the large number of abandoned mines and the lack of viable entities to address pollution from such site, pollution control regulations such as those found in the CWA are applied rarely or only when cleanup activities are initiated.

The presence and application of water quality standards can complicate reclamation of abandoned mine sites and the use of innovative technologies at such sites. Although specific issues may vary from site to site, both large (Superfund) and small sites are affected. Water quality standards–related issues impact reclamation of abandoned mine sites in several ways, including the following:

- requirement to fully comply with strict water quality standards and not allow partial water quality improvements
- designation of water bodies with the highest possible use qualification regardless of monitoring data to determine whether use is being achieved
- near-complete reliance on numeric criteria to represent and be protective of a highly complex and variable aquatic ecosystems
- use of broad, jurisdiction-wide use classifications and lists of associated chemical criteria that lack precision and can inadvertently result in either a lesser or greater level of protection than was actually intended when the water quality standards were adopted

The CWA and most states allow for setting site-specific standards based on toxicity testing or related methodologies. Common methods used to develop site-specific standards include the following:

- water effects ratio procedure
- recalculation procedure
- resident species procedure

Although these procedures allow for flexibility to tailor water quality management options to specific watersheds, the cost of obtaining these data, as well as the cost of conducting all the potential biological and chemical tests required, is often considerable. With any system unable to meet effluent standards, EPA recognizes through its

The National Oil and Hazardous Substances Pollution Contingency Plan preamble states that a technical Impracticality determination should be based on "...engineering feasibility and reliability, with cost generally not a major factor unless compliance would be inordinately costly."

(55 FR 8788, March 8, 1990)

many years of experience that restoration to at least drinking water quality may not always be achievable due to limitations of available remediation technologies. In these cases EPA must evaluate whether groundwater restoration at Superfund and Resource Conservation and Recovery Act groundwater cleanup sites is attainable from a technical and practical perspective. For information on technical impracticability see “Technical Impracticability for Ground Water Cleanups” at [www.epa.gov/superfund/health/conmedia/gwdocs/tec\\_imp.htm](http://www.epa.gov/superfund/health/conmedia/gwdocs/tec_imp.htm).

## 4.2 Trading

Water quality trading is a recent approach to achieve water quality goals more efficiently. Trading is based on the reality that different sources in a watershed can face very different costs to control the same pollutant. Trading programs allow facilities facing higher pollution control costs to meet their regulatory obligations by purchasing environmentally equivalent pollution reductions from another source at lower cost, thus achieving the same water quality improvement at lower overall cost.

Total maximum daily limits (TMDLs) are developed to improve and protect watersheds that are currently impaired (water quality is such that it affects designated uses, for example, fisheries). The limits are unique to each watershed and basically define the total amount of material (e.g., copper) that can be discharged into the watershed. If the current load exceeds the TMDL, no new discharges are allowed. Loads in historic mining districts are often very high, and uses are affected. Some states have allowed mining companies to treat discharges adjacent to their operation to reduce the total load to the watershed. By treating adjacent historic discharges as well as the new discharge, the total load with new mining is less than the original load, and the overall quality of the watershed is improved.

## 4.3 Good Samaritan Legislation

The proposed Environmental Good Samaritan Act is intended to encourage landowners and others to reclaim abandoned mineral extraction lands and eliminate water pollution caused by abandoned mines, oil and gas wells by protecting those who volunteer to do such projects from civil and environmental liability. A model act by the American Legislative Council can be viewed at <https://www.heartland.org/Article.cfm?artId=8270>.

Any landowner who provides access to the land without charge or compensation for a reclamation or water pollution abatement project is eligible for protection under the Environmental Good Samaritan Act. Additionally, any person, corporation, nonprofit organization, or government entity that participates in a project is eligible for protection if they meet the following conditions:

- provide equipment, materials, or services for the project for no profit
- did not cause or create the abandoned mineral extraction land or water pollution
- were not ordered by the state or federal government to do the work
- are not performing the work under a contract for profit, such as a competitive bid project or a government-financed construction contract
- are not the surety that issued the bond for the site



Typical conditions that are suitable for land reclamation projects include abandoned mine pits and underground mine entrances, refuse piles, dangerous high walls, structures or equipment from past mineral extraction operations, sites where the bonds were forfeited and unplugged oil and gas wells.

Pennsylvania's Good Samaritan Law states, "A landowner or person who voluntarily provides equipment, materials or services at no charge or at cost for a reclamation project or a water pollution abatement project in accordance with this chapter [see text box below] may be immune from civil liability...." (see Pennsylvania Title 27, Part VI, Subpart C, Chapter 81. Good Samaritan, <http://members.aol.com/StatutesP7/27C.Cp.81.html>).

This chapter is intended to encourage the improvement of land and water adversely affected by mining and oil and gas extraction, to aid in the protection of wildlife, to decrease soil erosion, to aid in the prevention and abatement of the pollution of rivers and streams, to protect and improve the environmental values of this Commonwealth and to eliminate or abate hazards to health and safety. It is the intent of the General Assembly to encourage voluntary reclamation of lands adversely affected by mining or oil or gas extraction. The purpose of this chapter is to improve water quality and to control and eliminate water pollution resulting from mining or oil or gas extraction or exploration by limiting the liability which could arise as a result of the voluntary reclamation of abandoned lands or the reduction and abatement of water pollution. This chapter is not intended to limit the liability of a person who under existing law is or may become responsible to reclaim the land or address the water pollution or anyone who by contract, order or otherwise is required to or agrees to perform the reclamation or abate the water pollution. (Part 8103)

Pennsylvania provides a project proposal worksheet ("Environmental Good Samaritan Project Proposal," [www.depweb.state.pa.us/growinggreener/lib/growinggreener/5600-pm-mr0020.doc](http://www.depweb.state.pa.us/growinggreener/lib/growinggreener/5600-pm-mr0020.doc)) for applicants to complete and submit to the state Department of Environmental Protection, Regional Mining Office for review and approval.

## 5. RECOMMENDATIONS

### 5.1 Outstanding Questions

- Is there adequate funding for studies and demonstrations to determine the effectiveness of the emerging technologies?
- How can we better understand the benefits and limitations of application of these emerging technologies?
- Can state and federal regulatory agencies take a fresh look at the current laws and rules to finding ways to facilitate mine waste cleanups? A partial cleanup may be beneficial over the short term.
- Connecting remedial source controls for primary and secondary media might achieve end-use protection objectives and reduce toxicity over time (an approach partially used at the Kennecott Utah Copper Corporation site in Utah to address other mine-related impacts).

Until questions and hindrances are addressed, federal and state remedial budgets will continue to be strained because the implementation of standard treatment options may be cost-prohibitive.

## 5.2 Mine-Impacted Waters

### Issue

Mining-impacted waters may be difficult to treat cost-effectively to levels protective of human health and the environment.

### Solution

The ITRC Mining Waste Team will investigate, using case studies of field or laboratory tests, new or emerging technologies to treat constituents of mining-impacted waters. Following the collection of data and information on a suite of potentially available treatment technologies, the team will evaluate their performance relative to existing or recommended treatment goals. Since these technologies will in all likelihood hold some unique features and be unfamiliar to consultants and the regulatory community, the team will develop appropriate ITRC guidance and associated Internet-based training.

The team has tentatively concluded that, to protect human health and the environment and encourage treatment of mining-impacted waters, some regulatory flexibilities should be considered applicable to specific problems. The team will investigate the need and appropriateness of these regulatory flexibilities and formulate alternative recommendations to encourage cleanup of mining-impacted waters in a cost-effective and timely manner.

## 5.3 Solid Mining Waste

### Issue

Solid mining waste is not a specifically regulated waste and involves huge volumes of material. The volume of material alone makes some techniques for minimizing the risk unreasonably costly. On the other hand, the exposure posed by direct and indirect ingestion of some of this waste is a major health concern.

### Solution

The team will investigate, using case studies of field or lab tests, new or emerging technologies to minimize the threat from solid mining wastes. Following the collection of data and information on a suite of potentially available treatment technologies, the team will evaluate their performance relative to existing or recommended treatment goals. Several of the categories requiring investigation are as follows:

- covers and capping
- excavation, treatment and disposal
  - land application
- reuse
  - regulations prevent transporting materials off site
- reining (beneficiation)
  - emphasis on regulatory flexibility

- liability of the source after re-mining
- transportation of the product and waste
- chemical stabilization
- cyanide heap leach detoxification
- in-place treatment
  - passivation
  - immobilization

Since these technologies will in all likelihood hold some unique features and be unfamiliar to consultants and the regulatory community, the team will develop appropriate ITRC guidance and associated Internet-based training. The team has concluded that, to protect human health and the environment and encourage treatment of solid mining waste, some regulatory flexibilities should be considered applicable to the problem. The team will investigate the appropriateness of these regulatory flexibilities and recommend an appropriate solution within the guidance document.

#### **5.4 The Relationship Between Mine-Impacted Waters and Mining Solid Waste**

##### Issue

The entire affected system should be considered during the assessment of a site. Remediation, mitigation, or management of a particular media (e.g., mining-impacted waters, soils, process waste) in isolation from other contaminated media may not provide an optimal solution or offer a net environmental benefit.

##### Solution

Net environmental benefit analysis can be an effective alternative to evaluate the overall benefit remediation delivers. The ITRC Mining Waste Team should evaluate the net environmental benefit analysis (and similar analyses) and provide an objective evaluation of its ability to improve the selection of an appropriate remedial alternative to protect human health and the environment. Regulatory flexibility may be required to base outcomes on improved health and environmental conditions, regardless of the compliance standards which are often based on contaminant concentrations.

#### **5.5 Preventing Solid Waste and Water Pollution During the Active Mining Process**

##### Issue

Building on members' past experience, the team suspects that the management of waste and by-products of the mining process can improve. There are a number of issues that prevent or minimize full advantage of these management techniques.

##### Solutions

The ITRC Mining Waste Team should investigate any barriers to taking full advantage of pollution prevention technologies/techniques during the mining process, including the reentrance/redevelopment of existing mining properties. The team will clearly delineate any

barriers and recommend solutions to allow use of the resource while still providing equal or better protection of human health and the environment (see Burckle 2006). This effort will also include a review and evaluation of any state and federal environmental Good Samaritan laws.

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**Appendix A**  
**State Mining Issues**

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## STATE MINING ISSUES

### **Vermont**

*John Schmeltzer*

Vermont's major issues are abandoned mines generating acid mine drainage (AMD) and regulatory barriers to addressing AMD. Vermont has three mine sites on the National Priority List (NPL). The Superfund requirement to meet applicable or relevant and appropriate requirement (ARARs, i.e., water quality standards at end of pipe) is challenging, if not impossible. Also, Vermont has an abandoned asbestos mine and would be interested to know what kind of reclamation, if any, has been done at asbestos mines sites in other states.

AMD in Vermont is mostly from copper but includes nickel and some iron; no lead.

Vermont has a small mine reclamation/cleanup program and relies heavily on EPA Superfund to address problems. Meeting the end-of-pipe standards for water treatment is an unreasonable goal for AMD cleanup. We are trying to reduce the copper load to <450 µg/L.

Vermont simply doesn't have the resources to properly evaluate proposed alternatives during cleanup. The state needs a decision tree to help understand the applicability and limitations of various technologies to address AMD and other mine-related environmental problems.

The State Historic Preservation Office (SHPO) has placed a high value on tailings piles from historic mining practices; however, they continue to contribute to contamination. The amount of tailings is about 12 acres, and to preserve them the office would have to help control the AMD. So far EPA has spent \$800K toward historic preservation at one site. The large amounts of precipitation in Vermont contribute to AMD in tailings piles, generating around 3 million cubic yards of mine tailings.

Additionally, Vermont has asbestos mining resulting in 42 million tons of tailings. The major concern is erosion and sedimentary migration of asbestos. Airborne threats exist as well but are still being assessed. Mining ended in 1993, and the state is still defining the threat.

### ***Comments/Questions for Vermont***

- Pennsylvania convinced EPA Region 3 to establish AMD as a nonpoint source, therefore avoiding the barrier created by the end-of-pipe standards.
- Utah also contends with historical preservation issues periodically when dealing with its lead, copper, silver, gold, and other metal-mining legacies.
- Minnesota: One site is trying to blend a structure in with the surrounding areas.

## Missouri

*Julieann Warren*

Past and present lead mining has occurred in 38 counties in southern Missouri, and smelting has occurred in St. Louis and Kansas City. In addition, other heavy-metal mines like zinc and barite typically had lead ore closely associated with the other metals. There were three main mining districts in Missouri: (1) Southeast Missouri Lead District, which includes the Old Lead Belt and the currently active Viburnum Trend; (2) the Tri-State District, which includes several counties in southwest Missouri, Cherokee County, Kansas; and Ottawa County, Oklahoma; and (3) the Central District, which produced much less ore than the other two and was centered around the Lake of the Ozarks. Contamination of residential properties, groundwater, private water wells, and/or streams has been documented at 12 former lead mining or smelting sites. Lead-contaminated sites have also documented children with elevated blood-lead associated with exposure to site media, mainly soil. Several of these sites are very large, covering significant percentages of entire counties.

**Taken together, the impacted area from lead mining in Missouri could exceed any other state's total acres of Superfund sites.** Unlike most other hazardous waste sites in the state, mining smelting sites result in real, direct exposure and heavy metal poisoning of people and wildlife. This effect is due in part to the historic and widespread nature of the contamination. People and wildlife are living in or in intimate contact with the contaminated areas. The policy dilemma related to these sites is whether the state and EPA should aggressively pursue investigating more and more new sites when state, federal, and private remedial funds to address the problems are scarce. According to a report issued to the Government Accounting Office by EPA Region VII, it will cost approximately \$1.345 billion to clean up the lead mining and smelter sites in Missouri.

### *Comments/Questions for Missouri*

- Kimberlee Mulhern from the U.S. Army Corps of Engineers pointed out the Good Samaritan legislation proposed by President Bush is viable; however, new owners turn into Potentially Responsible Parties (PRPs), which is a definite barrier to its full implementation. The Good Samaritan program is a voluntary cleanup program. Kimberlee sent the URL for the March 30<sup>th</sup>, 2006 testimony by John Mudge of Newmont to Committee on House Transportation and Infrastructure Subcommittee on Water Resources and Environment regarding good Samaritan Legislation: [www.knowledgeplex.org/news/156933.html](http://www.knowledgeplex.org/news/156933.html)
- Along with the Western Governor's Association, Utah is looking at the benefits of the Good Samaritan program. Doug Bacon (Utah) provided the testimony of Joseph G. Pizarchik (Director, Bureau of Mining and Reclamation, Pennsylvania Dept. of Environmental Protection) and Paul Frohardt (Administrator, Colorado Water Quality Control Commission, on behalf of the Western Governor's Association and the Western States Water Council.
- Pennsylvania has an active state voluntary program to treat coal mine drainage. The state seems to be leading the effort in the United States.
- Reduce the load without meeting water quality standards.
- Companies tend to become PRPs if they try to be a Good Samaritan. Many states are adopting it as law.

## **Utah**

*Douglas Bacon, Department of Environmental Quality, Division of Environmental Response and Remediation, slide outline*

### ***Abandoned Mines***

- Ownership/viable PRPs often in question
- Physical safety hazards (i.e., dump stability, open shafts, and adits)
- Prevalent across the Western United States
- Environmental contaminants
  - Water contamination
  - Mercury
  - Adjacent land redevelopment and illegal incursions

### ***Regulatory Constraints to Environmental Cleanups***

- Clean Water Act constraints under Section 402 prevent potential partial cleanups.
- No provision under 402 to protect a party from becoming legally responsible for continued migration or discharge of contaminants.
- Disincentive to have pollution concerns partially addressed.

### ***Groundwater Impacts***

- Acid mine drainage, process water infiltration, leach water infiltration, and mine runoff have led to a legacy of groundwater impacts.
- As a limited resource, groundwater is increasingly relied upon to provide sources of drinking water in the western United States.
- Present a myriad of technical, financial, and logistical concerns that have to be addressed to ensure appropriate cleanup.
- Regulatory involvement, coordination, and roles fluctuate and add a level of complexity to the PRP's response work.
- Passive treatments versus active treatment alternatives raise concerns on local, state, and federal levels.
- Length of time for cleanup does require recognition of changes to applicable laws.
- Provision of long-term operation, maintenance, and replacement of control and treatment components needs to be ensured and overseen.
- Institutional controls and knowledge can be difficult to ensure over the length of the cleanup work.

### ***Land Use and Redevelopment***

- Current soil cleanups consider current land uses.
- Consideration of redevelopment pressures is not often incorporated during risk management decisions.
- Population growth places redevelopment pressure on viable land resources near metropolitan areas.
- Future surface contamination cleanups often are left as a legacy to be addressed when the land use changes.

### ***Underlying Constraints***

- State's meaningful involvement/regulatory coordination

- Sustainable financial resources to cover response actions (short- and long-term) and provision of oversight
- Protection of remedies, redevelopment, institutional controls, and institutional knowledge
- Disincentives because of current regulatory constraints
- Competing jurisdictions and/or interests
- Community support and ownership

### *Comments/Questions for Utah*

- Physical hazards don't rank high in alternative identification and selection.
- EPA doesn't deal with physical hazards.
- Oklahoma recently participated with agencies and U.S. Army Corps of Engineers developing a subsidence identification report. Turned into a buyout program and relocation of residents.
- Is Kennecott abandoned or active? Departments see it differently. Note: Kennecott is still very active. Currently, the annual financial statements document that the mine will continue to operate the open pit until 2017. After this time frame, Kennecott and Rio Tinto will consider if investment into underground mining is a viable option. Some portions of Kennecott's property are not active, while some still are. Remediation oversight is provided by EPA Region VIII and Utah Department of Environmental Quality, Division of Environmental Response and Remediation for both active and nonactive areas. Reclamation of nonactive areas is provided by the Utah Division of Oil, Gas, and Mining. The distinction between active/nonactive areas is sometimes blurred.
- There is a remining operation in southern Utah. Constellation Copper is a copper-recovery operation using both heap-leach and solution extraction/electrowinning processes in Lisbon Valley, Utah (approximately 72 km southeast of Moab). The operation plans to produce approximately 1 million pounds of copper per year. There are also a multitude of active mine claims across the state, but operations at the claims are limited.

### **Oklahoma**

*David Cates, Oklahoma*

Tar Creek Mine was the governor's preference for cleanup in 1980. It covers 40 square miles and has miles of underground mine workings at multiple levels (100–400 feet below ground level). The workings had to be dewatered since they are in the shallow aquifer. After mining ended, the workings filled with water, and an acidic mine pool was formed that now exists above the regional source of drinking water.

Mine tailings are locally known as "chat." Chat is a heterogeneous mix of mainly chert particles with minor amounts of carbonates ranging from clay-sized up to 3/8 inch. It contains Pb and Zn with the highest concentrations in the fine-sized fraction of chat. Larger particles make up more than 90% of the estimated 75 million tons now existing at the site. The original amount is estimated to have been 165 million tons. Historically, much of the chat has been used for ballast, fill, and construction material (including aggregate in asphalt and gravel roads). After mining terminated, a mine pool formed containing 50–75 thousand acre/feet of water. The pH is around 6.0 with high TDS relative to fresh water (i.e., 3000 mg/L), high sulfate with Fe, Zn, Mn, Pb, and Cd occasionally above maximum contaminant levels. Groundwater discharges began in 1979

that impacted Tar Creek with pH 3 water and metals loading. Metals loading of the sediments have migrated into downstream rivers and lakes.

Superfund organizes operable units around media. Operable Unit (OU) #1 is groundwater and surface water. In the mid-1980s deep wells were plugged, and diversion structures were constructed to reduce or eliminate discharges. The diversions did not work to stop the discharges, and EPA invoked fund balancing ARAR waivers. The discharges continue even at high concentrations exceeding water quality criteria for receiving streams.

OU #2 is related to mine waste in residential areas and was identified by high blood-lead levels in area children in the early 1990s. The mine waste operable unit is subdivided into residential properties (OU #2) and nonresidential chat piles and mill ponds (OU #4). To date approximately 2100 residential properties with lead above 500 ppm have been remediated at a cost of \$100–120 million. The state approves the use of chat for some industrial construction (encapsulated in asphalt or concrete) and has conducted several land reclamation projects with subaqueous disposal of mine waste into subsidence features. EPA is evaluating subaqueous disposal of chat and injection of chat fines back into the flooded mine workings. OU #5 deals with sediments and is led by EPA Region 7. Recently EPA Regions 6 and 7, some federal agencies, the states in the tri-state area, and several tribes collected water and sediment samples along the Spring River and its watershed. This is an example of a good cooperative effort among multiple agencies.

In 2000 the state task force recommended a wetland or nature preserve for the site, but a technical review by the president's Council on Environmental Quality didn't approve the recommendation. At least part of the basis was that the wetland might create an attractive nuisance. In 2003 the Oklahoma plan for Tar Creek was funded with \$45 million to do land reclamation, passive treatment of mine water discharges, paving chat roads, and plugging open mine shafts mainly in the perimeter areas of the site.

There are also many physical hazard issues (subsidence and mine shafts) at the site outside the jurisdiction of EPA. Based on a multiagency subsidence evaluation report, a voluntary buyout of several small communities in the area is being conducted that even includes some of the residential properties already remediated.

In summary some of the major issues include the following:

- The large size of the site (with both solid mine waste and mining-impacted waters).
- Multiple agencies have jurisdiction making agency cooperation essential, especially in the early years.
- Native American ownership has made the Bureau of Indian Affairs a PRP along with several of the mining companies.
- Lowered property values prevent owners from securing loans (related to environmental hazards of the contaminants and physical hazards of subsidence).
- Oklahoma and EPA will work toward removal of the Superfund designation from some of these areas that have been remediated.
- Cost of remediation is costly to the state through the matching provisions and operations and maintenance requirements.
- Waiver of ARARs using the fund balancing waiver has hampered future remedial actions for Tar Creek that would address environmental issues.

- Some contaminants are nonhazardous yet still impact the beneficial use of drinking water.
- Need for something similar to Superfund for large non-coal-mining sites that would enable funding for abandoned sites and better coordination in multiagency jurisdictions.

### *Comments/Questions for Oklahoma*

- The ability to delete partial properties from Superfund designation seems to vary from EPA Region to Region.
  - Doug Jamison: Colorado has been successful deleting portions of the site from Superfund designation before the entire site is completed. They have conducted partial deletions.
  - Linda Elliot: Vermont has also done partial deletions from Superfund designation.
- Applicable Relevant and Appropriate Requirements
  - Doug Jamison: How did the state respond to use of the ARAR waiver?
  - OK did support it originally with lowering of the beneficial use designations of Tar Creek but has changed its position. It has limited if not eliminated some of the ability to obtain resources to protect the water quality. Of the original \$45 million federal funding for the Oklahoma Plan for Tar Creek in 2003, only about \$25 million went to remediation (including land reclamation, plugging mine shafts, paving of chat roads, and passive treatment systems for mine water discharges). The other \$20 million is being redirected to property buyout to address public safety issues based on the subsidence evaluation. Unfortunately, some of the sites which were remediated are on the buyout option. A senator redirected the funding at a congressional level.
  - Paul: Is surface water runoff and erosion from chat piles an environmental issue?
  - David: Yes, however, compared to mine water discharges, the contaminant loading is less. It is important to construct good passive treatment systems for the mine water discharges now and pursue runoff and erosion impacts using interim measures and pilot projects in conjunction with OU #4 remediation and chat-washing operations.
  - Paul: Does the reuse of chat require they separate fine and coarse material?
  - David: It is not a requirement, but the courser material is typically separated to be used for aggregate in asphalt. The sand-size fraction separated during washing is ideal for super-pave asphalt designs. When the specs call for fines, it is more cost-effective to use local sources for fines rather than transport chat fines to the construction site. In chat-washing operations, chat fines are removed as suspended solids and are placed in retention (settling) ponds. The water is recirculated through a series of settling ponds and reused to wash the chat (total retention system with no discharges). The ponds will require a cap in the future, which concerns the state from an O&M cost standpoint. Some local county road-building projects use pile run chat as aggregate without any particle separating.
  - Paul: If chat is encapsulated in a matrix, the metals exposure is not an issue.
  - David: Yes.
  - Paul: Is remining an option?
  - David: It has been evaluated for the concentrates of fines in the mill ponds, but nothing economical has been found. The state is concerned that if you cap a pond then find a method in the future to remining the fines, do you now want to rip up a cap and remining or leave it well enough alone? Even though mine shafts are sources of recharge and discharge, they are generally considered by EPA as safety issues not addressable under Superfund unless it is a worker safety issue.

- Paul: Yard remediation isn't particularly popular. When remediation begins, they get immediate complaints. Is it more popular when the PRP conducts the yard remediation vs. EPA?
- David and Julieann: Yes. Similar remediation in Missouri was led by PRP and went more smoothly.
- Julieann: Have you looked at phosphate treatment for cleanup (soil stabilization). Missouri is considering phosphate treatment on 40 sites and is looking for others who have done this successfully.
- David and team seem to have no experience in this.

## **Minnesota**

*Paul Eger*

Iron mining is currently the major mining activity in the state. The state also has significant copper, nickel, platinum, and palladium resources, and with the recent increase in metals prices, the potential for sulfide mining in the state has increased dramatically. The state is currently developing an Environmental Impact Statement on a proposed open-pit Cu, Ni, platinum, palladium mine. This mine will generate about 400 million tons of waste rock, and about 50% will have the potential to be acid generating. The state is looking at pollution prevention techniques for newly open mines. It currently uses wetland remediation systems for mine drainage treatment, plus innovative capping techniques to minimize infiltration. In Minnesota, iron mining does not currently require financial assurance for reclamation, but new nonferrous operations will need financial assurance. Mineral prices are increasing the interest in what were low-concentration reserves. Stockpile drainage is being treated using constructed treatment wetlands. All are surface-flow wetlands.

### ***Comments/Questions for Oklahoma***

- Valentine Nzengung: What are the most critical parameters to ensure application of constructed wetland?
- Paul: Balancing hydrological analysis and good metal-loading analysis. Source reduction may be necessary as well. Adequate area is the main criteria for effective treatment. Some systems were installed without enough area, and they are now required replace create additional substrates in the wetland. Contaminants are Cu, Ni Co Zn.

## **Pennsylvania**

*Jeff Painter, State POC, Pennsylvania Department of Environmental Protection, Office of Energy and Technology Deployment*

Mostly issues are legacy issues (see testimonies from Joseph G. Pizarchik, Director, Bureau of Mining and Reclamation, Pennsylvania Department of Environmental Protection for a more detailed description of Pennsylvania mining issues). Two primary issues exist:

- AMD: (from Pizarchik's statement) According to a 1995 EPA Region III list, 4486 miles of streams were affected by mine drainage in Pennsylvania, Maryland, Virginia, and West Virginia; 3158 were in Pennsylvania. These discharges have a significant impact on Pennsylvania's streams and rivers.
- Abandoned coal-mined lands reclamation: pits, ponds, highwalls, and other physical hazards. The state feels current (active) mining practices are adequate.

### ***Comments/Questions for Pennsylvania***

- Dave Mosby: Is funding sufficient to address the abandoned mine land issues?
- Jeff: Abandoned mine land funding is insufficient.
- Paul: You have a lot of active watershed groups. Has that increased since the Good Samaritan law?
- Jeff: Yes, there are several hundred watershed organizations. Pennsylvania offers various project funding sources for watershed cleanups and deployment of innovative technologies. For example, Energy Harvest contains components of deployment that result in air/watershed cleanup, but it has to have some energy-related component to the technology. Other cleanup-driven technologies successfully deployed include those for the recovery of iron (and other metals), which is used to provide pigments for materials such as crayons and paints/stains.
- Paul: Are you looking at the concept of heat pumps?
- Jeff: Yes, we would consider related proposals.
- Paul: Does all proposed mining require an acid mine accounting?
- Jeff: Minnesota has a requirement for proposed coal mines that there is an acid base accounting required.
- Paul: If it is acid generating in Pennsylvania, are they still allowed to mine?
- Jeff: The Bureau of Mining and Reclamation could better answer that. My program crosses over into other DEP programs, particularly when there is airshed/watershed improvements coupled with energy-related matters, such as waste coal reuse and utilizing mine discharges for electric power generation. For example, Pennsylvania has explored proposals for the installation of electric-generating turbines at effluent points at (abandoned) mine discharges such as the 40K gpm discharge at the Jeddo mine drainage tunnel.

### **Colorado**

*Doug Jamison and Mary Scott*

Geographically, metals mining follows the Colorado mineral belt. Coal mining is in the northeast plains and some mountainous areas. Active mining includes the Victor gold mine and the Henderson moly mine. The Climax moly mine is planned to open in 2009. Colorado also has several coal mines. Colorado has 20 NPL sites; 7 are mining and 1 smelter. Sizes range from a single mine (Smuggler) to a 400 square mile Central City Study Area. Within the watersheds there exist 1500 abandoned mines, including prospect holes, etc. There are also what is considered NPL-caliber sites. These include an ASARCO site where a cleanup was done without Comprehensive Environmental Response, Compensation and Liability Act (CERCLA), two sites in Breckenridge, and three Natural Resource Damage Assessment sites (one in southwest Colorado and two near the Denver area). Colorado's Voluntary Cleanup Program has several



small sites as well. Colorado has a number of active Uranium Mine and Mill Tailings Recovery Program sites.

### *Issues*

- Acid mine drainage (long-term treatment, e.g., Clear creek and Summitville): The state spends an average of \$1 million annually to run a single treatment site. The state has a hazardous waste fund (funded with fees within hazardous waste tipping fees), but at current spending the fund will have been spent. The state needs to find more efficient ways of treatment and additional capacity. What treatment technologies are available to upgrade and increase efficiency? Spending projections are based on EPA cost-sharing formula.
- Mine pool management issues: Currently, mine water runs down the tunnels and is treated in a treatment plant. How do we better manage the mine pool at the source? We would like to understand the regional water travel so we can minimize the amount of water requiring treatment. Colorado doesn't have a constant flow because of the seasonal variation in weather conditions. Typically, the high water-flow season occurs April 30 through June 30.
- Stream standards: The Superfund sites in the state confront the agencies with an inability to achieve baselines standards for streams. Colorado normally tries to modify a stream standard to something which is achievable. The goal is to set a protective standard based on the aquatic community but also considers the costs. This process normally takes years to work through. The stream standard modification is based on a species list, which may not be an appropriate for that stream. What do other states do? Is there a methodology to establish a nonnumeric stream standard that is protective of the existing biological community? Adjudication and water rights also affect a stream standards change.
- Colorado has hundreds of mine waste piles. A typical remedial measure is to remove the material and place it in a landfill or cap the pile in place. Colorado needs new cap designs and the ability to evaluate the functionality of the cap and determine when maintenance of the cap is no longer required.
- Tailing dewatering: Colorado has little experience in dewatering tailings piles. The state normally reviews trend analyses of surface water quality in and near tailings pile. Are there information and data on passive waste pile dewatering, including the time frame? What about active dewatering technologies?
- Colorado normally constructs an armored cap and revegetates waste piles. A soil cover is placed on a mine waste pile, amendments are added, and monitoring is performed. There appear to be a variety of soil amendments and opinions on proper soil amendments. Lime is often used to buffer the acid potential of the soil. Do mine waste treatment sludges contain pharmaceuticals?
- Lead toxicity issues: Average action level is 500–1000 ppm. At California gold sites, action level is 3500 ppm based on the risk assessment, and that seems to be appropriate. Action levels have been achieved. The key point for lead toxicity issues and blood-lead levels is education. Colorado is curious about how other states deal with residual risk.
- Overall, the sheer numbers of sites requiring attention in Colorado is overwhelming.

### *Comments/Questions for Colorado*

- Dave: Missouri has common problems. Experience with bioavailability, Soils amendments, pharmaceuticals in sewage sludge. Could be a focus group of this team. They recommend sludge as a good reclamation material. Institutional controls have no good answer.

- Colorado: The state has environmental covenants provisions. The current culture dislikes the regulatory environment.
- Missouri has had resistance, but it normally subsidizes.
- Colorado: The state is still dealing with lead issues in Leadville. ASARCO has declared bankruptcy.
- Missouri: EPA did a cleanup and a pretty organized community effort. Jasper County. County doesn't have money.
- Colorado: The state has a trust but is spending down, and the argument is on how to spend it.
- Dave: Water quality standards. (Metals) specific species not present in the standard-setting process. Metals are going down when they reevaluate the standard setting process.
- Colorado: Are you familiar with the recal method to establish water quality standards?
- Colorado's voluntary cleanup best addresses small sites. It is a small, nonregulatory program. The final evaluation is based on a determination, "Have they done what they said they were going to do?" Higher fees to conduct cleanup within the program can obtain more state oversight, which can result in a stronger letter of approval.
- Minnesota has a voluntary cleanup program and an accompanying closure letter.
- Utah has a Voluntary Cleanup Program which does result in a certificate of completion and waiver of liability. Applicant has to pay for the oversight by the state. Utah has used it in development areas.
- Missouri has had no mine sites go through voluntary cleanup. One site tried but was a failure.
- Utah and Colorado like the accelerated time frame available in Voluntary Cleanup Programs.
- Minnesota: Do you have watersheds groups that (clear creek) assist in the cleanup, e.g., Good Samaritan Act? Work in associate with a larger foundation. Normally is pretty minimal cleanup that goes into Voluntary Cleanup Programs.
- David: Do you have any site with passive treatment?
- Colorado: Clear Creek Central City Silver mine at 9500 feet with neutral water discharging from the adit. Passive treatment (wetland) performed well for one year but after that it failed. To make it a full-scale treatment facility would approach active treatment. One or two more were installed as well but also failed primarily due to the lack of maintenance of the treatment systems. This begins to approach a more active treatment where it is dependent on adequate if not large maintenance. Space in a mountainous terrain also restricts adequate system design.
- EPA Headquarters expects to change their policy on operation and maintenance related to passive treatment of AMD. Through first 10 years, plants are cost-shared 90/10 with EPA. Possible after construction the cost share may revert to 100 % state.
- Dave Mosby: What can we do about companies going bankrupt?
- Doug Jamison: ASARCO is large, and they have two sites. Where they circumvented the CERCLA process, they were successful. ASARCA was in, and then through bankruptcy they were out, and the state has to take on the responsibility for cleanup. When bankruptcy is filed, all work on cleanup is halted. What happens when they emerge from bankruptcy? Before bankruptcy they were funding cleanup from the trust. Bankruptcy froze the trust.
- Dave: Missouri is putting in seven claims on ASARCO for cleanup. They need to define their liabilities so any purchasers can identify all liabilities.
- Paul: Canadian companies set up a fund, which is progressively funded (mineral land royalty fund exists, but the states don't get any of it.) Reclamation is bonded, but the reclamation folks have a tough time dealing with cleanup. Higher metal prices are used to encourage them to deal with bonding during the high side.
- David Cates: Regarding AMD, can you recover metals during the treatment process?

- Colorado: No one has ever demonstrated it. At the Breckenridge site local companies are trying to use a sulfide PPT process for metals recovery and sludge maintenance process.
- Paul: Heard of a Hydromet process being tried by Biotec (a company at Breckenridge site).

## **Maine**

*Rob Peale, Senior Geologist, Maine Certified Geologist, Maine Department of Environmental Protection (MDEP)*

Maine has many small- to medium-size metallic mineral deposits in different areas of the state, including some massive sulfide deposits associated with volcanic belts discovered as recently as the late 1970s. Maine promulgated rules for metallic mineral exploration, advanced exploration, and mining in 1991 during a period when it appeared that some of these deposits could be economically exploited. Based on economic conditions, the lack of mining infrastructure and culture, and a perception among some in the mining industry that Maine is “anti-mining,” it is not likely that any of these deposits will be exploited in the near future. One possible exception is that current gold prices might revive interest in a gold-rich gossan associated with the Bald Mountain massive sulfide deposit in Portage.

Maine also has historic metal-mining areas in the towns of Blue Hill and Brooksville on a coastal peninsula between Belfast and Mount Desert Island. Mine-related contamination in these towns has impacted ecological and drinking water resources. Active mining in these areas began in the late 1800s and ceased in the 1970s.

Based on the lack of currently active metal mines and mining development, the major metallic-mining issues facing Maine are related to historic mines where remediation never took place or was not effective. The following outlines describe the issues in these historic mining areas.

### *Blue Hill Mining District*

- Located in town of Blue Hill.
- Primarily volcanogenic massive sulfide deposits containing copper, zinc, lead, etc.
- Includes the Kerramerican Mine discussed separately below.
- Includes the Douglas Mine and several other smaller mines operated in the 1880s where no closure or remediation has taken place. No viable responsible parties have been identified for these mines.
- Waste deposits include extensive waste rock piles, use of waste rock in roads and driveways, some smelter slag.
- Unclosed adits, shafts, and waste rock piles present physical hazards on residential properties and along roads.
- Many private homes on private water supplies located throughout the area.
- Extensive sampling of private water supplies by MDEP showed some ARD impacts to wells and springs. With only one or two exceptions, ARD contamination does not generally exceed primary drinking water standards.
- Visual observations and surface water studies associated with the Kerramerican Mine environmental investigation indicated extensive impacts to surface waters draining the district including to Second Pond. There appear to be measurable impacts to biota as well as

exceedance of ecologically based water quality standards. The Carleton Stream system draining the Blue Hill Mining District exceeds EPA TMDLs and is on the EPA TMDL list.

#### *Kerramerican Mine*

- Also known as Blackhawk Mine.
- Volcanogenic massive sulfide deposits exploited as recently as the 1960s and 1970s for copper and zinc.
- Underground mine with entrance along shore of Second Pond. Deposit extended under pond.
- Waste deposits include extensive waste rock and tailings with limited vegetated cover.
- Site has been characterized hydrogeologically, and an ecological risk assessment was performed. A long-term monitoring plan is operating for surface water and groundwater.
- Remedial program has been approved by MDEP including natural and geotextile covers, alteration of drainage, and some consolidation of waste rock. No active treatment of water is planned.
- Noranda Mining has managed characterization and remedial planning and is in negotiations with Black Hawk Mining over cost-sharing issues. Work has been done by Noranda on a voluntary basis and overseen by the MDEP's Uncontrolled Sites Program.
- Negotiations are also in progress to turn over environmental liabilities and remedial activities to a third party.
- New residential water supply development in one area southeast of the site is at risk from a portion of the tailings disposal area which extends into two separate groundwater sheds. Cause of groundwater and surface water contamination is hypothesized to be waste rock in the core of a tailings dam.
- Remediation should decrease ecological impacts from the Kerramerican Mine but probably will not eliminate all the impacts due to other unremediated areas in the Blue Hill Mining District. Much of the area may still not meet water quality standards.

#### *Callahan Mine*

- Located in Brooksville, Maine. Also known as Harborside or Penobscot Mine.
- Volcanogenic massive sulfide exploited primarily for copper and zinc.
- Open pit mine located in estuary. Streams were redirected, and the estuary was drained to allow mining. Following shutdown, dam structures were removed, and estuary allowed to redevelop. Salmon and oyster farming started in estuary but shut down due to economic conditions and high metals concentrations.
- Waste deposits located between estuary and ridge to south include waste rock piles and tailings deposit behind dam. Original cover materials have mostly eroded away. Rough roads to top of waste deposits make them accessible and popular due to good views of estuary and bay.
- Characterization of the site is in progress under the oversight of EPA Superfund Program and the MDEP. Majority of ecological studies have been completed and hydrogeological investigation will begin in summer of 2006.
- State of Maine is only viable responsible party at this time due to its ownership of the estuary and receipt of royalties. Maine Department of Transportation is acting as responsible party, and State of Maine is funding work. Coeur d'Alene Mines is PRP but not willing to accept any responsibility.
- There is an extensive "mine layer" of grey silty material with high metals concentrations underlying much of the estuary and adjacent tidal cove. Generally covered with up to several inches of recent sediment.

- Three to four residential drinking water supplies adjacent the open pit area show weak to strong evidence of ARD impacts. One well exceeds primary drinking water standards for lead and cadmium and has pH as low as 4.6. Risk of additional drinking water supply impacts in the future is low due to topography and location of mine and waste areas relative to developable land.
- Initial surface water sampling from mine waste areas indicates neutral rock drainage with high metals concentrations. Site is generally dry with very limited perennial drainage or seepage. Ore zone was reported to be carbonate rich.

### *Comments/Questions for Maine*

- Paul: Are the contaminated sediments from runoff or pit sediment?
  - Most of the estuary are underlain by contaminated sediments.
  - There is a gray layer called the “mine layer” with high metals values. Metal concentrations decline about 2 feet below this layer.
  - While dewatering the mine and discharging into the cove, they contaminated the sediment.
- Dave Mosby: Time period
  - 60–early 70s discovered in 1880s.
  - Volcanic—pyroclastic, agglomerates, submarine volcanic vent associated with a calcareous carbonate rock.
  - It was closed in 1972.
  - Much of the contamination was released during active mining. The contaminated sediments have been redistributed.
  - Drainage of the area goes into the estuary. There are several residential wells. One shows high Zn, Cd, and Pb.
  - There is one acid mine drainage.
  - Capping will likely be a remedy for the waste rock piles.
  - Maine is the responsible party for the Callahan Mine.
  - Waste pile volume/size (1 million tons of ore).
  - Biotic impact—uncertain but the analytical work includes some data gaps. We will update the data next year.
  - What is the risk driver? Ecology, human health, and the local residents’ outcry.
  - The site is fenced.
  - Beautiful recreational area. Some are using the mine problems to prevent further development.
  - No land value impact.
  - Metal prices alone will dictate redevelopment?
  - Waste piles (dry) are barren.
  - The ore was milled and concentrated on site.
  - Maine has medium- to small-size mines.
  - Not a strong tradition in Maine.

**Appendix B**  
**Mining Waste Team Contacts**

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## **Appendix C**

### **Acronyms**

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## ACRONYMS

ALD	anoxic limestone drains
AMD	acid mine drainage
ARAR	applicable or relevant and appropriate requirement
ARD	acid rock drainage
BOD	biological oxygen demand
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
COC	contaminant of concern
CSM	conceptual site model
CWA	Clean Water Act
EPA	(U.S.) Environmental Protection Agency
GCL	geocomposite liner
ITRC	Interstate Technology & Regulatory Council
LBOS	limestone-buffered organic substrate
NPDES	National Pollution Discharge Elimination System
NPL	National Priority List
OU	operable unit
PRP	potentially responsible party
RAPS	reducing and alkalinity-producing system
SLS	sodium lauryl sulfate
TDS	total dissolved solids
TMDL	total maximum daily limit