EPA/DOE MINE WASTE TECHNOLOGY PROGRAM

Technology Testing for Tomorrow's Solutions

2005 ANNUAL REPORT

MINE
WASTE
TECHNOLOGY
PROGRAM

EPA DOE Montana Tech Implemented by MSE Technology Applications, Inc.

...cover photos

Belmont Mine in Butte, Montana

Lilly-Orphan Boy Mine near Elliston, Montana

Students at Landusky Pit as part of a Mine Waste Technology Program Workshop

Highwall Stabilization using Furfuryl Alcohol Resin Sealant at Golden Sunlight Mine near Whitehall, Montana

Lee Mountain Mine near Rimini, Montana

EPA/DOE

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2005 ANNUAL REPORT

Prepared by:

MSE Technology Applications, Inc.
200 Technology Way
P.O. Box 4078
Butte, Montana 59702

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National Risk Management Research Laboratory
Cincinnati, Ohio 45268

and

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INTRODUCTORY MESSAGE

BACKGROUND

The Mine Waste Technology Program (MWTP) is a congressionally mandated program that was started in 1991. It is an interagency agreement between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE). The program is headquartered at the Mike Mansfield Advanced Technology Center in Butte, Montana. The technology demonstrations are performed by MSE Technology Applications, Inc. (MSE), while basic research is performed by Montana Tech of the University of Montana and other academic institutions. The National Risk Management Research Laboratory in Cincinnati, Ohio, performs the technical oversight of the program. DOE performs program administrative oversight.

BALANCE

Mining is essential to maintain our way of life, but significant investment is necessary to mitigate the effects that mining has on the environment and ensure sustainable development of the mineral resources of the United States.

For the past 14 years, MWTP has been committed to developing, evaluating, and deploying technologies that provide innovative solutions to successfully treat active and remote abandoned mines at substantial cost savings compared to traditional technologies.

2005 RESULTS

The MWTP activities have been very diverse in recent years, and 2005 is no different. Highlights are summarized below.

- During the summer of 2004, MSE implemented modifications to the Integrated Passive Biological Treatment at the Surething Mine in Montana to alleviate plugging problems and improve the removal of the most recalcitrant metal—manganese. These modifications were successful and results through the summer of 2005 indicated that over 90% of the manganese is now being removed. The investment by MWTP to modify this system will lead to a better understanding of how to design, operate, and maintain passive biological systems for treating acid rock drainage at remote sites.

- Over the past 3 years, the Anchor Hill Pit at the Gilt Edge Mine National Priorities List (NPL) site near Deadwood, South Dakota, has been the site of a joint effort by EPA Region 8 and the MWTP. During 2005, over 10 million gallons of treated water was discharged from the Anchor Hill Pit after meeting South Dakota discharge standards. The project's aim is to demonstrate and evaluate an innovative in-situ process for treating approximately 70 million gallons of acidic mine water containing high levels of dissolved metals, selenium nitrate, and sulfate. EPA estimates that in-situ use of this technology will avoid 20% to 50% of the operational costs associated with a conventional water treatment plant. Full-scale use of the pit in an operational mode is anticipated in the future.

- Since 2002, the MWTP in collaboration with the Deer Lodge Valley Conservation District and the U.S. Department of Agriculture/Natural Resources Conservation Service's Bridger Plant Materials Center has been evaluating acid/heavy metal tolerant plant species near Anaconda, Montana. The soils at the test site have a pH of about 4.5 with several hundreds of parts per million of arsenic, copper, lead, and zinc. Several seed releases have resulted from this project to ensure that suitable species exist for reclamation efforts in the Northern Rocky Mountain Region.

More results attained by the MWTP in 2005 are presented in this annual report.

PARTNERSHIPS

Partnerships were continued with private industry, academia, and other government agencies. Within EPA, the program is coordinated and teamed, where appropriate, with the Superfund Innovative Technology Evaluation (SITE) program to leverage the funding and maximize the effectiveness of both programs. Strong collaboration occurred between the MWTP and EPA Regional Offices, particularly Regions 8 and 10. The EPA also has strong interaction, cooperation, and assistance from the mining teams in the EPA Regional Offices.

FUTURE PROGRAM DIRECTION

During 2005, the MWTP evolved into an issues-driven program focused on working with other entities to move toward solutions for one of the largest environmental issues facing the United States and the world. A major challenge for the MWTP will be meeting the need for this work with the decreased, limited funding available.

In 2006, coal projects will be added. By combining the knowledge base and research and development work on wastes from coal and metal mining, a synergism will be developed that would avoid duplication of effort and would lead to the development of an increased number of new strategies for dealing with mine waste. With this annual report, the MWTP recognizes its major accomplishments and looks forward to continuing to provide innovative, economical, sustainable solutions for hard-rock mine waste problems in the United States.

Diana R. Bless
EPA-NRMRL MWTP Project Officer

Helen O. Joyce
MSE MWTP Program Manager

INTRODUCTION

Presently, there are more than eighty abandoned mining sites on the U.S. Environmental Protection Agency's National Priorities List (NPL). Many of these sites are categorized as mega-NPL sites (those that cost more than $50 million to cleanup). Mining waste generated by active and inactive mining production facilities and its impact on human health and the environment are a growing problem for government entities, private industry, and the general public. The nation's reported volume of mine waste is immense. Primary sources of heavy metal releases to the environment are mining and mining-related activities based on industry's reporting in the most recent Toxic Release Inventory (TRI). It found that the hard-rock mining industry released 3.5 billion pounds of toxic pollution in 1998, almost half of all toxic pollution released that year in the United States. Total estimated remediation costs for these sites range from $32 to $72 billion.

Because many of the mines are composed of sulfide minerals, the production of acid rock drainage is a common problem from these abandoned mine sites. The combinations of acidity, heavy metals, and sediment have severe detrimental environmental impacts on the delicate ecosystems in the West. It is estimated that 40% of watersheds in the West have been negatively impacted by mining activities.

In recent years, environmental practices employed by the mining industry have improved considerably. Installation of best management practices for control of stormwater runoff, improvements in treatment of wastewater, better management of tailings and waste rock, and more efficient metal recovery technologies have all reduced environmental impacts from mining projects, but wastes resulting from mining activities remain a significant issue.

PROGRAM OVERVIEW

MISSION

The mission of the Mine Waste Technology Program (MWTP) is the development of cost effective technologies to achieve cleanup of mine waste with substantial cost savings compared to traditional technologies. Identification and implementation of these technologies is necessary to improve the economics for current and future mining opportunities in the United States and to ensure that sustainable practices are implemented at these mines.

In accomplishing this mission, MWTP develops and conducts a program that emphasizes treatment technology development, testing and evaluation at bench- and pilot-scale, and an education program that emphasizes training and technology transfer.

HISTORY

The MWTP is a congressionally mandated program that was started in 1991. It is administered through an interagency agreement between the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) and is based out of Butte, Montana. The MWTP is implemented by MSE Technology Applications, Inc. (MSE), which performs technology demonstrations. Basic research is performed by Montana Tech of the University of Montana (Montana Tech) under subcontract to MSE. EPA's National Risk Management Research Laboratory (NRMRL) provides technical program oversight, while DOE's Western Environmental Technology Office performs administrative oversight.

The fiscal year (FY) 1991 Congressional Appropriation allocated $3.5 million to establish a pilot program in Butte, Montana, for evaluating and testing mine waste treatment technologies. The MWTP received additional appropriations of $2.25 million in FY91, $5.0 million in FY95, $2.7 million in FY96, $5.0 million in FY97, $6.0 million in FY98 and FY99, $4.3 million in FY00, $3.9 million in FY01 and FY02, $3.5 million in FY03; $3.9 million in FY04, and $2.1 million in FY05.

A budget summary is presented to reflect the expenditure of dollars during the fiscal year. MWTP funds support many entities including EPA, DOE, MSE, Montana Tech, other universities, private businesses, and other public entities.

Through the MWTP, over 70 distinct projects have been completed or are currently being performed by MSE and Montana Tech. Nineteen projects were active during 2005. A summary of each active project is included in this 2005 Annual Report.

MANAGEMENT ROLES AND RESPONSIBILITIES

Management of the MWTP is specified in the Interagency Agreement between EPA and DOE. The roles and responsibilities of each organization represented are described below. The MWTP organizational chart is presented in Figure 1.

U.S. ENVIRONMENTAL PROTECTION AGENCY

The Director of NRMRL in Cincinnati, Ohio, is the principal EPA Office of Research and Development representative on the Interagency Agreement Management committee. NRMRL personnel are responsible for technical direction, quality assurance, budget, schedule, and final scope definition.

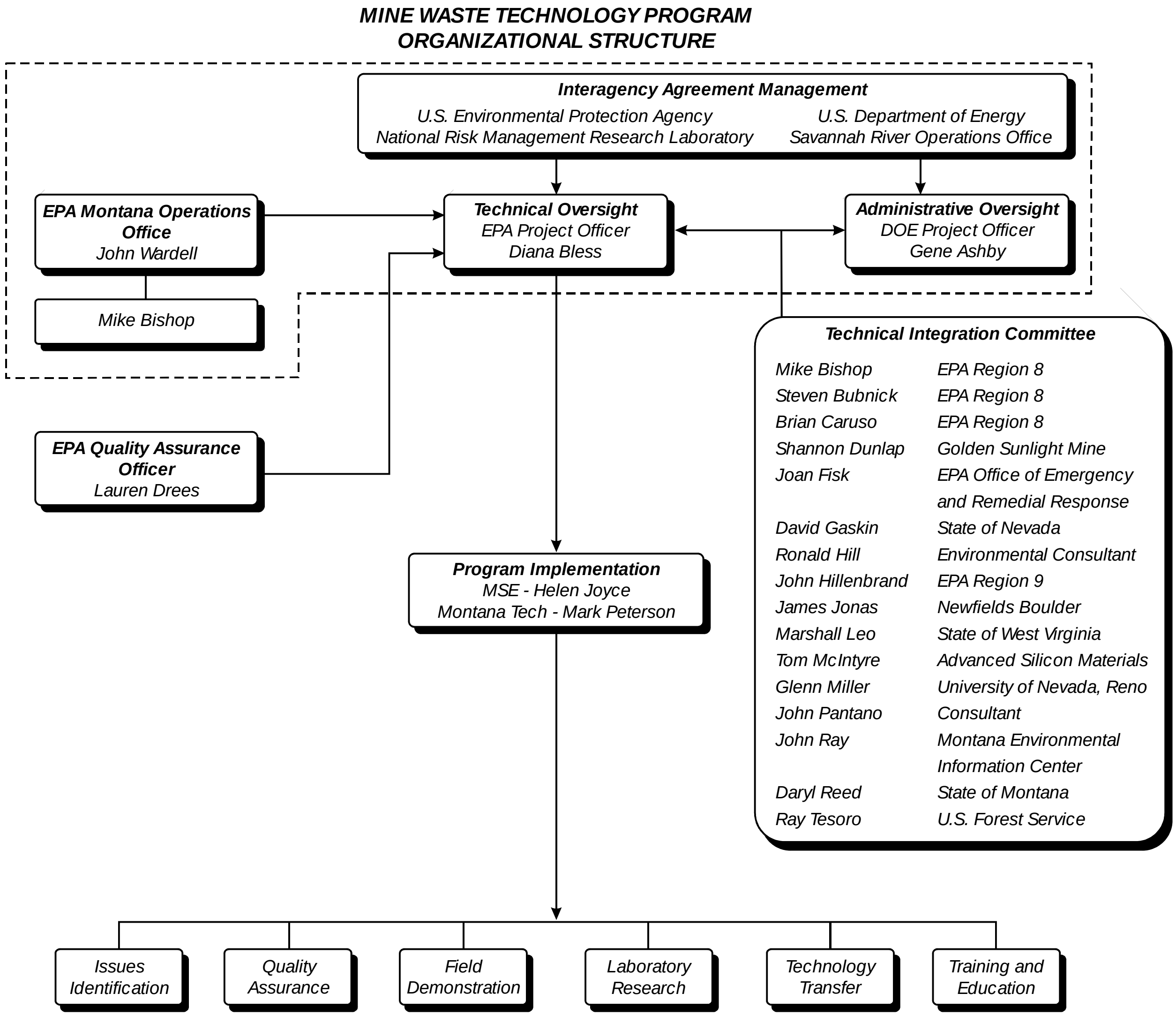

Figure 1. MWTP organizational chart.

U.S. DEPARTMENT OF ENERGY

The Director of the Western Environmental Technology Office Laboratory (WETO) is the principal DOE representative on the Interagency Agreement Management committee. WETO personnel provide contract oversight for the MWTP with assistance from the Savannah River Operations Office. MSE is responsible to WETO for adherence to environmental, safety and health requirements; regulatory requirements; National Environmental Protection Act requirements, and implementation of all projects.

MSE TECHNOLOGY APPLICATIONS, INC.

MSE, under contract with DOE, is the principal performing contractor for MWTP. The MSE MWTP Program Manager is the point of contact for all MWTP activities. The Program Manager is responsible for program management and coordination, project status reporting, funds distribution, and communications.

An MSE project manager has been assigned to each MWTP project and is responsible for overall project direction, control, and coordination. Each project manager is responsible for implementing the project within the approved scope, schedule, and cost. MSE also performs oversight of activities at Montana Tech.

MONTANA TECH OF THE UNIVERSITY OF MONTANA

As a subcontractor to MSE, Montana Tech is responsible to the MSE MWTP Program Manager for all work performed outlined in relevant contracts. Work performed by Montana Tech in 2005 included basic research projects and training and education components of the program.

TECHNICAL INTEGRATION COMMITTEE

A request for proposals goes out periodically when funding is available. The Technical Integration Committee (TIC) is responsible for reviewing and ranking incoming proposals. The TIC is comprised of technical experts from EPA and cooperating agencies, academia, environmental stakeholders, and industry and their consultants. Final reports are additionally peer-reviewed in accordance with EPA's strict policy for scientific products.

There are priority areas for research. Most MWTP projects can be categorized under one of the following issue areas: source control; acid drainage/water treatment; trace metal removal; remote locations; pit lakes; modeling; or cyanide destruction. Occasionally, projects not easily categorized are performed under the miscellaneous activities category.

COMMUNICATION AND COOPERATION

The MWTP will be making a concerted effort to improve communication/cooperation with other entities with similar missions, such as the Rocky Mountain Regional Hazardous Substances Research Center, the Acid Drainage Technology Initiative, and International Network for Acid Prevention. A collaborative effort will be necessary to address such a huge problem.

The MWTP continued to support the Superfund Program in 2005 by performing demonstrations at mining-related National Priorities List mega sites that included:

- Anaconda Company Smelter (Montana);
- Silver Bow Creek/Butte Area (Montana);
- Upper Tenmile Creek Mining Area (Montana);
- Gilt Edge Mine (South Dakota); and
- Bunker Hill Mining and Metallurgical (Idaho).

MWTP has strong interaction, cooperation, and assistance from the mining teams in the EPA Regional Offices, especially Regions 7, 8, 9, and 10. The program also has strong cooperation from industry, and a substantial amount of support is leveraged from mining companies hosting technology demonstrations.

Another willing partner is the academic community (such as Montana Tech of the University of Montana, University of Montana–Missoula, Montana State University–Bozeman, and other academic institutions) that can conduct the more basic type of research related to kinetics, characterization, and bench-scale tests at minimal cost to the program, while at the same time providing environmental professionals to meet the demands of industry, academia, and the regulatory community.

ISSUES IDENTIFICATION

Issues identification activities focus on identifying mine waste technical issues and promising innovative treatment technologies. Issues and technologies are screened and prioritized in volumes related to a specific mine waste problem/market.

Following completion of a volume, appendices are prepared. Each appendix links a candidate technology with a specific site where such a technology might be applied. The technology/site combinations are then screened and ranked.

Volumes completed to date are listed below. To obtain copies of these volumes, send an email to mwtp@mse-ta.com.

- Volume 1, Mobile Toxic Constituents—Water and Acid Generation
  - Appendix A–Remote Mine Site
  - Appendix B–Grouting
  - Appendix C–Sulfate-Reducing Bacteria
- Volume 2, Mobile Toxic Constituents—Air
- Volume 3, Cyanide
  - Appendix A–Biocyanide
- Volume 4, Nitrate
- Volume 5, Arsenic
- Volumes 1-5 Summary Report
- Volume 6, Pyrite
- Volume 7, Selenium
- Volume 8, Thallium
- Volume 9, Pit Lakes
- Volume 10, Mercury

More recently, issues have been identified through literature reviews and contacts with EPA, state regulatory entities, and industry representatives.

QUALITY ASSURANCE

The objective of this activity is to provide support to individual MWTP projects by ensuring all data generated is technically defensible and that it supports the achievement of project objectives. To accomplish this, a Quality Assurance Project Plan (QAPP) is written for each project and approved by EPA prior to data collection. Other functions of this activity include assessing projects, validating data, implementing corrective action, and reporting to program/project management.

EPA approved the MWTP Quality Management Plan in 200l, which was updated during 2005. NRMRL assesses the MWTP Quality System every 3 years and performs one or more technical system reviews annually. During 2005, NRMRL performed a quality systems audit, as well as two technical systems reviews. No findings resulted from these audits.

FIELD DEMONSTRATIONS

Field demonstration topics were chosen after a thorough investigation of the associated technical issues was performed, the specific wasteform to be tested was identified, peer review was conducted by TIC, and sound engineering and cost/scheduling determination of the demonstration were formulated.

MSE continued eight field demonstrations during 2005. Five field demonstrations were completed. Montana Tech performed two field demonstrations during 2005.

BENCH-SCALE RESEARCH/TESTING

For technologies not ready for field demonstration or to provide research projects for Montana Tech graduate students, bench-scale research is also performed. MSE had two active bench-scale projects, while Montana Tech had four ongoing bench-scale research projects during FY05.

TECHNOLOGY TRANSFER

MSE is responsible for preparing and distributing reports for the MWTP. These include routine monthly, quarterly, and annual reports; technical progress reports; brochures; CDs; and final reports for all MWTP activities. Final reports are additionally peer-reviewed in accordance with EPA's strict policy for scientific products. MSE also publicizes information developed under MWTP in local, regional, and national publications. Other means of information transfer include public meetings, workshops, and symposiums.

Several MWTP personnel presented papers at conferences across the United States to communicate MWTP successes and lessons learned to ensure the user community is aware of ongoing activities. MWTP personnel also regularly serve on organizing committees for conferences with a mine waste focus.

EDUCATIONAL PROGRAMS

MWTP continued to educate graduate students in the Mine and Mineral Waste Emphasis Program during 2005. This interdisciplinary program contains elements of geophysical, hydrogeological, environmental, geochemical, mining and mineral processing, extractive metallurgical, and biological engineering. Graduates of the program are fast becoming leaders for industry and regulatory agencies helping to promote technology usage and acceptance worldwide.

Through traditional college coursework, short courses, workshops, conferences, and video outreach, MWTP educates professionals and the general public and brings the specific information being generated by bench-scale research and pilot-scale technologies to those who work in mine- and mineral-waste remediation. The MWTP also provided workshops under the Native American initiative.

LOOKING AHEAD TO 2006

During fiscal 2006, the following new projects will be funded under the Mine Waste Technology Program (MWTP).

RESOURCE RECOVERY FROM FLOODED UNDERGROUND MINE WORKINGS--BUTTE, MONTANA (MSE)

Beneficial recovery of auxiliary resources from flooded underground mine workings in mine waste impacted areas will be investigated. Specifically, the feasibilities of recovering irrigation water and geothermal heat from the Belmont mine will be determined. A century of historic mining practices in the highly mineralized Butte, Montana, district resulted in many hundreds of miles of flooded underground mine workings. For almost three decades, land developers disregarded this area. However, in the past few years, the area has become home to several public facilities. Continued redevelopment of the area could benefit significantly from a low cost supply of irrigation water and a low cost heat supply. This MWTP project will determine the cost-effectiveness of utilizing underground water for nonagricultural irrigation and employing closed loop heat exchanges for supplementary building heat.

TECHNOLOGY TRANSFER – SELENIUM (MSE)

The Selenium Removal Treatment Alternatives project conducted a demonstration of several technologies for removing selenium to drinking water standards from selenium-bearing groundwater. The technologies evaluated included a catalyzed cementation process developed by Dr. Larry Twidwell at Montana Tech in Butte, Montana; a biological process developed by Applied Biosciences, Inc. of Park City, Utah; and ferrihydrite adsorption, the U.S. Environmental Protection Agency's (EPA) designated Best Demonstrated Available Technology (BDAT) for selenium removal from water. Both the cementation and biological processes showed better performance than ferrihydrite adsorption, and both processes have been improved upon since the Selenium Removal Treatment Alternatives project was completed in 2000. The purpose of this project is to investigate the applicability of, and hopefully implement, these technologies to remove selenium from leachate from coal mining-related valley fills in West Virginia.

INFLUENCE OF ANIONS ON THE REMOVAL OF ARSENIC BY COPRECIPITATION AND LONG-TERM STABILITY OF FERRIHYDRITE AND MODIFIED FERRIHYDRITE (MONTANA TECH)

The main objective of this proposed project is to examine change as a function of depth in the geochemistry and stable isotope composition of mine shaft water in Butte, Montana. This project is a continuation/outgrowth of two previous MWTP projects, which focused on the geochemistry and stable isotope composition of mine water in the Berkeley Pit lake and the Kelley Mine shaft, Anselmo Mine shaft, and Steward Mine shaft of the East Camp flooded mine workings, and the West Camp Extraction Well that drains the West Camp flooded mine workings. These previous projects, in conjunction with ongoing monitoring by the Montana Bureau of Mines and Geology (MBMG), have documented the incredible diversity in the chemistry of mine waters in the

Butte district, as well as the various processes, both biological and geological, that have influenced these waters. However, a good understanding exists of vertical changes in chemistry of the Berkeley Pit lake, very little information exists on similar changes in chemistry or microbiology of the flooded mine shafts. Typically in the past, MBMG has collected samples of mine shaft water from a depth of 100 feet below static water level. Although some field parameter profiles for the top 300 feet of several shafts were obtained in 2000, no water quality samples were collected. Thus, no information is available for field parameters or water samples at depths greater than 300 feet, despite the fact that the vast majority of the underground mine workings are at depths between 1,000 and 5,000 feet. Monitoring to date has only characterized a two-dimensional slice of the very top of the mine water complex—more than 90% of the accessible water in the flooded complex has never been sampled.

VERTICAL GRADIENTS IN BIOGEOCHEMISTRY OF FLOODED MINE SHAFTS IN THE BUTTE, MONTANA FLOODED MINE COMPLEX (MONTANA TECH)

Arsenic removal by adsorption on a ferri-oxyhydroxide (ferrihydrite) surface is EPA's BDAT. This technology is used throughout the industry for removing arsenic from wastewaters; however, long-term stability of ferrihydrite is questionable. During the MWTP project, *Modified Ferrihydrite for Enhanced Removal of Arsenic from Mine Wastewater*, it was observed that the removal of arsenate from solution appeared to be greatly influenced by the choice of the ferric salt compound chosen as the iron reagent. This was unexpected and has not been observed or evaluated by other investigators and could be a significant development in the understanding of the EPA BDAT ferrihydrite coprecipitation and adsorption technologies. This project will have two major components: 1) evaluating the influence of the anions on the removal of arsenic from wastewater and drinking water; and 2) evaluating the long-term stability of ferrihydrite and aluminum modified ferrihydrite.

ACCOMPLISHMENTS

DESCRIPTIONS, ACCOMPLISHMENTS, AND FUTURE DIRECTION

This section describes accomplishments of the Mine Waste Technology Program (MWTP) and includes project descriptions, major project accomplishments during 2005, and future project direction.

ACTIVE PROJECT DESCRIPTIONS

The following sections describe each MWTP project that was active during 2005. The projects are categorized by the primary issue addressed. Issues addressed by projects in 2005 included: Source Control; Sustainability; Acid Drainage/Water Treatment; Trace Metal Removal; Pit Lakes; Modeling; Cyanide Destruction; and Miscellaneous Activities.

SOURCE CONTROL

ELECTROCHEMICAL TAILINGS COVER

Primary Issue Addressed: Source Control

Secondary Issue Addressed: None

Project Site: MSE's Mike Mansfield Advanced Technology Center in Butte, Montana

Collaborating Entities: MSE, Enpar Technologies, Inc., Placer Dome's Golden Sunlight Mine

Cost Share: In-kind services provided by Golden Sunlight Mine.

Project Description

This project is being conducted at the MSE Technology Applications, Inc. (MSE) test facility in Butte, Montana. The purpose of the demonstration is to gather performance information for the electrochemical cover technology developed by Enpar Technologies, Inc., of Guelph, Ontario, Canada.

Fresh, nonoxidized tailings along with soil cover were transported from the Golden Sunlight Mine (GSM) near Whitehall, Montana. Lined, in-ground test cells, each equipped with a leachate collection system, along with a common sprinkler system, were constructed at MSE's test facility. Two test cells, loaded with tailings and capped with soil cover, were constructed as identical control cells, receiving no electrochemical cover treatment. Two additional test cells, loaded with tailings and capped with soil cover, were constructed as identical test cells and were equipped with the electrochemical enhancement. Equal amounts of water were applied to all four test cells through the summers of 2004 and 2005, since their installation in September 2003. Leachate was pumped from each test cell to maintain an artificial water table and to provide water for analytical purposes. Leachate water quality was monitored by regular sampling and analyses. Oxidation of the acid-generating tailings in all four cells is being assessed primarily by monitoring sulfate concentrations, along with specific conductance measurements. Sulfate mass produced by the two cells equipped with electrochemical cover treatment will be compared to that produced by the two control cells with no electrochemical cover treatment. It is anticipated that the two control cells will show higher sulfate concentrations and higher specific conductance, resulting from tailings oxidation. The field installation was to be monitored for 2 years, at which time, it will be dismantled and the tailings returned to GSM.

Status

Accomplishments in fiscal year (FY) 2005 included resuming irrigation and leachate collection in the spring of 2005, conducting multiple sampling events, and regularly checking the functional health of the electrochemical covers. Leachate analytical results were inconclusive at the end of FY05; data from all four cells indicated that soluble salts were still being flushed from the tailings with no noticeable indications of tailings oxidation. Dismantling of the field system was scheduled for early FY06, with the tailings to be returned to the Golden Sunlight Mine, and tailings samples obtained for acid-base accounting analysis to assess the effect of the electrochemical cover. It is anticipated that the acid-base accounting analyses will provide an indication of the performance of the electrochemical cover relative to the control cells.

PASSIVE REMEDIATION OF SULFIDE WASTES: A STUDY OF OXYGEN DIFFUSION THROUGH COMPOSITE BARRIER COVERS

Primary Issue Addressed: Source Control

Secondary Issue Addressed: None

Project Site: Montana Tech of the University of Montana

Collaborating Entities: Montana Tech

Cost Share: None

Project Description

The main objective of this project is to determine oxygen flux through one component of a typical barrier cap at a variety of moisture conditions. Oxygen flux through topsoil will be determined through a combination of percent oxygen measurements and the use of theoretical equations. The goal is to develop a best fit curve to describe oxygen diffusion under differing moisture conditions.

The theory behind oxygen movement is that oxygen will move through material such as waste rock by processes called diffusion and/or convection. Based on this process, several researchers have presented methods of modeling to represent this movement. A recent method for determining oxygen movement through a geosynthetic clay liner (GCL) system was developed in 1999 by a group of Canadian researchers. In a 1999 paper entitled *Evaluation of Diffusive Gas Flux through Covers with a GCL* (Aubertin), the researchers specifically set out to determine the rate of oxygen movement through GCLs. Earlier methods of modeling were only able to estimate the influence of a GCL on oxygen diffusion. In this study, the GCL was specifically examined to estimate the diffusion. This method does not produce a depth of oxygen diffusion; rather, it produces a rate at which oxygen diffuses per year and an acceptable range for the prevention of acid rock drainage (ARD) production. A critical parameter in determining acid generation is the flux of oxygen, which determines the rate of acid production through the oxidation of sulfide materials contained in the waste materials. Controlling this rate over time will control the rate of acid production. Determination of the diffusion coefficient is a key parameter in determining oxygen flux. Materials at or near saturation exhibit reduced oxygen fluxes owing to the relatively low solubility of oxygen in water and the low diffusion coefficient for oxygen in water relative to that in air.

Status

Five diffusion cells were constructed of 8-inch PVC, the cells were filled with soil and compacted to 90%, which mimics field conditions. The upper and lower reservoirs of each cell were connected to oxygen meters to record oxygen concentrations. The meter connected to the upper reservoirs also has the capability to measure carbon dioxide concentrations; thus, those measurements have also been recorded. Measurements of oxygen and carbon dioxide began in April 2005 and have been ongoing since that time. Thus far, oxygen diffusion has been studied at moisture contents of 6%, 10%, and 13%. The cells are under preparation for measuring oxygen concentrations at a moisture content of 16%. Two cells began having problems retaining moisture at 13% moisture content, and water retention became troublesome in all cells when attempting to increase soil moisture to 16%.

As expected, oxygen diffusion decreased as moisture content increased. Measured oxygen concentrations in each of the five cells were very similar at 6% and 10% moisture content. However, at 13% moisture content, one of the cells that had water retention problems had an oxygen concentration curve that differed notably from the other four cells. One unexpected finding in this project was the apparent consumption of oxygen in the cells, and a corresponding production of carbon dioxide. In an attempt to determine the origin of the oxygen consumption, the soil was analyzed for metals and sulfur content. These analyses indicated that there were neither sufficient metals nor sulfur in the soil to cause oxygen consumption. Total organic carbon (TOC) was also quantified, and a TOC content of 5 mg TOC/g_{soil} was determined. This concentration of TOC is sufficient to cause oxygen consumption. Data collected throughout this project will be used to determine an oxygen diffusion coefficient. An in-depth evaluation of the data, along with the determined diffusion coefficient will be provided in the final report, which is expected to be completed in fiscal 2006.

SUSTAINABILITY

ACIDIC/HEAVY METAL-TOLERANT PLANT CULTIVARS DEMONSTRATION, ANACONDA SMELTER SUPERFUND SITE

Primary Issue Addressed: Sustainability

Secondary Issues Addressed: Source Control, Characterization

Project Site: Research has been performed (over the past 10 years) at various locations within and adjacent to the Anaconda Smelter Superfund site. The present focus is the Moto-X site located in the Lost Creek drainage, north of Anaconda, Montana.

Collaborating Entities: MSE, Deer Lodge Valley Conservation District (DLVCD) and U.S. Department of Agriculture/Natural Resources Conservation Service Bridger Plant Materials Center (BPMC)

Cost Share: In-kind services (facilities and labor) provided by the collaborating entities; partial funding under the Montana Department of Justice's Clark Fork Restoration Fund Grant Program (2000-2004).

Project Description

Presently, grass, forb, and shrub species commercially available for reclaiming acidic/heavy metals-contaminated (A/M) soils often come from outside the Northern Rocky Mountain region. These cultivated varieties may not tolerate the climatic-edaphic stresses (in addition to A/M pollution stresses) as well as would the A/M-tolerant ecotypes indigenous to the region. Over the past decade, plant populations exhibiting A/M tolerance potential have been collected from the Anaconda Smelter Superfund Site and evaluated in laboratory, greenhouse, and field trial studies. The results to date indicate that self-sustaining plant communities comprised of native A/M tolerant ecotypes are possible. Thus, the long-term goal of this project is to formally compare the performance of local seed mixtures against comparable mixes now commercially available. If the local ecotypes (of the particular grass/forb species) are indeed best performing, they would be made available for numerous full-scale reclamation of hard-rock mine/mill/smelter sites in the region.

Status

The following activities occurred in fiscal 2005: collection and laboratory analysis of plant and soil samples from the Anaconda area; field evaluations of plant performance; and production of seeds (at the Bridger Plant Materials Center) from the most promising grass/forb accessions. Although there has been some mortality, the top performers of the 2003 and 2004 growing seasons continue to demonstrate their ability to withstand the harsh soil conditions at the Moto-X site. A local accession (9081620) of slender wheatgrass is the top performer, having average canopy cover and biomass production values of 75% and 0.82 kg dry leaf and stalk biomass (LSB), respectively. These results exceed the original project objectives of 30% to 50% and 0.1 to 0.2 kg/m^2 LSB, respectively. Other local accessions that met these performance criteria–whereas their cultivated counterparts did not–include another slender wheatgrass (9081621) and big bluegrass (9081633). All three local accessions also met the project's plant vigor and heavy metals uptake criteria.

During the previous growing seasons, the only forb/shrub species showing significant (9.5 seedlings/ft^2) emergence was winterfat Open Range Germplasm. However, after the 2005 season, the following additional plants were observed: indigenous silverleaf phacelia (9081632), Old Works fuzzytongue penstemon, Richfield firecracker penstemon, and Northern Cold Desert winterfat. The surviving plants of Open Range winterfat and the phacelia (above) exhibited good vigor, growth, and seed production.

In the seed mixture trials, the experimental mixes that contained native local source materials were far superior to the developed mixes that consisted of native nonlocal source (upland mix) and introduced cultivars (waste management areas). However, it was estimated that the majority of plants in the experimental mixtures, both upland and waste management areas, continue to be 9081620 slender wheatgrass, which was the best overall performer on this particular site.

The tissue analyses show that the heavy metal concentrations in and on the plant tissue sampled from the Stucky Ridge plots were generally within the tolerable limits for consumption by domestic livestock and wildlife.

The overall performance on the Stucky Ridge plots was quite variable, with strips running north and south that had poorer plant vigor and biomass production. The Pryor slender wheatgrass strips between replications (running east and west) exhibited waves of good and poor establishment and performance. Soil samples (0–6 in.) were taken under four plant stands of slender wheatgrass ranging from excellent to very poor in hopes of explaining this variability. It was thought that the incorporation of the amendments may have created strips with varying pH. Soil analysis for pH indicated no difference in pH (all 6.8 to 7.3) under the varying stand of slender wheatgrass. Therefore, this variability is still unexplained.

A/M-tolerant Washoe Germplasm basin wildrye (Figure 2a), Prospector's Germplasm common snowberry, and Source-Identified Old Works Germplasm fuzzytongue penstemon have been released by the BPMC. Seed from the wildrye has been distributed to two commercial growers in Montana, while penstemon seed has been distributed to one grower each in Washington and Idaho. No growers have yet shown interest in production of the snowberry.

A final project report will be released (under the Mine Waste Technology Program) in late spring 2006. Approximately $245K was awarded by the State of Montana to the DLVCD/BPMC in December 2004 to continue development of A/M-tolerant releases through 2008.

During the winter of 2006, Copperhead Selected class germplasm slender wheatgrass (9081620), shown in Figure 2b, will be submitted for release consideration to the Variety Release committee at Montana State University and to the Pure Seed Committee at the University of Wyoming. If the release is successful, G_1 seed will be made available to commercial growers in the spring of 2006.

Figure 2a. The USDA's Bridger Plant Materials Center released Foundation class Washoe germplasm basin wild rye. (Leymus cinereus is shown in photo.)

Figure 2b. The Bridger Plant Materials Center maintains the GI seed stock (slender wheatgrass shown here) for those A/M accessions exhibiting commercial potential.

Plant materials that are being considered for release in 2007 are silverleaf phacelia (9081632) and big bluegrass (9081633). Other potential releases within the next 3 years include western wheatgrass (9081968), bluebunch wheatgrass (9081636), and Wood's rose (9081638).

SUSTAINABILITY OF SUBSTRATES IN SULFATE-REDUCING BACTERIA BIOREACTORS

Primary Issue Addressed: Acid Drainage/Water

Secondary Issue Addressed: Sustainability

Project Site: Currently, a site with acid mine drainage (AMD) draining to the North Clear Creek in the town of Black Hawk, Colorado, is being considered for project implementation. Originally, the McClelland Tunnel site located in Clear Creek County, Colorado, was designated as the project site. However, due to an extended drought period, the metal load carried by the AMD at this site decreased to the level that made it unsuitable for the project investigations. Several other AMD sites located in the proximity of Golden, Colorado, were then considered and subsequently eliminated mostly because of problems with obtaining site access agreements from their owners.

Collaborating Entities: The project is implemented by MSE Technology Applications, Inc. (MSE) in cooperation with Colorado School of Mines (CSM) in Golden, Colorado.

Cost Share: EPA Region 8 has provided in-kind support, particularly with site selection/access.

Project Description

The key step in sulfate-reducing bioreactor systems is the conversion of sulfate to sulfide and the subsequent precipitation of metal sulfides. The treatment of metal-containing waters in systems that rely on sulfate reduction include wetlands, bioreactors, and permeable reactive barriers. Long-term sustainability has been a key issue for systems based on sulfate reduction.

Recent advances in understanding critical components of sulfate-reducing systems has allowed the Mine Waste Technology Program to develop a better sulfate-reducing bioreactor system that considers the issues of sustainability of sulfate-reducing activity, flow distribution, maintenance, and placement at remote sites. A modular reactive cartridge (RC) design developed by MSE will be evaluated during this project. Specifically, testing will focus on the sustainability of flow through cartridges and the functionality of a newly-formulated, organic substrate consisting of walnut shells and corn stover (the plant residual remaining after harvest of the grain).

Important factors affecting sustainability of the organic substrate are the chemical forms in which organic carbon is present in the substrate. In general, organic carbon may be present in forms of organic acids; pectin, starch, or polysachharide; cellulose; or lignin. It is expected that tracking depletion of organic carbon from the organic substrate as a function of the form of organic carbon will give important information on biodegradability of the substrate in the presence of sulfate-reducing bacteria (SRB).

Since the project was designed to test the performance of a modular bioreactor system and the sustainability and functionality of a newly formulated organic substrate, a four-module treatment system will be constructed. This system (see Figure 3) consists of four RSc (modules) configured to operate in parallel. Each RC is an 8-foot-diameter-by-7-foot-tall plastic tank with a removable cover and appropriate piping to control the AMD flow and facilitate periodic maintenance.

The RCs are filled with 5-gallon bags containing an organic substrate composed of corn stover and walnut shells. The bagging material is plastic mesh with 0.5-inch openings not to inhibit the flow. For testing, two RCs will use substrate prepared as a 1 to 1 ratio (by volume) mix of corn stover and walnut shells. Two other RCs will be filled with a 1 to 2 ratio mix of corn stover and walnut shells.

The main advantages of using an organic substrate composed of corn stover and walnut shells are listed below.

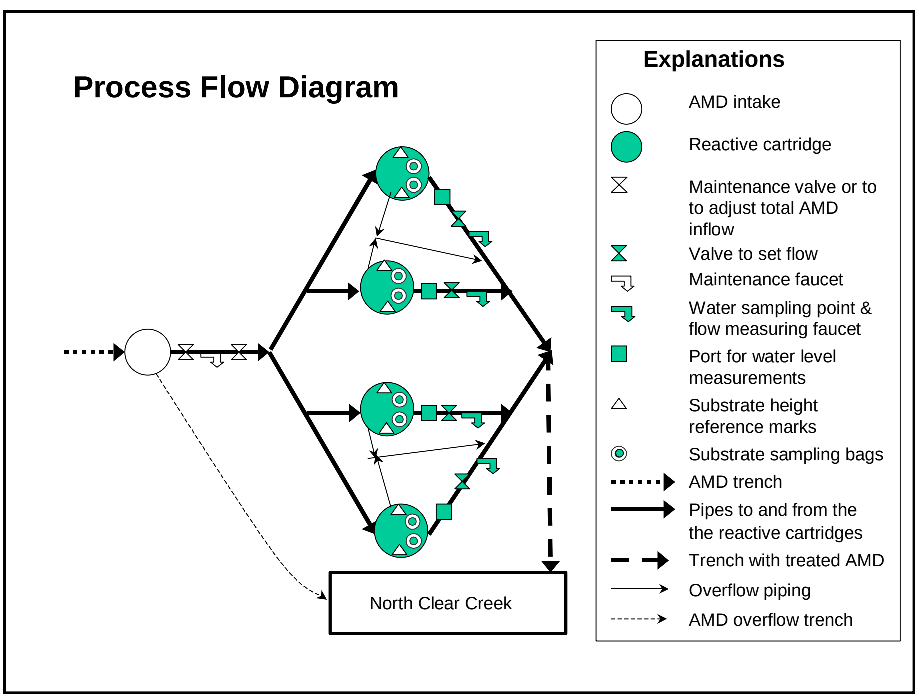

***Figure 3. Process flow diagram*.**

- Walnut shells are more recalcitrant to biodegradation; thus, they support good long-term operation of a bioreactor.
- Walnut shells provide a solid matrix structure because individual shells actually rest on each other. This structure minimizes time-driven compaction (settling) and works toward preservation of the initial permeability of the medium.
- Walnut shells contain a high percentage (56%) of total organic carbon (TOC).
- Corn stover, a widely available crop residual that remains in the field after harvesting corncobs, contains a high percentage of organic carbon in the form of cellulose that is used by cellulose degrading bacteria to produce substrates easily accepted by SRB.
- Corn stover includes nitrogen needed for healthy microbial activity.
- The easy biodegradable corn stover provides for a quick start of bioreactors and constitutes a relatively sustainable source of organic carbon for SRB, while walnut shells will provide organic carbon in the late stage of the bioreactor's operation.

Performance of the bioreactor system will be monitored by collecting and analyzing aqueous and solid matrix samples and by field measurements collected at the locations shown in Figure 3. The systems will be checked weekly for influent and effluent pH, alkalinity, rate of flow, and hydraulic head differential at inflow and outflow locations. Air and water temperature will be monitored weekly, and temperature profiles within the reactor systems will be measured monthly. Liquid samples will be collected monthly to evaluate the performance and effectiveness of the system as indicated by solution chemistry including concentration of dissolved and total metals. Solid phase samples of the organic substrate will be collected quarterly to monitor the decreases in solid phase of organic matter, TOC and its speciation, and changes in the microbial community structure.

Status

The implementation of the project is behind schedule due to climatic driven changes in the AMD composition at the original project site at McClelland Tunnel, and subsequent difficulties with obtaining site access agreements from the owners of alternative sites.

VISUALIZATION OF IN-SITU DOUGLAS FIR ROOTS AND ECTOMYCORRHIZAE IN THE CONTEXT OF PHYTO-REMEDIATION OF ACID MINE WASTES

Primary Issue Addressed: Sustainability

Secondary Issue Addressed: Characterization

Project Site: Badger Mine site, Butte, Montana, and Montana Tech Greenhouse

Collaborating Entities: Montana Tech

Cost Share: None

Project Description

Douglas fir (*Pseudotsuga menziesii*) is a coniferous evergreen tree with the capacity to colonize harsh and severe environments. Douglas fir may have physiological attributes allowing it to survive while being exposed to the potentially toxic levels of metals and low soil pH of acid mine wastes. These attributes may include fine root respiration rates indicative of an active metabolism, root turnover rates, resistance to metal toxicity, and/or ectomycorrhizal fungi associated with Douglas fir roots. For this project, the physiology of ectomycorrhizal Douglas fir will be investigated in the context of contaminated mine wastes and low soil pH. Ultimately, ectomycorrhizal fungi from the Douglas fir tree may be used in biological remediation processes and as a stabilizing agent for mine wastes. The objectives of this research are to: 1) define physiological attributes of Douglas fir trees that allow it to tolerate toxic soils; 2) determine whether the addition of ectomycorrhizal fungi provides a growth advantage for trees in these types of soils; and 3) install a minirhizotron to assess the development of Douglas fir root systems.

Status

Seedlings were planted at both the Badger Mine site and in the Montana Tech greenhouse in the autumn of 2004. In August 2005, survival rates were quantified as follows: Badger Mine site, mycorrhizal 20%, Badger Mine site nonmycorrhizal 7.5%, greenhouse mycorrhizal 90%, greenhouse nonmycorrhizal 70%. The autumn and winter of 2004 were unusually dry, which may have played a role in the poor survival rate of the Badger Mine site seedlings.

Ecophysiolgical measurements of both Badger Mine site seedlings and greenhouse seedlings began in November 2005. Flourescence and chlorophyll content measurements were completed within the month, while respiration measurements took longer due to calibration and warm-up requirements for the equipment. This extended measurement time was facilitated by harvesting entire seedlings and associated soil and keeping them alive in the laboratory.

Vegetative samples of both living and dead seedlings, along with soil samples, were submitted for metals analysis. Interpretation of analytical results is pending. An in-depth evaluation and analysis of the data will be provided in the final report that is expected to be completed in fiscal 2006.

USE OF BIOMONITORS FOR STUDYING CONTAMINATION IN RESIDENTIAL AREAS AND EFFICACY OF REMEDIATION

Primary Issue Addressed: Sustainability

Secondary Issue Addressed: Characterization

Project Site: Residential yards, Butte and Anaconda, Montana

Collaborating Entities: Montana Tech

Cost Share: None

Project Description

Nearly a century of mining and smelting activities in the Butte/Anaconda area of Montana resulted in widespread contamination throughout southwest Montana. Some of the mining impacted areas have been investigated and remediated as a direct result of the National Priorities List designations of sites in the area. Little is known, however, about the long-term health impact for residential populations exposed to contaminants on a daily basis. This project will perform a novel type of environmental health research to improve our understanding of actual, long-term exposure to widespread elevated metals concentrations in residential areas. This project will use domestic dogs as sentinel species to provide information on exposure patterns. While the overall goal is to improve our understanding of exposure to elevated metals in the environment, the following main objectives have been identified for this project to: 1) develop a simple, inexpensive biomonitoring system to characterize existing exposure patterns to contaminants in the community of Butte, Montana; and 2) help document the efficacy of localized remediation efforts using the biomonitors.

Status

Approximately 200 dogs and several cats have been sampled, mainly within Butte, completing the spatial sampling phase of this project. Four dogs have been sampled as part of the remediation campaign conducted in the Butte area. These four dogs have been sampled on several occasions, with 1 to 2 months between each sampling episode. Since sampling for the remediation campaign will take place during winter months, a control dog (a fifth dog) has been added to this phase of the project. The control dog lives at a residence that has not undergone remediation. Arsenic concentrations of sampled animals have been plotted with GIS and a spatial pattern is appearing. Dogs within the Butte Priority Soils boundary do appear to have elevated arsenic concentrations compared to dogs outside of this boundary. An in-depth final report detailing this study is expected in fiscal 2006.

ACID DRAINAGE/WATER TREATMENT

SULFATE-REDUCING BACTERIA DEMONSTRATION

Primary Issue Addressed: Acid Drainage/Water Treatment

Secondary Issues Addressed: Biological Treatment, Passive Treatment, and Remote Location

Project Site: Lilly/Orphan Boy Mine near Elliston, Montana

Collaborating Entities: MSE Technology Applications, Inc.

Cost Share: None

Project Description

This project focuses on an acid mine drainage biological sulfate reduction technology. Aqueous waste contained in the shaft and flowing through the tunnels of the Lilly/Orphan Boy Mine are being treated using the mine as an in situ bioreactor. A substrate composed of cow manure, wood chips, and alfalfa was added in 1994 to promote growth of the sulfate-reducing bacteria (SRB). The mineshaft extends to a depth of 250 feet, and it has been flooded to the 74-foot level for over 50 years. This is the level of the portal tunnel. Figure 4 shows a cross-section of the underground mine with the technology installation detailed.

Status

In 2005, this field demonstration was in its eleventh year. The analytical data generally demonstrates a decrease in dissolved metals concentrations within the mine tunnel. Manganese, however, is not removed because SRBs are not effective in its removal. The plot indicates that there is a significant increase in dissolved metals concentrations during a spring runoff; however, the levels decreased when flow rates returned to normal.

The final sampling for this project was conducted in July 2005. This sampling also included retrieving a sample from the shaft in situ bioreactor for characterization of the microbial community. This information will be included in the final report along with an economic evaluation of the technology.

INTEGRATED PASSIVE BIOLOGICAL TREATMENT PROCESS DEMONSTRATION

Primary Issue Addressed: Acid Drainage/Water Treatment

Secondary Issues Addressed: Biological treatment for dissolved metals removal, including manganese

Project Site: Surething Mine in the Elliston Mining District of Montana

Collaborating Entities: MSE Technology Applications, Inc. (MSE)

Cost Share: None

Project Description

The Integrated Passive Biological Treatment Process was designed by MSE as a multistage with sequential passage of acid rock drainage (ARD) from the mine adit through three adjacent anaerobic reactors and one aerobic reactor (see Figure 5).

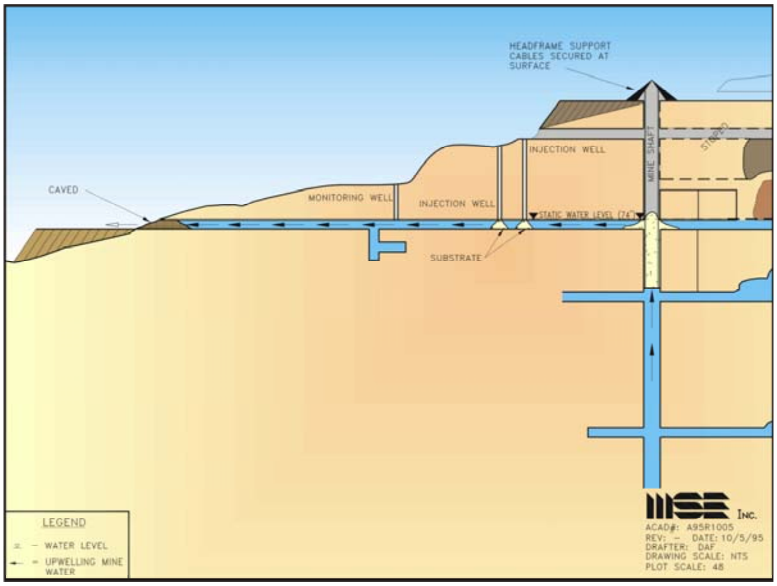

Figure 4. Mine cross-section.

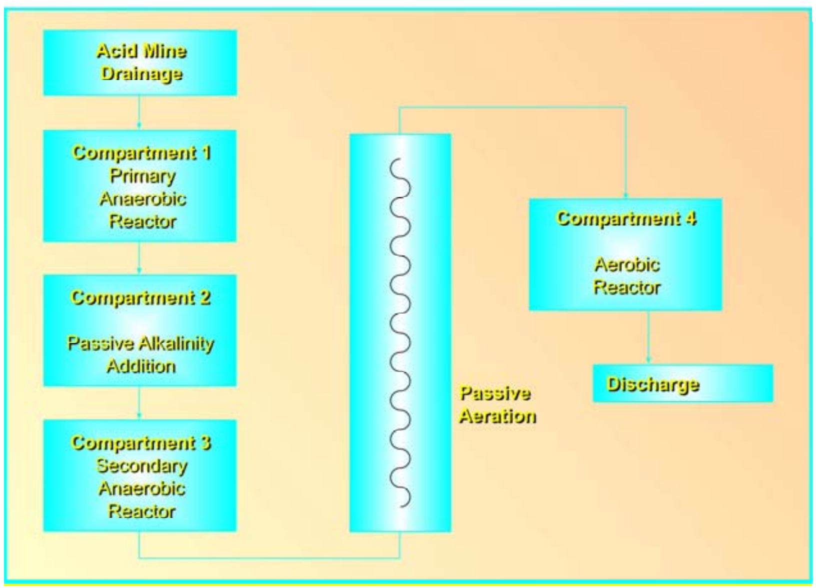

Figure 5. Block flow diagram.

Anaerobic treatment relied on sulfate-reducing bacteria that reduced dissolved sulfate to hydrogen sulfide, which reacted with dissolved metals to form insoluble metal sulfides. This bacterial metabolism also produced bicarbonates that increased pH of the ARD and limited dissolution of metal.

The first anaerobic reactor through which ARD passively flowed was constructed of a mixture of cow manure and walnut shells. Cow manure provided a source of easily degradable organic carbon and large populations of sulfate-reducing bacteria. The walnut shells provided a longer-term source of organic carbon and the structural strength needed to maintain permeability of the mixture. Bench-scale tests indicated that this initial reactor would successfully establish the sulfate-reducing conditions needed for the overall system, but also that it would be the first to fail due to bacterial incompatibility with the low pH of feed water. Sulfate-reducing capabilities also were challenged by the presence of iron ion in the ARD, 95% of which existed in the ferric state.

Drainage water then flowed passively through the second anaerobic reactor, which was constructed of limestone cobbles that added alkalinity to the water. Earlier laboratory tests indicated that the previous cell's reduction of ferric iron to ferrous iron reduced the extent of limestone *armoring* from ferric iron precipitates during ARD residence in this reactor.

The third adjacent reactor, containing the same cow manure/walnut shell mixture as the first, served as the primary driver of sulfide-precipitating reactions that removed metals from solution. With the exception of manganese, concentrations of all target metals in water exiting this reactor were below the most stringent of Montana's Water Standards.

Drainage water leaving the final anaerobic reactor was aerated by routing it through 300 feet of corrugated pipe *riprap*. The water was allowed to additionally aerate in an above-ground tank for 2 to 3 hours before passively flowing into the fourth reactor for aerobic treatment. This final reactor was constructed of a shallow, baffled limestone bed that provided an environment for indigenous manganese-oxidizing bacteria to thrive and for subsequent removal of manganese as a precipitate (see Figure 6.)

<u>Status</u>

After 4 full years of testing and continued process development of the system, the demonstration concluded in October 2005 when maximum contaminant levels were attained for all target metals and pH of the water returned to a neutral range (see Table 1).

The system was winterized, and the site will be closed out in the spring. Samples were collected from the bioreactors for final characterization testing including identification of active bacteria and solids stability. The final project report will be completed by the end of fiscal 2006.

Figure 6. Aerobic bioreactor with manganese deposits.

Table 1. Surething Influent and Effluent Parameters Compared to Water Quality Standards.

ARD Parameter	Feed Concentration (mg/L)	Discharge Concentration (mg/L)	Montana Water Quality Standard (mg/L)
Aluminum	29.5	<0.04	0.087
Arsenic	0.127	<0.01	0.010
Cadmium	0.208	<0.00009	0.00076
Copper	2.35	<0.003	0.037
Iron	15.0	<0.014	0.3[1]
Lead	0.151	0.004	0.015
Manganese	26.7	0.037	0.050[1]
Zinc	22.7	<0.007	0.338
Sulfate	591	239	250[1]
pH	2.58	7.31	6.5-8.5
Ammonia/Nitrogen	0.11	0.37	4.61[2]

[1] EPA secondary maximum contaminant level [2] 16 °C, pH 7.3

PHYSICAL SOLUTIONS FOR ACID MINE DRAINAGE AT REMOTE SITES

Primary Issue Addressed: Acid Drainage/Water Treatment

Secondary Issues Addressed: Sustainability, Trace Metal Removal

Project Site: Susie/Valley Forge Mine in Rimini, Montana

Collaborating Entities: MSE Technology Applications, Inc. (MSE), Montana Tech of the University of Montana, Environmental Protection Agency (EPA) Region VIII, Montana Department of Environmental Quality (MDEQ), CDM Federal Programs Corporation (RACs VIII prime contractor, Landowners and Citizens of Rimini.

Cost Share: EPA Region 8 is opening the Susie mine and building a room to house the system inside. In addition, EPA Region 8 is taking care of the land access agreements and most of the permitting issues. Estimated in-kind services provided are $300,000.

Project Description

The Physical Solutions for Acid Mine Drainage at Remote Sites Project will demonstrate a low maintenance technology to reduce metals in mine drainages at remote sites. The project will also evaluate alternative energy sources to monitor and control the system.

Status

CDM Federal Programs has awarded the subcontract to open the Susie Mine and install a room to house the MSE proposed technology to remove arsenic and various heavy metals. During the week of August 15, 2005, the subcontractor opened the face of the adit. During a meeting on August 18, 2005, with EPA Region VIII, MDEQ, CDM, and MSE, it was decided to stabilize the entrance and winds and then identify an appropriate area inside the mine to make a room to house the treatment process. Budgetary issued were also discussed, and it was determined that the opening and building of the room inside the mine could possibly be completed in September 2005.

MSE has completed the treatment process design and is waiting for the final footprint of the room to finalize equipment layout and design. The estimated time for completion of the Susie Mine is the end of September.

PASSIVE TREATMENT TECHNOLOGIES FOR REDUCING METAL LOADING

Primary Issue Addressed: Acid Drainage/Water Treatment

Secondary Issue Addressed: Passive Treatment

Project Site: Primary focus is Canyon Creek, tributary of South Fork of Coeur d'Alene River and largest zinc load to South Fork

Collaborating Entities: EPA Region 10 and Coeur d'Alene Basin Project Focus Team meeting

Cost Share: None

Project Description

Historical mining practices and the naturally occurring geochemistry in the Coeur d'Alene Basin have resulted in contamination of soil, sediment, surface water, and groundwater. The purpose of this project is to evaluate passive treatment systems side-by-side while treating similar contaminated source water(s). The proposed work will: 1) evaluate new/promising materials for reactive bed-type application to remove zinc from neutral pH water; 2) start development of a chemistry based framework for matching media to contaminated water sources; and 3) provide performance data to support scale-up and economic evaluation of technologies. The information generated in this study will aid the U.S. Environment Protection Agency Region 10, Coeur d'Alene Basin Commission, and Idaho Department of Environmental Quality to evaluate and select passive treatment system designs for future implementation in the Coeur d'Alene Basin.

The Record of Decision for the Bunker Hill Operable Unit 3 Superfund site states that the goal is to reduce the zinc load to Canyon Creek by 50%. Figure 7 illustrates the dissolved zinc concentrations in the Canyon Creek groundwater. The Canyon Creek site is shown in Figure 8. Currently, Region 10/CH2MHill are considering treating a lower volume of higher zinc concentration groundwater in lower Canyon Creek rather than surface water. A hydrogeological evaluation must be conducted to evaluate feasibility of this alternative. Region 10/CH2M Hill are performing pilot testing of a lime high density sludge (HDS) system and a sulfate-reducing bacteria (SRB) bioreactor system. The Mine Waste Technology Program (MWTP) work complements this effort by focusing on new materials and passive treatment, as directed in the Record of Decision. The original project approach included bench-scale testing of materials followed by extensive on-site pilot testing of an unknown number of materials. The present approach will be to conduct bench-scale testing, evaluate technical and economic aspects, and conduct pilot testing only if it makes sense and fits within the MWTP budget and program priorities. High iron, low pH water was not sufficiently prevalent in Coeur d'Alene basin to warrant inclusion as a selected water; however, an effort is ongoing to identify a higher-hardness water to include in the study if such a water is deemed sufficiently different from the Canyon Creek groundwater that is currently the focus of this study. The likely media to be tested are listed below:

- Bauxsol;
- Apatite II™;
- juniper bark (U.S. Forest Service-developed material);
- ferrihydrite or ferrihydrite-coated sand;
- aluminum-modified ferrihydrite;
- granular ferric hydroxide;
- manganese dioxide-coated sand;
- ferrous sulfide;
- limestone/MgO;
- activated carbon/apatite; and
- zeolites (if available locally).

Status

A literature search was performed for potentially suitable materials. We had difficulties obtaining access from Hecla Mining for the Canyon Creek site selected for Region 10/CH2M Hill pilot testing.

Figure 7. Dissolved zinc concentrations in the Canyon creek groundwater.

Figure 8. Canyon Creek site.

Region 10 obtained access mid-September, and two wells were installed to provide groundwater for testing. Region 10 decided to perform lime HDS and SRB pilot testing at the Bunker Hill water treatment plant in Kellogg and transport water there for testing. Additional materials were identified for testing, and high iron, low pH water not sufficiently prevalent in Coeur d'Alene basin to warrant inclusion. Personnel are searching OU3 RI for higher-hardness waters to include, which must be sufficiently different from Canyon Creek

We also plan to finalize a list of materials, prepare QA test plan (may include small batch contacts as well as small columns), transport test waters to MSE Technology Applications, Inc., for testing, and execute test plan.

MODIFIED FERRIHYDRITE FOR ENHANCED REMOVAL OF HEAVY METALS FROM MINE WASTEWATER

Primary Issue Addressed: Acid Drainage/Water Treatment

Secondary Issue Addressed: Active Treatments

Project Site: Montana Tech

Collaborating Entities: Montana Tech

Cost Share: None

Project Description

Ferrihydrite adsorption of dissolved heavy metals is widely used throughout the world. Researchers Twidwell and Hohn have previously demonstrated that arsenic can be more effectively removed from solution by adsorption/coprecipitation using aluminum-modified ferrihydrite (AMF) compared to using ferrihydrite. This project further explores the possibilities of AMF by investigating dissolved heavy metals (cadmium, copper, nickel, and zinc) removal by adsorption/coprecipitation with AMF. Specific objectives are to investigate the adsorption characteristics of ferrihydrite and AMF for removing dissolved heavy metals under conditions that vary with respect to the Fe/metal or Fe+Al/metal mole ratio, the aluminum/iron mole ratio in the AMF, and pH. Additionally, both room and elevated temperature aging tests will be employed to test the relative stability of metal loaded ferrihydrite and AMF.

Status

Work done to date includes running factorial design tests to determine the influence of the Fe/metal or Fe+Al/metal mole ratio, the aluminum/iron mole ratio in the AMF, and pH on the response variables (final cadmium, copper, nickel, and zinc concentrations). These tests indicated that there is very little, if any, difference in the adsorption/coprecipitation characteristics of ferrihydrite and AMF with respect to the dissolved heavy metals concentrations. Factorial design tests, focusing on ferrihydrite, have also been run to investigate the influence of pH and interactive effects of each metal on recoveries of each metal. These tests indicated considerable competition among the four metal cations for adsorption sites on the ferrihydrite. Room temperature aging studies have been underway since May 2005, and elevated temperature aging studies began in December 2005. The aging studies emphaisze ferrihydrite, but AMF samples are also included.

A final report, detailing the findings of project work is expected in fiscal 2006.

DUAL ECOSYSTEM ENHANCEMENT: IN-SITU PITLAKE REMEDIATION BY SLAG-SILICATE ADDITION

Primary Issue Addressed: Acid Drainage/Water Treatment

Secondary Issue Addressed: Pit Lakes
Project Site: Montana Tech

Collaborating Entities: Montana Tech

Cost Share: None

Project Description

This project will investigate the potential for treating acid rock drainage using smelter slag from various inactive smelter sites in Montana. Thermodynamic calculations show that the silicates within basic smelter slags will increase the pH and, thereby, induce precipitation reactions. However, the level of remediation is dependent on the slag-silicates that are used. Because of their different compositions, three smelter slags in particular will be examined: the fayalite slag from the Anaconda Copper Company in Anaconda; the pseudowallastonite/ rankinite slag from Stauffer Chemical near Ramsey; and the olivine slag from ASARCO in East Helena. The initial overall objectives of this research project will be to collect representative slag samples from the three sources, experimentally verify that slag-silicates can be used to remediate acid rock drainage, and determine if the resulting equilibrium pH concurs with the free energy calculations. Kinetics of the reactions need to be relatively fast to be effective.

Status

Optimization work has been performed to determine slag concentrations and mesh size, as well as attainable solution pH for each of the three slags. After 12 hours of contact with Berkeley Pit water, it was found that the Stauffer pseudowallastonite/rankinite slag yielded the highest equilibrium pH (6.0 to 7.8) of the three slags. The Stauffer slag contains the most calcium of the three slags and is relatively iron free. Equilibrium pH of the Anaconda fayalite slag after 12 hours contact with Berkeley Pit water ranged from 3.4 to 4.5. For the ASARCO olivine slag, equilibrium pH ranged from 4.1 to 5.4 after 12 hours contact with Berkeley Pit water. The low end of the pH ranges corresponded to slag concentrations of 100 g/L and a particle size of 48 mesh, or approximately 300 µm diameter particles. The mid-range pH values corresponded to a slag concentration of 100 g/L and a particle size of 270 mesh, or approximately 50 µm diameter particles. The high range pH values correspond to a slag concentration of 300 g/L and a particle size of 270 mesh.

TRACE METAL REMOVAL

MODIFIED FERRIHYDRITE FOR ENHANCED REMOVAL OF ARSENIC FROM MINE WASTEWATER

Primary Issue Addressed: Trace Metal Removal

Secondary Issues Addressed: Acid Drainage/Water Treatment

Project Site: Not applicable

Collaborating Entities: Montana Tech

Cost Share: None

Project Description

The main objective of this project was to investigate the adsorption characteristics of ferrihydrite and aluminum modified ferrihydrite for removing both arsenate and arsenite species as well as investigating the relative stability of the products that will be most effective in removing arsenic from mine wastewaters.

Arsenic removal by adsorption on a ferrihydrite surface is used throughout the world for removing arsenic from wastewaters; however, long-term stability of ferrihydrite, especially in outdoor storage ponds, is questionable. This has been shown by many studies that have demonstrated amorphous ferrihydrite propensity to convert to crystalline goethite (FeOOH) or hematite (Fe_2O_3) with a drastic decrease in solid surface area in a matter of months. Pathways for these crystallizations have been studied in great detail but have not yet been completely defined. The adsorptive properties of the crystalline goethite or hematite solids for arsenic have been shown to be much less than the ferrihydrite amorphous solid. Previous investigations have demonstrated that aluminum modification of the precipitated ferrihydrite changes the adsorptive properties of the solid so that it is much more effective for adsorbing arsenic than is unmodified ferrihydrite. The rationale behind the concept of using a modified-ferrihydrite structure for the adsorption of arsenic from aqueous solution is based on the idea that by incorporating other element ions into the ferrihydrite structure the modified structure should adsorb arsenic ions and heavy metal ions more effectively due to better matching of ion and adsorbent atom to atom distances.

Status

The laboratory testing for this project is complete, but analytical results of the 1-year aging test are pending. The final report is expected to be finished in fiscal year (FY) 2006. Six separate full factorial two-level design matrix tests were conducted. Five of these tests used modified ferrihydrite as the adsorption surface, and one used ferrihydrite as the adsorption surface. Each design matrix test consisted of ten experiments (i.e., eight required by the design matrix and two midpoint tests) to investigate the influence of ferrihydrite:arsenic and modified ferrihydrite: arsenic mole ratio, initial arsenic concentration, and pH on removing arsenic. Preliminary analysis of the elevated temperature aging study on the sulfate-bearing water revealed that arsenic is desorbed in appreciable quantities with time from ferrihydrite, but much less is released from modified ferrihydrite. Further testing revealed that the selection of reagent anion (chloride, nitrate, or sulfate) affects arsenate removal. A more in-depth evaluation and analysis of the data will be provided in the final report, which is expected to be completed in FY06.

PIT LAKES

BIOREMEDIATION OF PIT LAKES (GILT EDGE MINE)

Primary Issue Addressed: Pit Lakes

Secondary Issue Addressed: Biological Treatment, Characterization, Modeling

Project Site: Gilt Edge Mine Superfund site near Deadwood, South Dakota

Collaborating Entities: MSE Technology Application, Inc.; U. S. Environmental Protection Agency (EPA) Region VIII; CDM Federal Services; Arcadis-U.S.; South Dakota Department of the Environment and Natural Resources

Cost Share: Site logistical support and laboratory analytical support by CDM under EPA Region 8 Remedial Action Contract.

Project Description

This project focuses on an in situ treatment of the Anchor Hill Pit, an open pit at the Gilt Edge site originally containing approximately 70 million gallons of acidic water containing high levels of metals, sulfate, and nitrate. EPA Region 8's interest in this project is to conduct a treatability study as part of the site Remedial Investigation/Feasibility Study (RI/FS) process, while the Mine Waste Technology Program's (MWTP) interest is to develop data applicable to other similar sites. The treatment consisted of two steps. The initial step was to neutralize the pit lake with lime using a Neutra-Mill, essentially a floating lime slaker developed in Australia. The second step was to add nutrients to the pit to stimulate biological activity, which was intended to further improve water quality and create a long-term, stable system. After the two-step treatment, accomplished between March and May 2001, the project entered a monitoring mode where the pit lake was regularly physically and chemically characterized. The purpose was to see how well the treatments work and how stable the pit lake water becomes, e.g., if metal sulfides are produced, does the system reoxidize and remobilize those metals.

Status

Project accomplishments in fiscal year (FY) 2005 included continuation of monitoring the pit water chemistry via obtaining analytical samples regularly as well as vertical profiles of physical measurements. In 2002 to 2003, the pit lake had become strongly meromictic, i.e., stratified such that the vertical water column does not mix during the year. The surface zone was well-aerated, while the deeper zone was very anoxic. This meromictic condition remained throughout FY05, and the only noticeable change in pit water chemistry was the slow continuation of sulfate reduction in the deep portion of the pit due to the presence of excess carbon and nutrients.

In FY05, a continuing effort was devoted toward discharging treated water from the pit. During the winter, while the pit was frozen over, approximately four million gallons of water was pumped from immediately beneath the ice, aerated via a riprap, and successfully discharged, meeting all applicable South Dakota state water quality criteria. An additional ten million gallons of surface water were discharged in August 2005. Also in August 2005, concentrated hydrogen peroxide (H_2O_2) was added to the deep, anoxic zone with the goal of eliminating excess hydrogen sulfide, which would hopefully lead toward discharge of more water. The remainder of FY05 was spent monitoring the outcome of the hydrogen peroxide addition. It is expected that monitoring will continue through the winter of 2005-2006, with the project being considered complete at that point. The final report is expected to be completed in FY06.

ALGAL BIOREMEDIATION OF THE BERKELEY PIT-LAKE SYSTEM—AN IN-SITU TEST USING LIMNOCORRALS

Primary Issue Addressed: Pit Lakes

Secondary Issues Addressed: Biological Treatment

Project Site: Berkeley Pit Lake, Butte, Montana

Collaborating Entities: Montana Tech and Montana Bureau of Mines and Geology

Cost Share: In-kind service provided by the Montana Bureau of Mines and Geology.

Project Description

The main objective of this project was to perform an in-situ field demonstration using limnocorrals to investigate the bioremediation potential of algae in the Berkeley Pit lake. A secondary objective is to ascertain the role that nutrification of the algae has on the bioremediation results.

Limnocorrals are an enclosed experimental apparatus, open at the top and closed at the bottom, used to simulate actual physical, chemical, and biological conditions of the lake environment within a controlled volume of water, allowing for biomanuipulation of one to several aspects of the natural environment. Manipulation in this experiment will consist of nitrification of limnocorrals using nitrate and phosphate concentrations to stimulate algal growth. It is postulated that if properly nutrified, dissolved metal concentration in the Berkeley Pit will decrease due to increasing algal biomass. Three replicate limnocorrals were set up, and nitrification was used as the variable. Specifically, one was nutrified with 5 mg/L nitrate and 2 mg/L phosphate, one was nutrified with 10 mg/L nitrate and 4 mg/L phosphate, and one was used as a control. The set of three was replicated three times (nine limnocorrals total). To document the importance of algal nutrification in bioremediation effectiveness, the nutrified limnocorrals were compared to non-nutrified limnocorrals and open water. An array of physical, chemical, and biological information has been collected. All variables were combined in a bioremediation matrix design using quantitative chemical analysis of samples to determine the interrelationships of the variable to each other at the end of the experiment.

Status

All data collection and interpretation has been completed for this project. Algal counts from the November 2004 sampling event indicated that nutrification increased algal counts. The level of nutrification had little effect on algal counts, but counts in nutrified limnocorrals were much higher than those in the control limnocorrals. Algal counts in the nutrified limnocorrals decreased with increasing depth. Bacteria counts increased with time in all limnocorrals, but neither depth nor level of nutrification played a role in bacteria counts. Pertaining to metal concentrations, time appeared to be the most significant factor having an effect within the limnocorrals. Depth and level of nutrification appeared to have no significant effect on the concentrations of any of the metals investigated. Arsenic and iron were the only two constituents that had a statistically significant change in concentration between July and November 2004 in response to the limnocorral treatments.

Project results are being assembled into the final report, which is expected to be completed in fiscal 2006.

MODELING

CONTAMINANT SPECIATION IN RIPARIAN SOILS DEMONSTRATION

Primary Issue Addressed: Modeling

Secondary Issues Addressed: In situ Treatment; Lead Stabilization

Project Site: University of Idaho

Collaborating Entities: MSE and University of Idaho

Cost Share: University of Idaho

Project Description

The focus of this project is to evaluate phosphorus-lead soil interactions with respect to mineralogical stability. It is an investigation into the reaction processes that take place when phosphate amendments are added to riparian soils containing lead and other solid-phase materials. Phosphorus (P) has shown excellent potential for the remediation of lead-contaminated soils and reduction of lead bioavailability. However, no existing information correlates the reaction mechanisms of lead in field remediated soils with toxicological studies on waterfowl. This project will serve to fill this gap. In addition, this project will also serve to monitor how the speciation and bioavailability of the other contaminants are affected by phosphorus-based remediation treatments.

Status

Soil samples from the Coeur d'Alene River Basin were analyzed for mineralogy and metal contaminant speciation. Both phosphorus-treated soils and untreated soils were examined to determine the effect of P-amendment on metal speciation. Other studies have suggested P-amendments lead to precipitation of poorly soluble lead phosphate minerals. No evidence was found for this behavior in the present study. Instead, P appears to associate with iron-bearing minerals in the soil, whereas lead associates predominantly with manganese-bearing phases.

Based on the results of this research, a conceptual model can be developed for lead speciation and reactivity in the wetlands. This model can be used to predict lead bioavailability, transport availability, temporal fluxes as a function of water table and inundation, and impacts of remediation. Figure 9 shows a generalized system model. Information on mineral and contaminant speciation can be input into this model to predict processes for reactions between the various phases. This type of predictive model is needed to develop improved management and remediation strategies and to develop new experiments that will allow for quantitative analysis of contaminant availability.

A physiologically-based extraction test model for waterfowl was developed to measure the bioaccessibility of lead to waterfowl (W-PBET) (see Figure 10). The method was used to test lead bioaviability in field remediated soils. The lead concentrations from the W-PBET method were positively correlated to the bird feeding study results and indicate that the extraction test can be used to assess relative changes in bioaccessibility. Therefore, the test will be valuable to help manage and remediate contaminated wetland soils with respect to waterfowl.

The project final report will be completed in fiscal 2006.

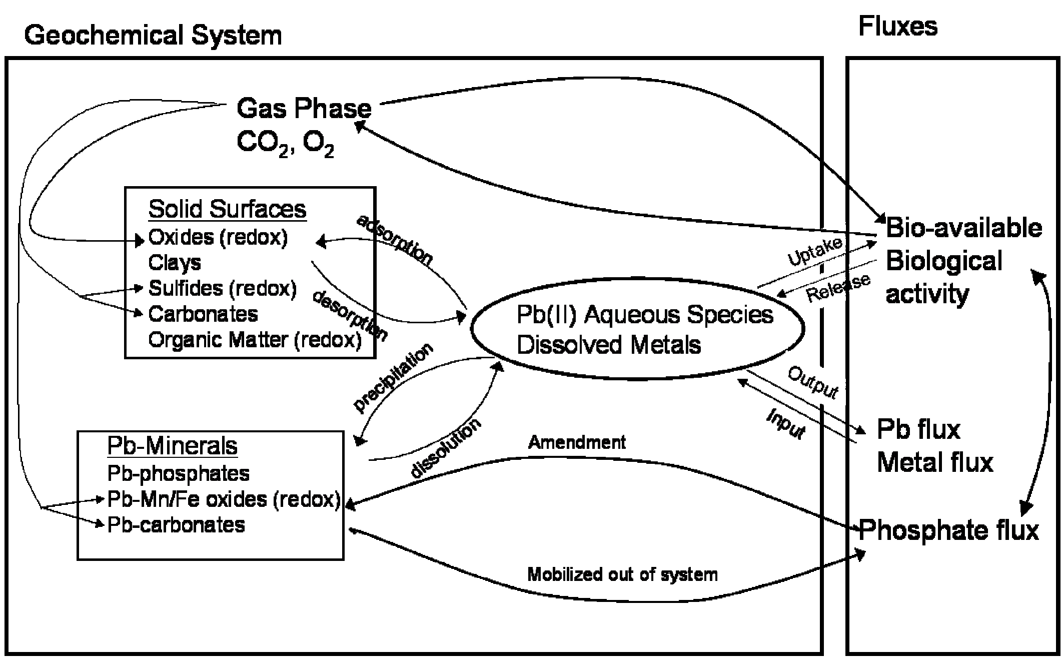

Figure 9. Geochemical system.

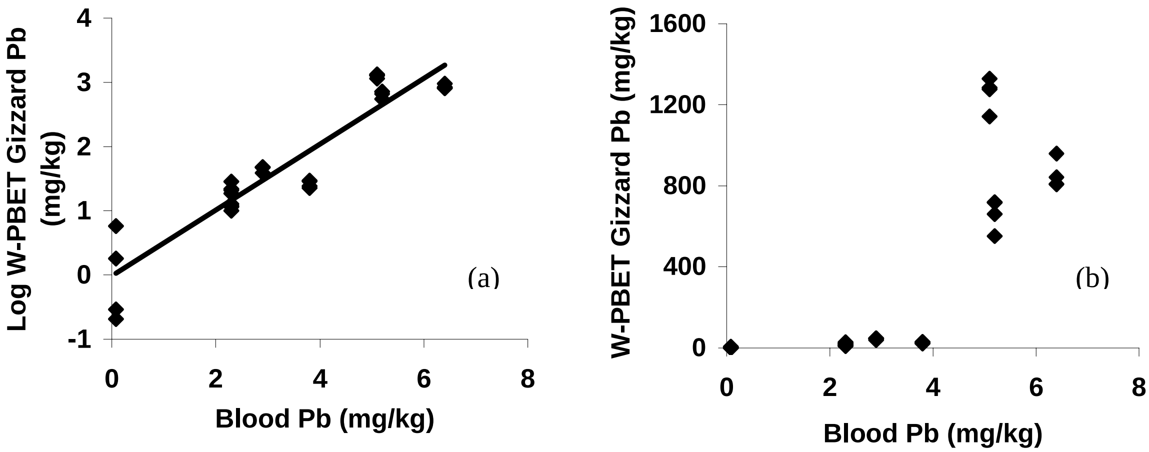

Figure 10. Graphed correlations between lead concentrations in W-PBET simulated gizzard and lead concentrations in the blood from in vitro testing on same soils.

CALPUFF MODELING OF COPPER SMELTER EMISSIONS

<u>Primary Issue Addressed</u>: Modeling

<u>Secondary Issues Addressed</u>: Aerial Deposition of Contaminants

<u>Project Site</u>: Anaconda Smelter

<u>Collaborating Entities</u>: Montana Tech

<u>Cost Share</u>: None

<u>Project Description</u>

The main objective of this study was to use the advanced features of the CALPUFF air diffusion modeling system to investigate and predict aerial impact in southwest Montana from the previously active Anaconda copper smelter and to identify terrain sites (or locations) that may warrant further investigation/characterization and, ultimately, remediation.

Until recently, models were not available to handle plume diffusion amid complicated terrain features such as the mountains in southwest Montana, and most of the models were not very accurate over long distances. CALPUFF, however, is a state-of-the-science model capable of predicting air pollution impact from many types of industrial sources. The model simulates plume transport and plume diffusion on scales ranging from tens of meters to hundreds of kilometers, and it addresses effects from complex terrain in addition to time-varying and space-varying meteorological conditions. CALPUFF was recently adopted as the U.S. Environmental Protection Agency's "preferred technique of assessing long range transport of pollutants and their impacts on Federal Class I areas" (Federal Register 2003). The goal of this project was to use the advanced features of the CALPUFF modeling system to investigate and/or predict the transport of airborne constituents from the Anaconda Smelter and to identify locations that may warrant further investigation, and possible remediation. This phase of the project focused primarily on arsenic transport.

Status

All modeling was completed, and work has begun on the final report, which is expected to be completed in fiscal 2006. Preliminary analysis of the model results shows arsenic deposition on the mountains east of Anaconda and the smelter. CALPUFF modeling indicates that concentrations increase with elevation. That is, deposition is higher on ridges and hilltops. Contour lines of arsenic concentrations predicted by the model have been plotted in terms of milligrams per square meter (mg/m^2) along with existing soil data. A more in-depth evaluation and detailed quantitative analysis of the data will be provided in the final report.

CYANIDE DESTRUCTION

CYANIDE HEAP BIOLOGICAL DETOXIFICATION, PHASE II

Primary Issue Addressed: Cyanide Destruction

Secondary Issues Addressed: Gold Recovery and Economics; Biological Treatment

Project Site: Placer Dome U.S., Cortez Gold Mine located in Crescent Valley, Nevada

Collaborating Entities: MSE Technology Applications; Inc.; Placer Dome U.S.; Cortez Gold Mine; Whitlock and Associates, Spearfish, South Dakota

Cost Share: In-kind services provided by Cortez Gold Mine.

Project Description

The Mine Waste Technology Program (MWTP) project, Cyanide Heap Biological Detoxification, Phase II, is ongoing at the Cortez Gold Mine (CGM) in northeastern Nevada using the Gold Acres Heap shown in Figure 11. Placer Dome, Inc., owns 60% of CGM through a joint venture with Kennecott Exploration Ltd. Placer Dome Inc., is a national and international mining company. This project is the second phase of the MWTP Cyanide Heap Biological Detoxification project, a large-scale column study conducted at McClelland Laboratories in Sparks, Nevada.

Many active mine sites, mines in the closure stage, and some abandoned mines have used cyanide to remove and recover precious metals. Discharges from these sites normally contain significant amounts of metal cyanide complexes and concentrations of thiocyanate, soluble heavy metals, nitrate, sulfate, and ammonia.

Chemical, physical, and biological processes have been developed to attempt to clean up seeps and discharges. Strong oxidants such as hydrogen peroxide, chlorine dioxide, Caros Acid, ozone, and sulfur dioxide have shown effectiveness in some applications. Biological processes, alkaline chlorination, reverse osmosis, and ion exchange have been effective in removing thiocyanate, cyanide, and heavy metals. Typically, biological processes incur lower capital costs at substantially lower operational costs while producing a treated effluent that is compatible with receiving waters and the environment.

The conventional method of heap detoxification consists of rinsing the spent heap leach pad with fresh or treated water until regulatory standards for solids and solutions are achieved. Several pore volumes of water are typically required to detoxify cyanide, which lengthens the treatment process. In addition, metals continue to be present in the heap effluent after cyanide detoxification that can prevent heap closure. Consequently, large quantities of solution are generated that require treatment and add to the overall treatment costs. Biological heap detoxification is a process that uses bacteria to detoxify a spent heap leach pad by destroying cyanide, nitrates, and sulfates and removing metals.

Status

The field demonstration was discontinued in October 2005; however, sampling will be ongoing until early 2006. The final project report will be completed in fiscal 2006.

Figure 11. Gold Acres Heap at Cortez Gold Mine.

MISCELLANEOUS ACTIVITIES

GEOCHEMISTRY AND ISOTOPIC COMPOSITION OF H_2S-RICH WATER IN FLOODED UNDERGROUND MINE WORKINGS IN BUTTE, MONTANA

Primary Issue Addressed: Miscellaneous Activities

Secondary Issues Addressed: Characterization; Modeling

Project Site: West Camp Pumping Well, Butte, Montana

Collaborating Entities: Montana Tech

Cost Share: None

Project Description

The focus of the study was to collect groundwater samples from the West Camp pumping well, which is a groundwater extraction well that drains flooded mine workings in the southwest portion of the Butte, Montana, mining district. Butte is well known for the Berkeley Pit lake, which is an open-pit copper mine flooded with over 100 billion liters of acidic and metal-rich water. The main objective of this study is to collect a suite of groundwater samples from the West Camp groundwater extraction well for comprehensive chemical and isotopic analysis to more fully understand the processes that control the geochemistry of the West Camp mine waters.

The project objective was completed by sampling the West Camp groundwater pumping well approximately six times over the course of 1 year (approximately every 2 months) and analyzing the waters for constituents such as trace metals as well as stable and radiogenic isotopes. Historic analytical results have revealed that the concentrations of many contaminants of interest are relatively low in the West Camp groundwater and typically below the previous instrument detection limits. In this investigation, however, the use of an inductively coupled plasma mass spectrometer technique lowered the detection limits. Other measurements included iron speciation (Fe^{+2}/Fe^{+3}), arsenic speciation (As^{+5}/As^{+3}), hydrogen sulfide (H_2S), dissolved organic carbon, and nutrient analysis.

Collection of data on the sulfur isotopic composition ($\delta^{34}S$) content of coexisting sulfate and sulfide tested the hypothesis that H_2S in the flooded West Camp was formed by bacterial sulfate reduction (BSR). It is widely recognized that BSR produces H_2S that is highly depleted in the heavy ^{34}S isotope relative to the sulfate from which it is derived. Depletion factors of greater than 30 per mil are typical of sulfide formed by BSR. In addition, new data on the oxygen isotopic composition ($\delta^{18}O$) content of water and coexisting dissolved sulfate may give clues as to the source of sulfate in the West Camp waters, the extent of bacterial sulfate reduction (which results in a shift in $\delta^{18}O$ of sulfate to more positive values), and possibly the mechanism of pyrite oxidation in the flooded mine workings (e.g., aerobic versus anaerobic).

Status

All project work has been completed on this project. An in-depth data review will be provided in the final report, which is expected to be published in fiscal 2006.

The results suggest that there are relatively few temporal changes in the West Camp mine water, both the physical and chemical parameters are remarkably stable with time, as are the isotopic composition of water and dissolved S species (H_2S, sulfate). Trace metal analysis confirms the very low concentrations of most common heavy metals, with arsenic being the only contaminant that is above regulatory standards. Most of the dissolved arsenic is present in the As(III) valence state, and all of the dissolved iron (Fe) is present as Fe(II), consistent with the strongly reducing nature of the mine waters in the West Camp. Nutrient levels are very low (nitrate and ammonia below detection, phosphate ~ 20 to 30 µg/L), as are concentrations of total and heterotrophic bacteria. Isotopic results confirm the hypothesis that H_2S in the West Camp waters was formed by bacterial sulfate reduction. Sulfate-reducing bacteria were isolated in the West Camp waters but were near the lower limit of quantification. Most of the bacteria responsible for H_2S generation may be present as biofilms, coating mineral or wood material in the flooded mine workings.

FINANCIAL SUMMARY

Total expenditures during the period October 1, 2004, through September 30, 2005, were $2,593,621, including both labor and nonlabor expense categories. Funding distribution of the expenditures is depicted on the performance graph in Figure 12.

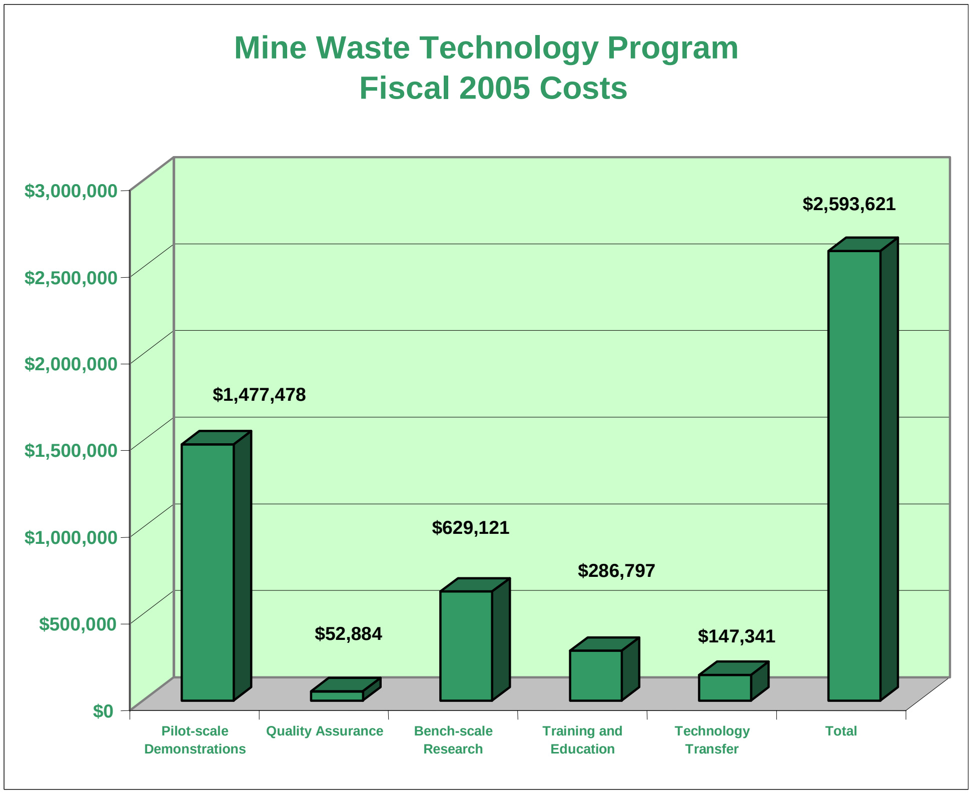

Figure 12. Mine Waste Technology Program fiscal 2005 funding distribution performance graph.

MWTP PROJECT MATRIX

Table 2 is a summary of all Mine Waste Technology Program projects performed since its inception in 1991. Information on issues addressed, technologies or processes demonstrated, the demonstration site, and a brief description of each project is also given. For information on these projects, refer to the web site: www.epa.gov/minewastetechnology.

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	**Prevention/Source Control**	**Acid Drainage/ Water Treatment**	**Biological Treatment**	**Passive Treatment**	**Active Treatment**	**Pit Lakes**	**Remote Locations**	**Sustainability**	**Modeling**	**Characterization**	**Technology or Process/ Provider**	**Demonstration Site/Location**	**Comments**
Acid Drainage/Water Treatment/Trace Metal Removal													
Remote Mine Site		♦		♦			♦			♦	Aquafix/Aquafix Systems	Crystal Mine, near Basin Montana	Aquafix system was used to deliver lime to AMD emanating from the adit of the Crystal Mine in Montana
Ceramic Microfiltration System		♦			♦						Ceramic Microfiltration System/ BASX Systems, LLC	Gregory Incline/ Black Hawk and Central City, Colorado	A ceramic microfiltration system was demonstrated.
Physical Solutions for AMD at Remote Sites		♦			♦		♦			♦	Active treatment system within mine/MSE Technology Applications	Susie Mine/ Rimini, Montana	This project will evaluate a technology for the removal of heavy metals from acid mine drainage in the Ten Mile Creek area of Montana in support of EPA Region 8.
Thallium Removal from Mine Waste Waters		♦			♦						Reductive Precipitation/ Montana Tech	Asarco East Helena Smelter water/MSE Technology Applications testing facility	Optimization studies on a thallium removal technology will be performed. The technologies will also be monitored for removal of other selected metals.
Arsenic Oxidation		♦			♦		♦				Photochemical oxidation and UV oxidation/Australian Nuclear Science and Technology Organization	Susie Mine, Rimini, Montana	This project demonstrated and evaluated arsenic oxidation and removal technologies.
Arsenic Removal		♦			♦		♦				Mineral-like Precipitation/ Montana Tech Alumina Adsorption/Zenon Ferrihydrite Adsorption/ optimized by MSE Technology Applications and Montana Tech	Asarco East Helena Smelter TVX Mineral Hill Mine water demonstrated at MSE Technology Applications testing facility	Two innovative technologies and the BDAT were evaluated for arsenic removal from various arsenic-contaminated waters.
Passive Arsenic Removal		♦		♦							Various reactive medias/ MSE Technology Applications	MSE Technology Applications testing facility/ Butte, Montana	

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	Prevention/Source Control	Acid Drainage/ Water Treatment	Biological Treatment	Passive Treatment	Active Treatment	Pit Lakes	Remote Locations	Sustainability	Modeling	Characterization	Technology or Process/ Provider	Demonstration Site/Location	Comments
Selenium Removal/Treatment Alternatives		♦	♦	♦	♦		♦				Biological Selenium Reduction/ Applied Biosciences Catalyzed Cementation/Montana Tech Ferrihydrite Adsorption—Best Demonstrated Available Technology/optimized by MSE Technology Applications	Kennecott Utah Copper Corporation/ Kessler Springs	Three selenium removal technologies were demonstrated (BDAT, Catalyzed Cementation and Biological Selenium Reduction) at the Kessler Springs site at Kennecott Utah Copper Corporation.
Long-Term Monitoring of a Permeable Treatment Wall		♦	♦	♦			♦			♦	Apatite II treatment media/ Phosphate-induced Metals Stabilization Northwest	Nevada Stewart Mine/near Pinehurst, Idaho	A passive treatment system using apatite was installed at the Nevada Stewart Mine near Pinehurst, Idaho for removal of zinc.
Nitrate Removal		♦	♦		♦						Nitrate Ion Exchange (NIX)/ Altair, Inc. Electrochemical Ion Exchange/ Selentec, Inc. Biological Denitrification/ Montana Tech	TVX Mineral Hill Mine/Gardiner, Montana	Demonstration of biological and electrochemical ion exchange technologies for nitrate removal at the Mineral Hill Mine near Jardine, Montana.
An Investigation to Develop a Technology for Removing Thallium from Mine Wastewaters		♦				♦					Reductive Precipitation/ Montana Tech	Montana Tech/ Butte, Montana	Two technologies for removing thallium from mine wastewaters were evaluated. One was manganese dioxide adsorption, which effectively removed thallium but was difficult to strip and regenerate. The other was reductive precipitation, in which metallic iron was used to create strongly reducing conditions, under which thallium could be effectively removed by sulfide precipitation. This second technology was very effective and is being further developed.

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	Prevention/Source Control	Acid Drainage/ Water Treatment	Biological Treatment	Passive Treatment	Active Treatment	Pit Lakes	Remote Locations	Sustainability	Modeling	Characterization	Technology or Process/ Provider	Demonstration Site/Location	Comments
Modified Ferrihydrite for Enhanced Removal of Heavy Metals from Mine Wastewater		♦			♦						Modified Ferrihydrite/ Montana Tech	Montana Tech, Butte, Montana	A series of experiments will be conducted to evaluate the adsorptive properties of modified ferrihydrite.
Metal Ion Removal from Acid Mine Wastewaters by Neutral Chelating Polymers		♦		♦	♦						Neutral chelating polymers/ Montana Tech	Montana Tech/ Butte, Montana	Neutral chelating polymers were investigated for their metal removal potential.
Removal of Arsenic as Storable Stable Precipitates		♦			♦						Apatite-like mineral precipitation/Montana Tech	Montana Tech/ Butte, Montana	A process was developed to remove arsenic from solution and generate a stable precipitate.
Removing Oxyanions of Arsenic and Selenium from Mine Wastewaters Using Galvanically Enhanced Cementation Technology		♦			♦						Galvanically enhanced cementation/Montana Tech	Montana Tech/ Butte, Montana	This project built on previous work showing cementation with metallic iron was very effective at removing arsenic and selenium (at any oxidation state) from solution. The project evaluated and proved the concept of accelerating the cementation reactions by the use of galvanic couples (particularly the iron-copper couple), which produced electrons for reduction much more rapidly.
Sulfate Removal Technology		♦			♦						Precipitation/Montana Tech Electrochemical metal reduction/Montana Tech	Montana Tech/ Butte, Montana	Two technologies for lowering sulfate were investigated, including precipitation of sulfate bearing compounds and electrochemical metal reduction of sulfate.
Metal Remediation/ Cementation		♦			♦						Reductive precipitation/ cementation/Montana Tech	Montana Tech/ Butte, Montana	This study developed a technology for treating acid mine water by validating the concept of reductive precipitation/cementation for removing heavy metals specifically cadmium, copper, nickel, lead, and zinc.

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	Prevention/Source Control	Acid Drainage/ Water Treatment	Biological Treatment	Passive Treatment	Active Treatment	Pit Lakes	Remote Locations	Sustainability	Modeling	Characterization	Technology or Process/ Provider	Demonstration Site/Location	Comments
Sulfate-Reducing Bacteria –Related Projects													
In Situ Source Control of Acid Generation using SRBs	♦	♦	♦	♦			♦	♦		♦	SRB System within Mine Workings/MSE Technology Applications	Lilly/Orphan Boy Mine/near Elliston, MT	For the past 10 years, a sustainable passive treatment using sulfate-reducing bacteria has significantly improved the quality of water emanating from the Lilly/Orphan Boy Mine, a remote, abandoned mine that discharges into a tributary of the Clark Fork River. The organic nutrient applied to stimulate the naturally occurring SRBs was applied only the first year—the treatment has become self-sustaining. The physical features of the mine were used as part of the treatment eliminating the need for capital investment in equipment, and the treatment has virtually no annual operating costs. The technology has been transferred from the MWTP to various U.S. Forest Service Sites and has led to several other MWTP projects.
Sulfate-Reducing Bacteria Reactive Wall		♦	♦	♦			♦			♦	SRB Systems of Various Configurations/MSE Technology Applications	Calliope Mine/ near Butte, MT	Three engineered bioreactors were constructed at the Calliope Mine to demonstrate the feasibility of using SRB passive technology.
Integrated Passive Biological Treatment System		♦	♦	♦			♦	♦		♦	Integrated Passive Biological Treatment System/MSE Technology Applications	Surething Mine, near Elliston, Montana	The Integrated Passive Biological Treatment Process project is demonstrating a technology consisting of a series of biological processes for the complete mitigation of acid mine drainage (AMD).

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	Prevention/Source Control	Acid Drainage/ Water Treatment	Biological Treatment	Passive Treatment	Active Treatment	Pit Lakes	Remote Locations	Sustainability	Modeling	Characterization	Technology or Process/ Provider	Demonstration Site/Location	Comments
Sulfate-Reducing Bacteria-Driven Sulfide Precipitation		♦	♦		♦					♦	Two-stage Bioreactor with Recycle/MSE Technology Applications	Golden Sunlight Mine, near Whitehall, Montana	A unique two-stage bioreactor system was designed to treat acid drainage waters. In one stage, acid drainage influent was mixed with recycled bioreactor effluent to reduce acidity and precipitate metals. Clear solution overflowed to the bioreactor stage where methanol was added as a food source for sulfate-reducing bacteria. Operation greatly improved the water discharged to the environment. The pH of the effluent averaged 6.0. The acidity, copper, aluminum, and zinc were reduced by greater than 99%. Iron was reduced by 94% and sulfate was reduced by 40%.
Gas-Fed Sulfate-Reducing Bacteria Berkeley Pit Water Treatment		♦	♦		♦	♦	♦				Biosulfide process/ Biomet of Canada	Mike Mansfield Advanced Technology Center, Butte, MT	The Biosulfide process was utilized to separate and recover copper and zinc from Berkeley Pit water. The process included a partial oxidation natural gas burner to produce a hydrogen-rich offgas, which was then fed along with nutrients to a sulfate-reducing bacteria reactor for production of hydrogen sulfide gas from process water. The hydrogen sulfide gas was used to recover copper and zinc as sulfides.
Improvements in Engineered Bioremediation of Acid Mine Drainage		♦	♦	♦				♦	♦		BEST Model/MSE Technology Applications, Butte, MT	Mike Mansfield Advanced Technology Center, Butte, MT	The BEST model was developed to aid in the design of passive treatment systems for AMD.
Biological Prevention of Acid Mine Drainage (Gilt Edge Mine)	♦		♦								Redox-mediated Biotransformation/ Green World Science under license to ARCADIS	Gilt Edge Mine/ near Deadwood, South Dakota	Carbon sources (animal feed-grade molasses and methanol) were added to saturated acid-generating waste rock to create reducing conditions and eliminate the production of acid mine drainage.

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	Prevention/Source Control	Acid Drainage/ Water Treatment	Biological Treatment	Passive Treatment	Active Treatment	Pit Lakes	Remote Locations	Sustainability	Modeling	Characterization	Technology or Process/ Provider	Demonstration Site/Location	Comments
Organic Degradation Rates, Phase I and II				♦				♦		♦	Natural Wetland/Montana Tech	Upper Blackfoot Mining Complex/ Lincoln, Montana	The primary objectives for this project were to determine the organic matter decay rate in sulfate-reducing wetlands and improve the understanding of how natural wetlands function in metals-contaminated regions.
Prevention/Source Control													
Clay-Based Grouting	♦						♦			♦	Ukranian clay-based grout/ Spetstamponazhgeologia Enterprises (STG)	Mike Horse Mine, near Lincoln, Montana	Clay-based grout was injected into the workings of the Mike Horse Mine in Montana
Underground Mine Source Control	♦						♦			♦	Polyurethane expandable grout/de neef Construction Chemicals, Inc.	Miller Mine, near Townsend, Montana	This project demonstrated that grout materials can be used to reduce and/or eliminate the influx of water into the underground mine system by forming an impervious barrier that results in reduced, long-term environmental impacts of the abandoned mine.
Surface Waste Piles—Source Control	♦						♦			♦	Spray-applied urethane grout/ General Polymers, Inc.	Peerless Mine, near Rimini, Montana	A surface waste pile at the Peerless Mine was capped using a spray-applied urethane grout. A French drain system was also installed to control groundwater flow at the site.
Source Control Tailings Cap	♦						♦			♦	IESCRETE/International Engineering Solutions Krystal Bond/Krystal Bond, Inc. Spray-applied, modified polyurea/Quality Maintenance Contractors	Mammoth Mine, near Townsend, Montana	This project identified a source control material for application on tailings at the Mammoth Mine in Montana.

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	**Prevention/Source Control**	**Acid Drainage/ Water Treatment**	**Biological Treatment**	**Passive Treatment**	**Active Treatment**	**Pit Lakes**	**Remote Locations**	**Sustainability**	**Modeling**	**Characterization**	**Technology or Process/ Provider**	**Demonstration Site/Location**	**Comments**
Prevention of AMD Generations from Open-Pit Mine Highwalls	♦							♦		♦	Furfuryl alcohol resin sealant (FARS)/Intermountain Polymer EcoBond™/Metals Treatment Technology Dupont Passivation Porcess/ University Nevada Reno UNR Magnesium Oxide/ University Nevada Reno	Golden Sunlight Mine/Whitehall, Montana	Various grout materials were applied to the highwall of the Golden Sunlight Mine to assess their effectiveness in acid prevention.
Remediation of Underground Mines Using Source Control/Passive Technologies	♦	♦		♦			♦			♦	Grouting and SRB Technology/MSE Technology Applications	Lee Mountain Mine near Rimini, Montana	This project will use a combination of two technologies to accomplish the remediation of an underground mine system. A source control (grouting) technology will be used to reduce the flow in the underground mine workings. A second, passive water treatment technology will be used to treat residual water discharging from the adit. The combination of the technologies is expected to increase the efficiency, longevity, and decrease the cost to operate the passive treatment system.
Remediation Technology Evaluation at Gilt Edge Mine	♦			♦			♦			♦	Silica microencapsulation/Klean Earth Environmental Company Envirobond/Metals Treatment Technologies Passivation Technology/ University of Nevada, Reno	Waste rock at Gilt Edge Mine/near Deadwood, South Dakota	The project generated performance and cost data for promising new technologies for preventing the oxidation of sulfide waste rock. The new technologies were compared to the presumptive remedy of lime treatment as well as to controls in which no treatment is performed.

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	**Prevention/Source Control**	**Acid Drainage/ Water Treatment**	**Biological Treatment**	**Passive Treatment**	**Active Treatment**	**Pit Lakes**	**Remote Locations**	**Sustainability**	**Modeling**	**Characterization**	**Technology or Process/ Provider**	**Demonstration Site/Location**	**Comments**
Microencapsulation to Prevent AMD	♦			♦				♦			Envirobond/Metals Treatment Technologies Silica microencapsulation/Klean Earth Environmental Company	Research Laboratory for Minnesota Department of Natural Resources/ Duluth, Minnesota	Various microencapsulation technologies were demonstrated. Microencapsulation is the isolation of sulfide minerals by precipitating a chemical *coating* on unoxidized pyrite or where the material is reacted with an oxidizing agent to produce ferric ions.
Electrochemical Tailings Cover	♦									♦	Electrochemical Tailings Cover/ Enpar Technologies, Inc.	MSE Technology Applications site/Butte, Montana	The purpose of this project was to gather performance and cost data for an electrochemical cover technology.
Biological Cover	♦		♦				♦			♦	Biofilm barrier/Center for Biofilm Engineering at Montana State University and MSE Technology Applications	Mammoth Tailings/near Cardwell, Montana	Biological cover placed on tailings to prevent formation of AMD at the Mammoth Tailings site in Montana. This technology was transferred to Golden Sunlight Mine during the Summer of 2004.
Microbial and Geochemical Responses in Acid Producing Tailings	♦		♦						♦	♦	Nutrification of tailings/Montana State University's Center for Biofilm Engineering	Center for Biofilm Engineering on the Montana State University Campus/Bozeman, Montana	This project will evaluate, at laboratory scale, the geochemical properties of mine tailings when microbes are used as the treatment technology.
Passive Remediation of Sulfide Wastes using Covers, Lime and Controlled Diffusion	♦			♦				♦			Various capping scenarios/Montana Tech	Montana Tech, Butte, Montana	The objective of this research is to recreate, in diffusion cells, sample capping scenarios for the mine waste closure of potentially acid generating materials with lime as an amendment. The cell will then be used to measure oxygen flux under a scale of saturation conditions that would accurately describe the oxygen diffusion through the capping alternatives presently being prescribed in the field.

Table 2. Summary of all Mine Waste Technology Program projects.

Project Name	Prevention/Source Control	Acid Drainage/ Water Treatment	Biological Treatment	Passive Treatment	Active Treatment	Pit Lakes	Remote Locations	Sustainability	Modeling	Characterization	Technology or Process/ Provider	Demonstration Site/Location	Comments
SITE In Situ Mercury Stabilization Technologies	♦										Silica microencapsulation/Klean Earth Environmental Company Phosphate-based treatment/E&C Williams	Sulfur Bank Mercury Mine/ Clear Lake, California	This project was conducted in conjunction with the SITE program. The project demonstrated the effectiveness of various technologies for in situ treatment/ stabilization of mercury contaminated mining materials.
Pit Lakes													
Bioremediation of Pit Lakes		♦	♦	♦		♦		♦		♦	Neutra-Mill/Earth Systems Redox-Mediated Biotransformation/ARCADIS Traditional Technologies to make water dischargeable	Gilt Edge Mine, Deadwood, South Dakota	An in situ treatment of the Anchor Hill Pit Lake at the Gilt Edge site in South Dakota is being performed.
Berkeley Pit Water Treatment		♦			♦	♦				♦	Two-stage lime treatment/Montana Tech	Berkeley Pit Lake, Butte Montana	A two-stage lime precipitation technology for treatment of Berkeley Pit water was demonstrated.
Berkeley Pit Innovative Technologies Project		♦			♦	♦					Zeolite Production Technology/International Hydronics Corporation Octolig™ and Conventional Precipitation/Metre General, Inc. Mine Remediation Services Hydrometrics Purity Systems, Inc. Geo2 Limited (2 projects) SPC International Corporation Technical Assistance International, Inc. Hydroplus Technologies	Berkeley Pit Lake, Butte Montana	Several technologies were investigated for treatment of Berkeley Pit water

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Berkeley Pit Limnocorrals		♦	♦	♦		♦				♦	Nitrification of Limnocorrals Algae/Montana Tech	Berkeley Pit Lake, Butte Montana	Limnocorrals have been used for about 40 years for experimental studies in lakes when it is necessary to test biological, physical, and chemical properties in situ while varying an aspect of the ecosystem on a small scale to determine the outcome. This project will test bioremediation potential in situ using limnocorrals with nitrification and inoculation with the algae as variables.
Dual Ecosystem Enhancement: In-situ Pit lake Remediation by Slag-Silicate Addition		♦				♦		♦			Slag Addition/Montana Tech	Berkeley Pit Lake, Butte Montana	Remediation potential of smelter slag for in-situ treatment of the Berkeley Pit will be evaluated.
Subaqueous Pyrite Oxidation		♦				♦				♦	Characterization Techniques/ Montana Tech	Berkeley Pit Lake, Butte Montana	This project demonstrated the potential importance of subaqueous pyrite oxidation by Fe^{3+}, with special attention to the possible role this process plays in the generation of acid in pit lakes. Stable isotopes were used to elucidate the primary mechanism of pyrite oxidation in the Berkeley Pit Lake (i.e., aerobic versus anaerobic).
Integrated Process for Treatment of Berkeley Pit Water						♦			♦		Spreadsheet Model/MSE Technology Applications	Berkeley Pit Lake, Butte Montana	The objective of this project is to develop integrated, optimized treatment systems for processing Berkeley Pit water.
Pit Lake System—Characterization and Remediation for the Berkeley Pit Pit Lake System—Deep Water Sediment/Pore Water Characterization and Interactions		♦				♦				♦	Characterization Techniques/ Montana Tech	Berkeley Pit Lake, Butte Montana	Interdisciplinary team of Montana Tech researchers studied various aspects of the Berkeley Pit Lake System.

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Pit Lake System—Biological Survey of Berkeley Pit Water Pit Lake System Characterization and Remediation for Berkeley Pit—Phase II		♦				♦				♦	Characterization Techniques/ Montana Tech	Berkeley Pit Lake, Butte Montana	Interdisciplinary team of Montana Tech researchers studied various aspects of the Berkeley Pit Lake System.
Pit Lake System Characterization and Remediation for Berkeley Pit—Phase III		♦				♦				♦	Characterization Techniques/ Montana Tech	Berkeley Pit Lake, Butte Montana	Interdisciplinary team of Montana Tech researchers studied various aspects of the Berkeley Pit Lake System.
Algal Bioremediation of Berkeley Pit Water, Phase II		♦	♦	♦		♦				♦	Adsorption of metals using algae/ Montana Tech	Montana Tech/Butte, Montana	This project was to further investigate some of the previously isolated extremophiles (specifically algae) from the Berkeley Pit Lake system that may be used as a potential solution for bioremediation.
Biological Cyanide Destruction													
Biocyanide		♦	♦		♦						Biological cyanide destruction/ Pintail Systems	McCoy Cove Mine, near Battle Mountain, Nevada	Biological destruction of cyanide was demonstrated at McCoy/Cove Mine near Battle Mountain, Nevada.
Cyanide Heap Biological Detoxification		♦	♦								Biological cyanide destruction/ Whitlock and Associates, Little Bear Laboratories, Compliance Technology, and Applied Microbiology and Biotechnology	McClelland Laboratories, Sparks, Nevada	Large-scale column tests of four biological cyanide destruction technologies were performed.

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Cyanide Heap Biological Detoxification		♦	♦							♦	Biological cyanide destruction/ Whitlock and Associates	Cortez Gold Mine, Crescent Valley, Nevada	This demonstration will be conducted at the Gold Acres Heap Leach Pad located at Placer Dome's Cortez Gold Mine in Crescent Valley, Nevada. The biological technology owned by Whitlock & Associates of Spearfish, South Dakota, will be used to destroy the cyanide present. The effect of the technology on heavy metals of concern will also be monitored.
Remote Monitoring													
Calliope Mine Internet Monitoring System							♦				Telemetry, monitoring data available on Internet/MSE Technology Applications	Calliope Mine/ near Butte, Montana	This project installed a system for download remote sampling data and images from the Calliope Mine.
Mine Site Telemetry—Fuel Cell							♦				Fuel Cell/Fuel Cell Technologies	Susie Mine/ Rimini, Montana	This project will evaluate the performance of a fuel cell supplied by the DOE National Energy Technology Laboratory as the power source for instrumentation and equipment at a remote mine site.
Remote Analytical Monitor							♦				Real-time monitor for Cu, Al, Zn/Johns Hopkins University-Applied Physics Laboratory	Johns Hopkins Applied Physics Laboratory/ Baltimore, Maryland	A system to monitor Cu, Al, and Zn was tested in the laboratory
Sustainability													
Phosphate Stabilization of Heavy-Metals Contaminated Mine Waste Yard Soils	♦							♦			In-situ lead stabilization using phosphoric acid/Missouri Department of Natural Resources	Joplin, Missouri NPL Site	In-situ phosphate stabilization of soils followed by revegetation of the treatment plots in Joplin, Missouri.

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Revegetation of Mining Waste Using Organic Amendments and Evaluate the Potential for Creating Attractive Nuisances for Wildlife	♦							♦		♦	Milorganite/Milwaukee Metropolitan Sewage District Ormiorganics/Organic Resource Management, Inc. St. Peter’s compost/City of St. Peter’s, Missouri	Doe Run Company/ Desloge, Missouri	Coarse and fine-grained tailings sites at as Doe Run Company site near Desloge, Missouri were amended with various compost materials and revegetated.
Acid/Heavy Metal Tolerant Plants	♦							♦		♦	Local accessions of grasses and forbs/Bridger Plant Materials Company	Anaconda Smelter Superfund Site/ near Anaconda, Montana	The goal of this project is to compare the performance of local acid/metal tolerant seed mixes against comparable mixes now commercially available.

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Linking Waterfowl with Contaminant Speciation in Riparian Soils	♦							♦	♦		In-situ lead stabilization using phosphoric acid/University of Idaho	Shoreline and Wetland plots/Rose Lake, Idaho	In the historic mining area of North Idaho, a century of lead smelting has left riverbanks and lake bottoms with lead-contaminated sediments. A U.S. Fish and Wildlife Service scientist reported that several studies showed that lead in soil sediments consumed by tundra swans and mallards poisoned and killed the birds. Mallard studies indicated that 36% of the adults in the area had clinical levels of lead poisoning mostly as a result of eating lead-contaminated sediments. Tundra swan studies indicated that 96% of the deaths in the area resulted from lead poisoning. The MWTP is filling a scientific information gap by correlating phosphorus-lead reaction mechanisms with the waterfowl toxicological data. The MWTP work will provide needed technical support to help allow for full-scale applications of phosphate amendment technologies and curtail potential lead poisoning of waterfowl from ingestion of lead-containing sediments. MWTP research on this project is being conducted at the University of Idaho with support from MSE, EPA-NRMRL, EPA Region 10, and the Idaho Department of Environmental Quality. An Associated Press article related to this project appeared in the April 19, 2004, issue of the *Montana Standard.*
Mine Dump Reclamation Using Tickle Grass Project	♦							♦		♦	Tickle Grass/Montana Tech	Montana Tech/ Butte, Montana	

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Investigation of Natural Wetlands Near Abandoned Mine Sites		♦	♦					♦		♦	Natural wetlands/Investigated by Montana Tech	Copper Gulch Wetland/near Jefferson City, Montana Fisher Creek Wetland/near Cooke City, Montana	The main objective of this project was to determine how and to what extent metals are being attenuated by natural wetlands at two remote locations in Montana. Representative samples of soil, groundwater, and surface water were collected for metal analysis. The hydrogeology of each wetland was characterized with the help of shallow piezometers to monitor water level and to collect groundwater samples. Each site was visited several times throughout the year to determine seasonal changes in hydrology or metal removal efficiency.
Mercury Transportation from Reclaimed Mine Sites								♦		♦	Biosamplers (mice)/ Montana Tech	Silver Creek Drainage/near Marysville, Montana High Ore Creek Repository/near Boulder, Montana	This project determined the uptake of mercury by selected plant species and the possible movement of mercury from plants to higher-level consumers such as mice.
Visualization of In-Situ Douglas Fir Roots and Ectomycorrhizae in the Context of Phytoremediation	♦							♦		♦	Ectomycorrhizal Fungi/ Montana Tech	Anaconda Smelter Superfund Site/ Anaconda, Montana	Douglas fir trees will be studied to determine physiological attributes that allow toleration of toxic soils and to determine whether the addition of ectomycorrhizal fungi provides a growth advantage for trees in these types of soils.
Monitoring and Evaluation of Remediation Strategies in the Helena National Forest								♦		♦	PST resin capsules and standard characterization techniques/ Montana Tech	Helena National Forest/near Helena, Montana	This project evaluated the effects of previously selected remediation methods on both abandoned upland as well as wetland mine sites near Helena, Montana.

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Use of Biomonitors for Studying Contamination in Residential Areas and Efficacy of Remediation								♦		♦	Biomonitors/Montana Tech	Residential areas/ Butte, Montana	Domestic dogs will be used to provide information on exposure patterns in mine waste impacted areas in Butte, Montana.
Miscellaneous Projects													
Geochemistry and Isotopic Composition of H_2S-Rich Water in Flooded Underground Mine Workings									♦	♦	Standard characterization techniques/Montana Tech	Travona Mine Shaft/ Butte, Montana	The purpose of this study is to collect water samples from Butte's West Camp for comprehensive chemical and isotopic analysis and to combine these results with geochemical modeling to more fully understand the processes that control the geochemistry of the West Camp mine waters in Butte, Montana.
Sludge Stabilization	♦							♦			Standard techniques/ Montana Tech	Montana Tech/ Butte, Montana	The properties and stability of sludge generated by remediation of acid mine waters was studied.
Photoassisted Electron Transfer Reactions Research		♦				♦					Photocatalysts/Montana Tech	Montana Tech/ Butte, Montana	Dissolved and solid photocatalysts were investigated for removal of cyanide and nitrate anions from mine waters.
Lead Abatement								♦			PR-40/LEADX™/PR-40AFX™ Carbon dioxide blasting technology	Residential Homes/ Butte, Montana	This project gathered cost and performance data on an innovative set of technologies capable of removing lead-based paint from interior decorative wood in residential housing.
Update of Case Studies											Case Studies/MSE Technology Applications	Gilt Edge Mine, South Dakota Golden Sunlight Mine, Montana Leviathan Mine, California	This project completed three case studies on mine sites initially done using funding from the EPA SITE Program. The work included comment incorporation from reviewers as well as updated information about each site. The three sites profiled in the original document included: Gilt Edge Mine in South Dakota; the Leviathan Mine in California; and the Golden Sunlight Mine in Montana.

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Artificial Neural Networks as an Analysis Tool for Geochemical Data									♦		Articial Neural Networks/ Montana Tech	Montana Tech, Butte, Montana	This project applies to artificial neural network (ANN) analysis of geochemical and similar data sets, such as those acquired from the Berkeley Pit in Butte, Montana. There are two main types of ANN, supervised and unsupervised networks, and both lend themselves to analyses of this nature.
Sulfide Complexes Formed from Mill Tailings Project										♦	Column study/Montana Tech	Montana Tech, Butte, Montana	This project investigated the possibility of leaching and mobilization of constituents (particularly arsenic, antimony, and zinc) in anaerobic sediments of tailings ponds by the formation of sulfide complexes.
CALPUFF Modeling of Copper Smelter Emissions									♦		CALPUFF Software/ Montana Tech	Anaconda, MT and the surrounding smelter fallout zone	The goal of this project is to use advanced features of the CALPUFF modeling system to study the impact of the Anaconda smelter plume throughout the region.

KEY CONTACTS

U.S. Environmental Protection Agency:

Diana Bless
U.S. Environmental Protection Agency
Office of Research and Development
National Risk Management Research Laboratory
26 W. Martin Luther King Drive
Cincinnati, OH 45268

Telephone: (513) 569-7674
Fax: (513) 569-7471
bless.diana@epa.gov

U.S. Department of Energy:

Gene Ashby
U.S. Department of Energy
Western Environmental Technology Office
P.O. Box 3462
Butte, MT 59701

Telephone: (406) 494-7298
Fax: (406) 494-7290
gashby@in-tch.com

MSE Technology Applications, Inc.:

Helen O. Joyce, Program Manager
MSE Technology Applications, Inc.
P.O. Box 4078
Butte, MT 59702

Telephone: (406) 494-7358
Fax: (406) 494-7230
helen.joyce@mse-ta.com

Montana Tech:

Mark Peterson, Montana Tech MWTP Project Manager
Montana Tech of the University of Montana
1300 West Park Street
Butte, MT 59701-8997

Telephone: (406) 496-4311
Fax: (406) 496-4116
MePeterson@mtech.edu