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GEOCHEMICAL TREATMENT AND PHYTOSTABILIZATION OF ACIDIC MILL TAILINGS FROM THE PINOS ALTOS MINING DISTRICT, GRANT COUNTY, NEW MEXICO

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ABSTRACT

Acid generating mine and mill waste (tailings) resulting from hard rock mining pose significant environmental problems throughout the Western United States. One such example occurred at the abandoned Mammoth Lode mine and mill facility located within the Pinos Altos Mining District of Grant County in southern New Mexico. Acid generating mine and mill wastes at the site were located adjacent to and inside the primary drainage channel to Bear Creek. Wastes were characterized by low pH, high exchangeable acidity, high future acid generation potential, low fertility, and elevated levels of soluble heavy metals. Based on the results of a successful pilot-scale plot study, the USEPA (Region 6) selected geochemical treatment and phytostabilization as the preferred full-scale mitigation technology for the CERCLA funded Removal Action at the Mammoth Lode site. During the removal, approximately 3,000 cubic yards of the acid generating waste was excavated and treated in lifts on a treatment pad. Geochemical amendments (triple super phosphate, calcium hydroxide, and pulverized limestone) were added to each lift to neutralize the current and potential acidity of the waste and to bind soluble heavy metals. After a mellowing period for pH stabilization to between 6 and 8 units, the treated lift was consolidated into a stable on-site repository. Organic amendments (site-generated wood chips) were added to the upper six lifts, or approximately six feet, of the treated waste. Slow release fertilizer and mycorrhizal fungi inoculum were also added to the upper lift to facilitate the phytostabilization process. A seed mixture of cool and warm season native and adapted grasses was selected to form the basis of phytostabilization and a long-term sustainable ecosystem on the repository and other reclaimed areas. Monitoring of the project over three growing seasons has indicated that geochemical treatment and phytostabilization is a viable and cost effective mitigation technology for acid generating mine and mill waste sites in southern New Mexico.

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INTRODUCTION

The Mammoth Lode site is an abandoned mine and mill facility located in the Pinos Altos Mining District, Grant County, New Mexico. The Pinos Altos District lies in the Pinos Altos Mountains, a small mountain range located approximately six miles north-northeast of Silver City, Grant County, New Mexico. Gold deposits were discovered in the Pinos Altos District around 1860 and were productive until the early part of the twentieth century. Both vein and placer deposits were exploited on a limited scale by the miners of Pinos Altos. Other metal production in the district included silver, lead, and zinc. The only large scale operation in the district was the Empire Zinc Cleveland Mine, on the west side of the range.

The Mammoth Lode mining claim was located in 1887. Initial development of the prospect consisted of two shallow pits and several trenches. A stamp mill was located down slope of the mine workings. The date of construction of the stamp mill is undetermined, but a diagram of the Mammoth Stamp Mill appeared in the 1902 edition of the Sanborn Fire Insurance Map for Pinos Altos, showing the location of a stamp battery, concentrating tables and an engine house. The claim was patented by Golden Giant Mining Company in March, 1928. Construction on the Mammoth property in the twentieth century included a ball mill and floatation cells located adjacent to the original mill. It is uncertain when production activities were abandoned at the site, but it appears to have been in the 1940s.

In 1995, the Mammoth Lode site consisted primarily of limited structural remains from the mining and milling activities, waste rock piles and mill tailings. The fine-grained waste rock and mill tailings occurred adjacent to the main shaft and mill area. The bulk of the tailings were within an ephemeral stream located down slope from the floatation cells. Tailings extended within the stream channel from the Mammoth Lode onto adjacent Bureau of Land Management (BLM) property and into Bear Creek (Figure 1).

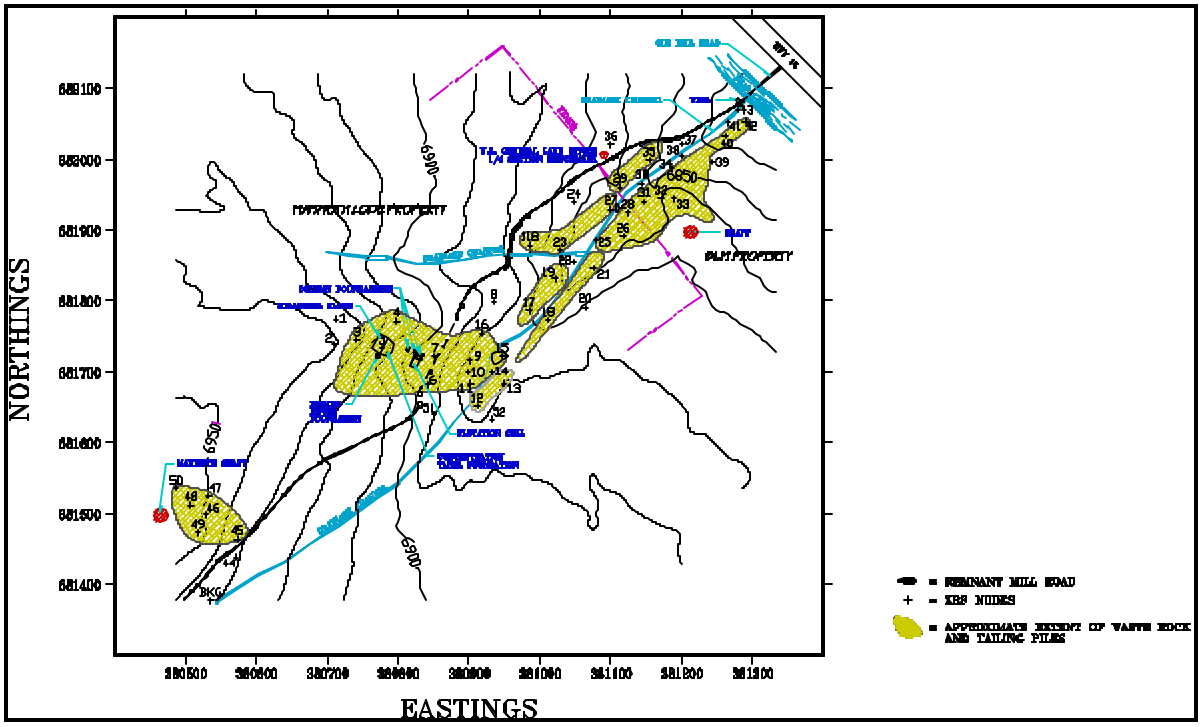

Figure 1. Mammoth Mill site feature map. Coordinates are NAD27 New Mexico West State Plane.

The U.S. Environmental Protection Agency (EPA) Region 6 Response and Prevention Branch (RPB) was notified about the Mammoth Mill site by the New Mexico Environment Department (NMED), which was concerned about acid rock drainage (ARD) and potential metals migration from the site into Bear Creek. In 1995, the EPA RPB began site characterization of the conditions present on the site. Based on the conditions identified, a pilot-scale plot study was undertaken to evaluate the potential for successful geochemical treatment and phytostabilization of the ARD material present on the site. Based on the results of the pilot-scale study, a full scale remediation of the site was undertaken. The following sections describes each of these three phases in more detail.

SITE CHARACTERIZATION

Site characterization was conducted in accordance with strategies detailed in Zehner et. al. (1997). Survey transects were established on the tailings materials at the Mammoth Lode site. *In situ* metals screening was conducted at fifty three transect nodes using a field portable X-ray fluorescence (XRF) spectrometer to estimate copper (Cu), lead (Pb) and zinc (Zn) concentrations. Three readings were taken at each node, which were averaged to derive metals concentration values. Ten percent the samples were analyzed by an independent analytical laboratory for Target Analyte List (TAL) metals (EPA SW846/6010) for confirmation of XRF results.

High accuracy Global Positioning System (GPS) surveys were performed to obtain positions of all XRF nodes. Overhead obstructions limited GPS satellite reception in some locations, so additional surveys were conducted using a total station survey unit to enhance position resolution and define cultural features. Geostatistical modeling and kriging were used to estimate grid metals concentrations from the XRF and survey data. Concentration isopleth maps were created using commercial contouring and mapping software (Figure 2).

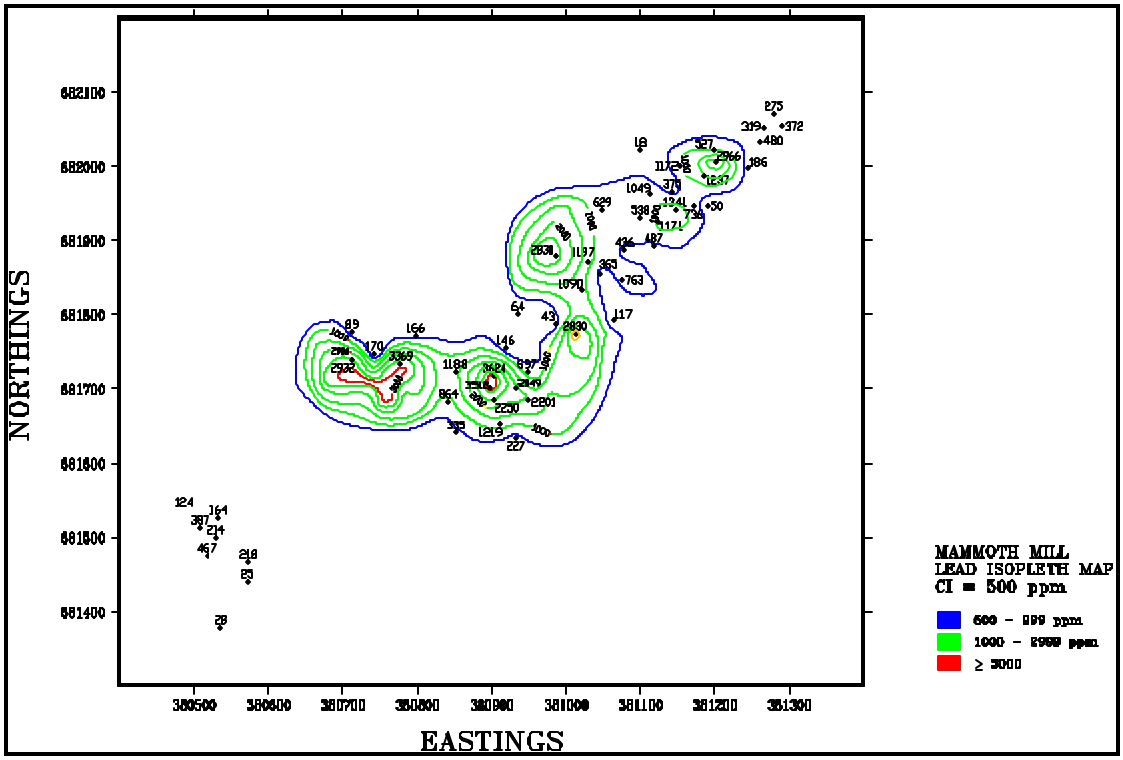

Figure 2. Lead concentration isopleth map from XRF survey of site. Circles are XRF sample points. Values are lead concentration in ppm. Map coverage is the same as Figure 1.

Composite soil samples were collected from six of the transect node locations and analyzed for standard acid/base potential tests (EPA 600/2-78-054), including neutralization potential (NP), exchangeable acidity (EXA), and sulfur forms. Acid generation potential (AP) was calculated from total sulfur. Soil samples were also analyzed for Target Analyte List (TAL) metals (EPA SW846/6010), water extractable metals (Page 1982, ASA No. 9 10-2.3.2), DPTA extractable Cd, Chromium (Cr), Cu, Iron (Fe), Manganese (Mn), Nickel (Ni), Pb and Zn (Page 1982, ASA No. 9 3-5.2.3), saturated past extraction cations (EPA 200.7), electrical conductivity (EPA 120.1), organic matter (USDA No. 60(24)), saturation percent (USDA No. 60 (2)), saturated paste soil pH (USDA No. 60(2)), texture by hydrometer (ASTM D422), water extractable nitrate (EPA 353.2) and potassium (EPA 200.7), $NaHCO_3$ extractable phosphorus (Page 1982, ASA No. 9 24-5.4.2), and water soluble boron.

Results of the site characterization revealed that mill tailings associated with the Mammoth Mill site covered approximately one acre in area and with an estimated volume of 3000 cubic yards. The tailings were void of vegetation and characterized by elevated concentrations of heavy metals (lead up to 3,600 ppm) and a low average pH (3.7 units). Further details on site characterization can be found in Cornelius et. al. (1997). According to Steffen, Robertson and Kirsten, Inc. (1992), mine rock and tailings with Net Neutralization Potential (NNP = NP - EXA - AP) values less than -20 tons of calcium carbonate ($CaCO_3$) per kiloton and NP:AP ratios less than 1:1 are considered potentially acid generating. The Mammoth Mill tailings had an average NNP of -22.27 and NP:AP ratio below 1:1, indicating a strong potential for future acid generation. Site characterization results were used to develop a pilot-scale study to evaluate the potential for geochemical treatment and revegetation of the mill tailings.

PILOT-SCALE REVEGETATION PLOT STUDY

A pilot-scale revegetation plot study was initiated in June, 1995 at the Mammoth Lode site to determine the potential for utilizing geochemical stabilization and revegetation to remediate the acidic, metals-contaminated mill tailings. The plot study addressed the following elements: 1) geochemical stabilization of the tailings; 2) addition of organic amendments and chemical fertilizers; and 3) revegetation and erosion control. In addition to the site specific data, the methodologies used in the plot study utilized information from the following sources: 1) the Streambank Tailings and Revegetation Studies-STARS (Reclamation Research Unit, et. al 1989; Schafer and Associates, et. al 1989; and Schafer and Associates and Reclamation Research Unit, 1993), a tailings revegetation study conducted on mill tailings in Silver Bow Creek, Butte, Montana by scientists from Schafer and Associates and the Reclamation Research Unit, Montana State University, Bozeman, Montana for the Montana Department of Health and Environmental Sciences, Helena, Montana in association with U.S. EPA Region 8; 2) a greenhouse revegetation potential study conducted as part of the Removal Site Assessment for the Blackhawk Mill Tailings site near Hanover, Grant County, New Mexico (Cornelius, et al, 1996); and, 3) information in Munshower (1994).

The Mammoth Lode revegetation study utilized three paired plots (six total), each with a size of approximately 10 by 10 feet. Geochemical stabilization was accomplished by the addition of calcium hydroxide, calcium carbonate and dicalcium phosphate to the tailings as described in Cornelius et al. (1997). Commercially available calcium hydroxide was added to each plot to neutralize all current acidity plus ten percent of potential acidity. One each of the three paired plots received enough additional calcium carbonate to neutralize the remainder of the potential acidity. The remaining plot of each pair received enough calcium carbonate to neutralize the tailings to a

final AP:NP ratio of 1:3. Calcium carbonate was added as crushed limestone from a local quarry source. Commercially available dicalcium phosphate was added to the tailings to enhance binding of metals and to enhance available P. After the addition of each amendment, the test plots were thoroughly tilled, watered and allowed to mellow.

Once the pH of the treated tailings fell below 8.5 units, a mixture of bark and saw mill waste was added to the plots at a rate required to bring the overall organic matter content of the upper six inches of the tailings to approximately two percent. Soil fertility analysis results indicated that N:P:K fertilizer should be amended at rates of 100:50:50 pounds per acre, which was applied to the plots as standard commercial fertilizer. Previous greenhouse studies on tailings from a nearby mine and mill site indicated that geochemical treatment may have caused a boron deficiency (Cornelius et. al. 1996), therefore, boron was applied at a rate of 1.5 lbs per acre as borax. In July 1995 each plot was seeded with a mixture of cool and warm season grass species and a nitrogen-fixing filler species (see Cornelius et. al. (1997) for details). The test plots were covered with biodegradable excelsior matting to provide surface erosion control and serve as a mulch for moisture retention.

The test plots were monitored and maintained through October 1995. Periodic maintenance included nutrient addition and irrigation of the plots. In October 1995, soil and plant tissue samples were collected for laboratory analysis. Test plots were also monitored without additional maintenance through September 1996. Vegetation cover was estimated within each plot on four sample dates during the first growing season (Cornelius et. al. 1997). Additional vegetation cover surveys were performed on two dates to document results of the second growing season.

Results of the geochemical stabilization of the mill tailings indicated that average soil pH increased from 3.7 to 6.3 units, exchangeable acidity decreased from 8.8 to 4.2 tons/kiloton, neutralization potential increased from 1.7 to 28.8 tons/kiloton, and acid/base potential increased from -14.2 to +17.0 tons/kiloton (Cornelius et. al. 1997). Native soils in the area of the Mammoth Mill site have soil pH values ranging from 5.5 to 7.5 units. No significant differences were observed in measured parameters from the test plots receiving the greater amount of calcium carbonate. The addition of logging waste increased the average soil organic matter from 0.5 to 1.73 percent. Soil fertilizer amendments increased plant nutrients from very low levels to levels conducive to plant growth, including boron, nitrogen, phosphorus and potassium.

Results from the short duration of this plot study indicate that revegetation was successful. Seed germination was observed within one week of sowing. Cover was relatively high on all sample dates (range 27-80%), even though all plots showed signs of intense grazing damage from local populations of deer, elk, and javelina. Observed seed production was low on all plots during the 1995 growing season. Several of the treatment plots had small areas within them characterized by very low plant cover. Both seed production and grass cover increased during the second (1996) growing season.

Plant tissue analysis of clover and blue grama from the test plots showed elevated heavy metal concentrations relative to plants from comparative background areas (data not shown). However, average concentrations of all metals were below Maximum Tolerable Levels of Dietary Minerals (MTLDM) standards for cattle (Subcommittee on Mineral Toxicity in Animals, 1980), except for Cd and Mg. Cadmium standards were based on human food residue considerations, and likely are biased high.

Results from the plot study at the Mammoth Lode indicated that geochemical treatment and phytostabilization is a successful and viable application for remediation of the pyritic mine waste at the site. The treated plots maintained a near neutral pH and an acceptable growing medium for the vegetative cover. The probabilities of long term stability of the treatment method also appear

favorable. The percent cover and density of the vegetation increased from the first growing season to the second growing season, surviving both extensive grazing pressure and extended drought conditions without supplemental irrigation or maintenance past the first growing season. Based on the success of the pilot-scale study a full-scale remediation plan was developed and implemented for the site.

FULL SCALE PROJECT

In October 1996, the Region 6 USEPA RPB initiated a Superfund removal action using geochemical treatment and phytostabilization as the remediation alternative at the Mammoth Lode site. The removal action was separated into the following work phases: 1) initial site preparation; 2) excavation, geochemical treatment, and consolidation of waste material; 3) site reclamation; and 4) maintenance and monitoring.

Phase 1 - Initial Site Preparation

Initial site preparation included restoration and construction of site roads, preparation of the on-site geochemical treatment pads and repository, and procurement of equipment and supplies.

Phase 2 - Excavation, Geochemical Treatment and Consolidation of Mine Waste

The removal construction contractor excavated approximately 3000 cubic yards of mine and mill waste for the Mammoth Mill Project. Excavation areas were defined and evaluated using XRF and soil pH data. Material was relocated to an on-site treatment pad for geochemical stabilization.

Geochemical treatment was based on the plot study results and proposed the use of dicalcium phosphate applied at a rate of five tons/kiloton of waste, calcium hydroxide applied at a rate of nine tons per kiloton of waste, and pulverized limestone applied at a rate of 17.5 tons/kiloton of waste. For the Mammoth removal, triple super phosphate (0-38-0) was substituted in place of dicalcium phosphate, as it was not readily available in the required quantities at the time of the removal. Triple super phosphate was readily available, had a lower cost per ton, and required less volume than dicalcium phosphate to treat the mill tailings. The triple super phosphate was applied at a rate of 2.5 tons/kiloton (acre-half foot) of treatment material. The sequence and timing for application of geochemical amendments and mellowing periods is important for obtaining the desired results. Cornelius et. al. (1997) gives a detailed discussion of the treatment methodology that was followed for this site.

The Mammoth Mill waste material was treated in thirteen, one foot thick treatment lifts. Amendment quantities were varied depending upon the specific characteristics of each treatment lift. A combination of heavy equipment ripping teeth and an agricultural disc plow were used to mix the tailings and geochemical amendments. After amendment addition and mixing, a mellowing period allowed for completion of metals binding and stabilization of soil pH to seven to eight units. As part of the mellowing process, water was applied periodically at amounts equivalent to 0.5 to 1.0 inches of precipitation to maintain soil moisture levels at approximately sixty to eighty percent saturation capacity.

Phase 3 - Site Restoration

Restoration activities at the Mammoth Mill site involved the physical stabilization and phytostabilization (revegetation) of the drainage/excavation area and the on-site repository. The treated tailings excavated from the Mammoth lode were consolidated to a single repository located east of the Mammoth shaft. The single repository had sufficient capacity for the treated tailings, was in an area previously disturbed by mining operations and did not require extensive engineering controls.

The upper three feet of the repository was amended with 20 tons of site-generated wood chips per kiloton of treated material to increase organic content. Nitrogen (N), phosphorous (P), and potassium (K) fertilizer was added to the upper surface at a rate of 200:100:100 pounds per acre. Boron as borax was added at a rate of 1.5 pounds per acre. A commercially available microrhyzal inoculum was also added to the top lift at manufacturer recommended application rates.

Restoration of the drainage/excavation area involved the use of limestone riprap and erosion control matting. On December 22, 1997 personnel demobilized from the Mammoth Mill site to allow for mellowing of the treatment material and to postpone revegetation activities to coincide with commencement of the summer rainy season.

On June 23, 1997 personnel and equipment were re-mobilized to the Mammoth Mill site to complete restoration activities. The drainage/excavation area and repository were revegetated with a seed mix consisting of native and adapted species of shrubs, sub-shrubs, cool season grasses and warm season grasses (Table 1). Seeding rates were based on critical area recommendations for southern New Mexico rangeland (Allison, 1992). An automated, temporary irrigation system was installed to maintain optimum moisture levels during the first growing season. Restoration activities were completed and personnel and equipment demobilized from the Mammoth Mill site on July 23, 1997.

Table 1. Plant species included in the seed mix for revegetation of the Mammoth Mill site.

Cool Season Grasses	Warm Season Grasses	Shrubs/Sub-Shrubs
Agropyron elongatum Tall Wheatgrass	*Bouteloua gracilis* Blue Grama	*Artemesia ludoviciana* Prairie Sage
Agropyron intermedium Intermediate Wheatgrass	*Bouteloua curtipendula* Side Oats Grama	*Atriplex canescens* Four-wing Saltbush
Agropyron dasystachium Thickspike Wheatgrass	*Hilaria Jamesii* Galleta	*Cercocarpus Montanus* Mountain Mahogany
Agropyron riparium Streambank Wheatgrass	*Muhlenbergia Wrightii* Spike Muhly	*Cowania mexicana* Mexican Cliffrose
Bromus marginatus Mountain Brome	*Panicum virgatum* Switchgrass	*Eurotia lanata* Winter Fat
Festuca arizonica Arizona Fescue	*Sporobolus airoides* Alkali Sacaton	*Rhus trilobata* Skunk Bush
Festuca ovina var. duriuscula Hard Fescue		

Phase 4 - Maintenance and Monitoring

Maintenance and monitoring at the Mammoth Mill site involved periodic site visits to evaluate/document the establishment of vegetation, monitor soil nutrient and ph levels, and perform any required maintenance on the irrigation system. The temporary irrigation system was dismantled in October 1997, after the first growing season. Total grass cover estimates for fall monitoring visits during 1997-1999 are presented in Table 2. Total grass cover has been stable on the site during the three growing seasons since the removal was completed. Grass cover of treated areas were comparable to a revegetated, disturbed control area.

Table 2. Fall 1997, 1998 and 1999 total percent grass cover estimates taken from revegetated areas at the Mammoth Mill Site.

Location	Total Grass Cover		
	Fall 1997	Fall 1998	Fall 1999
Disturbed Control	27	22	18
Repository	22	15	21
BLM Property	25	22	15

SUMMARY AND CONCLUSIONS

The USEPA Region 6 conducted a site characterization of the Mammoth Mill site in the Pinos Altos Mining District, Grant County, New Mexico. Results indicated that acid generating mine and mill wastes were located adjacent to and inside the primary drainage channel to Bear Creek. Wastes were characterized by low pH, high exchangeable acidity, high future acid generation potential, low fertility, and elevated levels of soluble heavy metals. A pilot-scale plot study was conducted, which indicated that geochemical treatment and phytostabilization was an appropriate full-scale mitigation technology for the CERCLA funded Removal Action at the site. During the removal, 3,000 cubic yards of acid generating waste was excavated, treated and transferred to an on-site repository. All impacted areas were treated with organic amendments and revegetated. Site remediation has been successful for three growing seasons, with treated waste and vegetation cover stable. The geochemical treatment and phytostabilization processes used for remediation of the Mammoth Mill site had a lower cost relative to conventional excavation and disposal remediation methods.

NOTICE

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METAL MINE TAILING REPROCESSING FOR ENHANCED VEGETATION ESTABLISHMENT: CLEAN TAILING TECHNOLOGY

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ABSTRACT

Mine tailing reprocessing was evaluated as an innovative reclamation technology for sulfide mine tailings. Mill tailings resulting from metal mining commonly cause resource degradation through oxidation of acid-forming minerals resulting in the release of metals and acidity to the environment. Reclamation technologies employed at the present time for sulfide tailing materials typically employ isolation or chemical treatment approaches for control of acid generation. Pyrite and other sulfides are not removed during treatment. The long-term permanence of these isolation and treatment technologies is therefore unknown, since sulfides may be exposed through deterioration of engineered caps or when amendments added during in-situ treatment are consumed or eroded. In laboratory and greenhouse evaluation of Clean Tailing Technology, sulfides were removed from tailings by reprocessing to create a more hospitable plant rooting media. Tailing reprocessing resulted in decreased total and water soluble metal levels in the cleaned tailing material. Vegetation establishment in the cleaned tailing media relative to growth in topsoil and lime amended tailings was measured and favorably demonstrates the potential for plant establishment and cost savings using Clean Tailing Technology. A field demonstration of the technology was implemented in 1999.

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INTRODUCTION

A history of environmentally insensitive tailing disposal practices has resulted in large scale ecological harm caused by acid mine drainage (AMD). In addition to water quality impairment, loss of vegetation, and prevalent erosion have resulted. In the state of Montana over 20,000 inactive or abandoned mine sites have been identified as contributing to degradation of over 1,000 miles of stream (Friel et al., 1991).

Current tailing reclamation practices in the United States are of two main types: capping, and in-place stabilization. Capping approaches are intended to provide waste isolation from air and water, though the degree to which this has been accomplished reflects the design of the cap, for which no standard design exists. Chemical barriers have been used in revegetation programs in Butte, Montana. Lime barriers of 4 to 6 cm were placed below coversoils of 50 cm thickness. This technique has been successful but a limited number of plant species has developed (Keammerer, 1992). Water-balance caps using thick soil and subsoil layers placed over waste are sometimes constructed in areas of limited precipitation where infiltration of water into waste can be prevented by storage and evapotranspiration (Strong, 1994). Engineered caps where soil is placed over impermeable geomembranes have also been constructed.

In-place stabilization of tailing material through the use of plants (phytostabilization) is an alternative tailing reclamation technology. This reclamation approach often requires addition of chemical amendments for control of conditions inhospitable to plant growth, most notably acidity. Lime addition is consequently the backbone of remedial efforts for in-situ revegetation of acid producing tailings. In the Clark Fork River Basin (Montana) where large expanses of acid-producing tailings are exposed, the STARS (Schafer and Associates and Reclamation Research Unit (RRU), 1993) and ARTS (RRU 1997) technologies are commonly considered for stabilization of acid producing tailings when sufficient soil resource is not available for capping or when damages caused by tailing excavation compel consideration of alternative reclamation approaches. These phytostabilization methods have demonstrated successful establishment of native plant species in lime amended tailings, yet concern exists over the permanence of these techniques.

Current reclamation techniques are subject to some limitations. Capping and tailing amendment can be very expensive. Phytostabilization techniques utilizing lime addition pose the additional threat of reacidification once the neutralizing capacity of the amendment has been consumed. In addition to the threat of reacidification, total metal concentrations are unchanged by in-place tailing reclamation. Water soluble metal concentrations in the rootzone are reduced by lime addition allowing for plant establishment, yet pH control is permanently required. High cost of implementation, coupled with risk of reacidification, causes concern for the permanence and feasibility of in-place tailing reclamation techniques.

Capping technologies utilizing soil or non-toxic geologic media are a common reclamation approach, although adequate amounts of cover material are frequently difficult to locate. If coversoil requires transportation to the site from another source, the costs may outweigh the benefits (Williamson et al., 1982). A major concern of all capping technique is that tailings are still present on the site with the same, or somewhat reduced, potential to generate acidity and release heavy metals. Degradation of cap integrity by erosion can re-expose tailings to weathering processes. Clay barriers can crack and plastic liners can be damaged or deteriorate, both of which undermine the application of capping techniques (Pulford, 1991).

Reprocessing of tailing materials has not been previously evaluated as a reclamation technology, but has been considered as an approach for recovery of metals. At INCO Ltd. Clarabelle Mill in Canada, sulfide minerals were removed from tailing material using froth flotation. The following conclusions were reached: 1) up to 94% of INCO's main tailings can be converted to low sulphur tailings, 2) low sulphur tailings showed a net neutralizing potential while non-reprocessed tailings remained potentially acid generating, 3) low sulfur tailings produced neutral seepage with low nickel, iron, and sulfate concentrations even after 1400 mm of cumulative rainfall and three peak oxidation periods, and 4) low sulfur tailings demonstrated low oxygen consumption, (Stuparyk et al., 1995).

In another study, four samples of tailings from three operating mines were characterized for acid generating potential and reprocessed to remove sulfide minerals. The sample contained 2.34% S, 4.15% S, 3.5% S, and greater than 20% S. All four samples showed an acid producing potential exceeded the neutralization potential. Using flotation, researchers were able to reduce the sulphur content to a range of 0.15-0.35% S, corresponding to recovery rates of 93%-98% (Humber, 1995).

In some instances, reprocessing may yield sufficient grades of economically valuable metals to consider recovery rather than disposal. Bench tests performed on copper-bearing open-pit strip waste showed considerable recovery of copper following crushing, sizing, flotation, and leaching techniques. Eight to fifteen percent recovery of other precious metals (gold and silver) was demonstrated (McKinney et al., 1973). According to research performed by Cristovici (1986), historic gold recovery by amalgamation and gravity concentration plants was low. Such tailings may still hold significant amounts of recoverable gold. Research determined the optimum grinding size for gold flotation at this site was 60% to 70% less than 74Fm, resulting in gold recovery of about 92%. This concentrate contained greater than 20 g Au/t. A forty-eight hour cyanidation treatment gave best results, regardless of grain size. Cristovici and others (1986) concluded recovery of gold from the tailings pond was economically feasible with the possibility to turn a profit by a relatively simple process.

Reprocessing of tailings has been selected as the remedial technology for cleanup at the Cleveland Mill Superfund site in New Mexico. Froth flotation has been evaluated as the best way to reduce metals concentrations in tailings materials at an abandoned lead and zinc mine

(Ecology and Environment, Inc., 1993). Eighteen acres along Little Walnut Creek and one of its tributaries were contaminated by tailings, ore, and dust with elevated metal levels. Excavation and transportation of material to a processing plant has been deemed the most economically, and environmentally sound alternative for treatment of the tailing material (U.S. Environmental Protection Agency, 1993).

EXPERIMENTAL METHODS

Tailing materials were field collected from three locations characterizing the dissimilar age, texture and administrative control of tailing materials in southwest Montana. The sites chosen for this study were: 1) an operational Copper Mine (CM), 2) a Superfund Site (SS) and 3) an abandoned tailings (AT) impoundment. These materials were field collected by hand excavation from the 0-60 cm depth at each site.

The effectiveness of different tailing reprocessing techniques was evaluated for each tailing material by a contracted laboratory specializing in mineral separation. The most effective method of sulfide separation was determined for each sample and applied to the 60kg bulk samples provided. Representative cleaned and sulfide concentrate fractions from each tailing sample were returned and utilized in laboratory and greenhouse testing at Montana State University. Subsamples were collected from each sample and submitted to an analytical laboratory for total metal and acid-base account analyses.

Water soluble chemistry evaluation of tailing treatments was performed through laboratory leaching utilizing Tempe pressure cells and deionized water. The treatments evaluated were cleaned tailings, cleaned tailings plus lime, lime amended tailings (STARS/ARTS technology), unamended tailings and a topsoil control (50% soil, 50% sand). Three pore volumes of deionized water were passed under pressure (0.5 bar) through each treatment and the resulting leachate collected. Analysis of the leachate for total metal levels, pH and electrical conductivity was performed. Five replications of each treatment were evaluated. Leachate levels of boron, calcium, copper, iron, potassium, magnesium, manganese, sodium, phosphorus, sulfur, zinc, chromium, cadmium, arsenic, and aluminum were determined.

Following completion of the laboratory leaching study, experimental tailing treatments were prepared for greenhouse evaluation of clean tailing reclamation (CTR) technology. The experimental design of the greenhouse study consisted of four treatments (unamended tailings, topsoil cap, lime amended tailings, cleaned tailings) from each of the three sites (CM, SS, AT). Two plant species were evaluated for growth response, *Elymus cinereus* (Basin wildrye) and *Poa pratensis* (Kentucky bluegrass). Five replications were performed of each treatment, resulting in 120 growth tubes. Seeds of these two plant species were placed in the growth tubes and were allowed to grow for 120 days in a climate controlled plant growth facility at Montana State University. After 120 days, above ground biomass was collected. Upon

harvesting, Munsell plant color, number of plants, height of each, and vigor were recorded.

Implementation of a field pilot test of CTR technology was conducted during 1999 at an operational mine generating acid producing tailing material. A specialty contractor provided spiral separation equipment which was used to reprocess approximately 200 dry tons cleaned tailing material. Test plots were allowed to dry over the summer (approximately 4 months) and subsequently regraded, amended with compost, fertilized and seeded. Mycorrhizae inoculated plants were also planted in replication at the test plots. Future monitoring will evaluate the effectiveness of these test plots.

RESULTS

All three tailing materials were successfully reprocessed resulting in a cleaned tailing material and high-grade sulfide concentrate. The high-grade concentrate represented approximately 10% of the original mass, while the cleaned tailings comprised approximately 90% of the original mass. Cleaning was performed by both gravimetric and floatation separation methods at the bench scale for each material. Floatation separation was effective on all tailing materials, though gravimetric separation performed well only on the CM and SS samples.

Reprocessing of tailing materials resulted in enrichment of sulfides in the high-grade concentrate and removal from the tailing material (Table 1). This process resulted

Table 1. Summary of mineral separation effectiveness for removal of sulfides from tailing materials.

Site	Bulk Tailings			Cleaned Tailings			Lime Cost Reduction
	Sulfide S	Lime Requirement (t/4000t)	Lime Cost ($/acre-2ft)	Sulfide S	Lime Requirement (t/4000t)	Lime Cost ($/acre-2ft)	
SS	3.9	487	19,500	0.17	21	850	96%
CM	0.58	72	2,900	0.28	35	400	51%
AT	0.08	10	400	0.05	6	250	37%

in prominent decreases in lime requirement, most notably from the SS sample where the tailing sulfide sulfur was reduced from 3.9% to 0.17%. Furthermore, scanning electron microscope study of the cleaned tailing material failed to identify any acid-forming sulfide minerals. Barite ($BaSO_4$), a non-acid-forming sulfate mineral was identified and likely contributed the trace sulfide sulfur content of the cleaned tailing material.

Coincident with recovery of sulfide minerals during reprocessing, Pb, As, Cu, Zn and other trace elements were recovered and express an elevated signature in the high-grade concentrate relative to the bulk tailings while the cleaned tailings demonstrated depressed levels of the same elements (Table 2). For example, the SS bulk tailings contained 167 mg Cu/kg while the cleaned tailings contained 96 mg Cu/kg. By contrast, the high-grade concentrate contained 708 mg Cu/kg. This represents a 4.23 fold magnification of copper from the bulk tailings to the high-grade while the cleaned tailings exhibited copper levels 42% lower than the bulk tailings. The degree to which any element is co-recovered with sulfide minerals is dependent on the complex mineralogical associations and weathering reactions occurring in each tailing media therefore confounding any broad prediction regarding the ability of CTR technology to reduce specific metal levels in tailings. Overall, total metals exhibit elevated levels in the high-grade concentrate compared to bulk tailing levels, while clean tailing exhibit reduced levels.

Each of the experimental treatments yielded water soluble constituents that were distinctly associated with the site and experimental treatment (Table 3). Statistically significant differences were evident for many comparisons between treatments observed within each site. Both the topsoil and unamended tailings were controls relative to the experimental treatments, yet both controls provide a different benchmark. The topsoil control was a very fertile, agriculturally productive soil while the unamended tailings control was a plant inhibitory or phytotoxic soil matrix. The degree to which deleterious plant available metal levels were observed was strongly related to pH. The pH of the SS unamended tailings was near 2.0 and corresponded to very high soluble metal concentrations. The AT soil material exhibited a pH near 3.0, and similarly expressed elevated soluble metal levels and no field plant growth. In contrast, the CM tailings were neutral (pH =7.0). This tailing material was fresh and unweathered, consequently pyrite oxidation had not expressed a negative influence on the soil solution pH.

As a general interpretation, the data suggest that the topsoil treatment has the highest levels of plant nutrients and low water soluble levels of plant inhibitory elements. The unamended tailings expressed high levels of plant inhibitory elements, and moderate to high levels of plant nutrients, while the experimental treatments expressed low levels of both nutrients and plant inhibitory elements. Exceptions to this general trend are observed. It is also emphasized that some unexpected trends were observed. For example, water soluble arsenic levels in the topsoil treatment were in excess of the tailing treatments. Water soluble As in the SS control was highest and significantly greater than the topsoil which was also significantly greater than the clean, lime and clean+lime experimental treatments.

Greenhouse plant performance of clean tailing technology was evaluated (Krueger, 1997), but is not included in this paper. Establishment of vegetation at the field demonstration site will be recorded during summer 2000.

Table 2. Total metal levels in field tailing samples, cleaned tailings and high-grade concentrates following mineralogical separation by reprocessing.

Site	Treatment	Mo (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	Mn (mg/kg)	Fe (%)	As (mg/kg)	Al (%)	Ag (mg/kg)	Au (µg/kg)
CM	none (field sample)	161 (2)	1290 (3)	24 (2)	285 (3)	343 (3)	2.5 (3)	68 (2)	7.2 (2)	0.49 (1)	3 (1)
CM	reprocessed (clean tailings)	130 (2)	1060 (3)	22 (2)	265 (3)	336 (3)	2.1 (3)	3.5 (1)	6.5 (1)	0.50(1)	21 (1)
CM	reprocessed (high-grade concentrate)	1270 (2)	14300 (3)	345 (3)	1440 (3)	701 (3)	32 (3)	8480 (2)	2.1 (2)	6.1 (2)	374 (1)
SS	none (field sample)	22 (2)	167 (3)	196 (2)	330 (3)	134 (3)	5.1 (3)	30 (3)	6.4 (2)	3.3 (2)	38 (1)
SS	reprocessed (clean tailings)	13 (1)	96 (3)	202 (3)	334 (3)	132 (3)	2.6 (3)	21 (2)	7.3 (2)	2.0 (1)	176 (1)
SS	reprocessed (high-grade concentrate)	66 (2)	708 (3)	186 (3)	165 (3)	98 (3)	30 (3)	76 (1)	2.4 (2)	5.9 (2)	343 (1)
AT	none (field sample)	61 (2)	196 (3)	1300 (3)	157 (3)	112 (3)	1.5 (3)	87 (2)	3.9 (2)	22 (2)	501 (1)
AT	reprocessed (clean tailings)	39 (2)	127 (3)	837 (3)	91 (3)	108 (3)	1.2 (3)	69 (2)	3.1 (2)	16 (2)	570 (1)
AT	reprocessed (high-grade concentrate)	180 (2)	780 (3)	5170 (3)	692 (3)	112 (3)	3.9 (3)	315 (2)	6.2 (2)	100 (2)	3200 (1)
Topsoil	none (50% soil/50% sand)	4.2 (1)	18 (2)	15 (2)	40 (2)	264 (2)	2.1 (2)	6.7 (2)	2.3 (2)	na	na

(2) number in parentheses represent number of measurements, mean values are presented
na- not analyzed

Table 3. Median water soluble chemistry observed during Tempe cell leaching of experimental treatments (n=5).

Site	Treatment	Element												
		B (µg/L)	Ca (mg/L)	Cu (µg/L)	Fe (µg/L)	K (µg/L)	Mg (µg/L)	Mn (µg/L)	Na (µg/L)	P (µg/L)	S (mg/L)	Zn (µg/L)	As (µg/L)	Al (µg/L)
CM	control	151 d**	19 c	2 c	4 c	1300 c	3000 c	82 d	1800c	6 c	20 c	3 c	4 c	70 a
CM	lime	13 b	30 c	1 b	2 a	1300 c	11 a	0 a	1200 b	0 a	2.1 a	0 a	2 b	38 a
CM	clean	77 c	2.1 a	0 a	2 a	650 a	240 b	1 b	620 a	20 c	2.0 a	2 c	0 a	22 a
CM	clean + lime	11 a	18 b	1 b	2 b	870 b	17 a	0 a	1000 b	3 b	9.0 b	1 b	2 b	28 a
	topsoil	404 e	100 d	5 d	34 d	4000 d	22000 d	20 c	5400d	42 d	93 d	8 d	11 d	156 c
SS	control	127 d	26 b	757 d	136700 e	86 b	11000 c	828 d	250 c	742 d	180 e	770 e	141 e	13000 d
SS	lime	73 c	66 c	6 b	4 a	18000 d	35 a	1 a	490 d	0 a	31 b	0 a	6 c	56 b
SS	clean	12 b	7.9 a	59 c	1030 d	27 a	440 b	32 b	130 b	2 b	9.0 a	60 d	3 a	260 c
SS	clean + lime	7 a	42 d	1 a	7 b	20 a	9700 c	445 c	47 a	2 b	40 c	20 c	5 b	13 a
	topsoil	404 e	100 e	5 b	34 c	4000 c	22000 d	20 b	5400 e	42 c	93 d	8 b	11 d	156 c
AT	control	185 c	1.6 a	1066 d	975 d	330 b	690 c	320 e	0.41 c	8000 b	14 b	899 d	5 b	4580 a
AT	lime	13 b	30 c	2 b	3 a	210 b	400 b	1 a	0.10 b	0 a	21 c	1 a	4 b	20 b
AT	clean	12 b	1.7 a	15 c	45 c	310 b	150 a	36 c	0.55 d	0 a	2.4 a	75 c	1 a	30 b
AT	clean + lime	7 a	28 b	0 a	2 a	33 a	610 c	112 d	0.076 a	0 a	23 c	14 b	1 a	0 a
	topsoil	404 d	100 d	5 c	34 b	4000 c	22000 d	20 b	5.4 e	42000 c	93 d	8 b	11 c	156 c

*Kruskal-Wallis non-parametric ANOVA ($P<0.05$)
**values followed by different letters are significantly different

CONCLUSIONS

Tailings resulting from metal mining at three different sites were successfully reprocessed for separation of pyrite and other sulfides from silicate minerals. This process resulted in a high-grade sulfide concentrate representing 10% of the original material volume and dominated by the mineral pyrite. Coincident with the recovery of pyrite, heavy metals and arsenic were co-recovered and were found at elevated levels in the sulfide concentrate compared to the bulk tailing material. Conversely, the cleaned silicate tailing material consisted of 90% of the original material mass and exhibited decreased metal concentrations. Greenhouse plant growth and water soluble leaching characteristics of cleaned tailing material was subsequently evaluated and compared to untreated tailings, lime amended tailings and a topsoil control. The highest levels of water soluble plant nutrients and best plant growth was observed in the topsoil treatment, while the cleaned and lime amended treatments demonstrated comparatively lower plant growth and lower levels of plant macronutrients. The unamended control treatments demonstrated the highest observed water soluble metal concentrations and lowest level of plant performance, particularly on tailing sites with low pH.

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RECLAMATION OF THE PIEGAN-GLOSTER MILLSITE

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ABSTRACT

The Piegan-Gloster Millsite, an abandoned hardrock mine/mill site ranked No. 8 on the Montana Mine Waste Cleanup Bureau Priority List, is located in the Marysville Mining District, Lewis and Clark County, Montana. Hardrock and placer mining for gold and silver dates back to the 1870's. The site is located within the Piegan Creek drainage basin, a 5-square mile area of steep, forested terrain with some open grassland contained within private and Bureau of Land Management property. Piegan Creek discharges to Little Prickly Pear Creek, a Class III fishery, approximately two miles below the millsite. Elevation ranges from 4,520 to 6,000 feet above mean sea level and annual precipitation is 17 inches per year. Land use is primarily recreational and cattle grazing.

The Piegan-Gloster Millsite contains four tailings impoundments, two waste rock piles and a dilapidated mill. Site characterization and risk assessment studies indicated that three tailings piles, which contain an estimated 219,350 cubic yards and occupy 11.2 acres, presented the highest risk to human health and the environment. The tailings contain moderately elevated concentrations of lead, zinc, manganese, mercury and cyanide. Tailings were being eroded and released to Piegan Creek during stormwater/snowmelt runoff events resulting in surface water quality degradation and impacts to stream sediments.

An EE/CA indicated that an in-place containment reclamation strategy offered a cost-effective method for controlling direct contact and impacts to surface water quality. Tailings were excavated from the estimated 100-year floodplain, consolidated and graded to minimize erosion; the stream channel was reestablished and stabilized using natural backfill and riprap; water runon controls were established; the tailings areas were capped with 1.5 feet of soil, fertilized, seeded and mulched; and reclaimed areas were fenced to control cattle grazing. From the initial work plan development to the reclamation construction, the Piegan-Gloster Millsite project took 24 months to complete at an expenditure of $838,990.

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INTRODUCTION

The Piegan-Gloster Millsite is an abandoned hardrock mine/mill site ranked No. 8 on the Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (MDEQ/MWCB) Priority Sites List. The mine/mill workings and tailings impoundments are located in the Marysville Mining District, Lewis and Clark County, Montana. The district produced gold and silver in the late 1800's to early 1900's from placers and epithermal quartz and carbonate veins hosted in igneous and/or metamorphic rocks (Walker, 1992). The site is located within the Piegan Creek drainage basin and occupies portions of Sections 15, 16, 21, 22, 27 and 28 of Township 12 North, Range 6 West, Montana Principal Meridian (Figure 1). The elevation of the site ranges from 4,520 feet above mean sea level, where Piegan Creek discharges to Little Prickly Pear Creek, to 6,000 feet above mean sea level at mine workings near the Gloster Townsite. The terrain surrounding the site is generally rugged, consisting of relatively steep (20 to 30 degrees) mostly timbered slopes with some open grassland. The site is located predominantly on private property that is surrounded by Bureau of Land Management (BLM) property. Annual precipitation is estimated at 16 to 17 inches per year. The area surrounding the site is important habitat for a variety of animals and birds and is considered critical winter range for elk and mule deer. Piegan Creek discharges to Little Prickly Pear Creek which is rated as a Class III fishery and is considered important spawning habitat for Rainbow and Brown Trout from the Missouri River. The current land use around the site area is primarily recreation and cattle grazing. The nearest residence is located approximately 1.5 miles from tailings impoundment TP-3 and the Great Divide ski resort is located approximately 1.5 miles south of the Piegan-Gloster millsite.

SITE CHARACTERIZATION

Site characterization work focused on the following evaluations: background soil chemistry, mine/mill waste chemistry and volumes, surface water and ground water chemistry, stream sediment chemistry, assessment of airborne particulate emissions, assessment of physical hazards and an evaluation of revegetation parameters. Table 1 summarizes mean chemistry results for tailings, waste rock, placer tailings and native soils. The tailings are moderately elevated in Pb, Zn, Mn, Hg and cyanide and slightly elevated in As and Cu relative to background soils. Waste rock and placers are only slightly elevated in these elements with the exception of Hg. Field observations, alkaline pH, low total sulfur concentrations (<0.2 percent) and positive acid/base accounting results indicate that the wastes from the Piegan-Gloster Millsite are not acid generating.

Surface water chemistry results indicate that Pb, As, Zn, Cu and Hg are elevated above background and, in many cases, exceed human health and/or aquatic life standards in Piegan Creek downstream of the tailing piles TP-2, TP-3 and TP-4. Stream sediment chemistry results showed that the same element suite, along with Mn and total cyanide, are also elevated above background concentrations in Piegan Creek below these tailings.

Tailing pile TP-1 and the majority of the placer tailings are well vegetated and are generally isolated from the Piegan Creek active stream channel. The waste rock piles are generally coarse-gained rock and are located well upstream of the headwaters of Piegan Creek. The near surface tailings in TP-2, TP-3 and TP-4 have particle size distributions that range from 74% to 90% silt and clay. These fines are elevated in Pb, Zn and Mn and present an

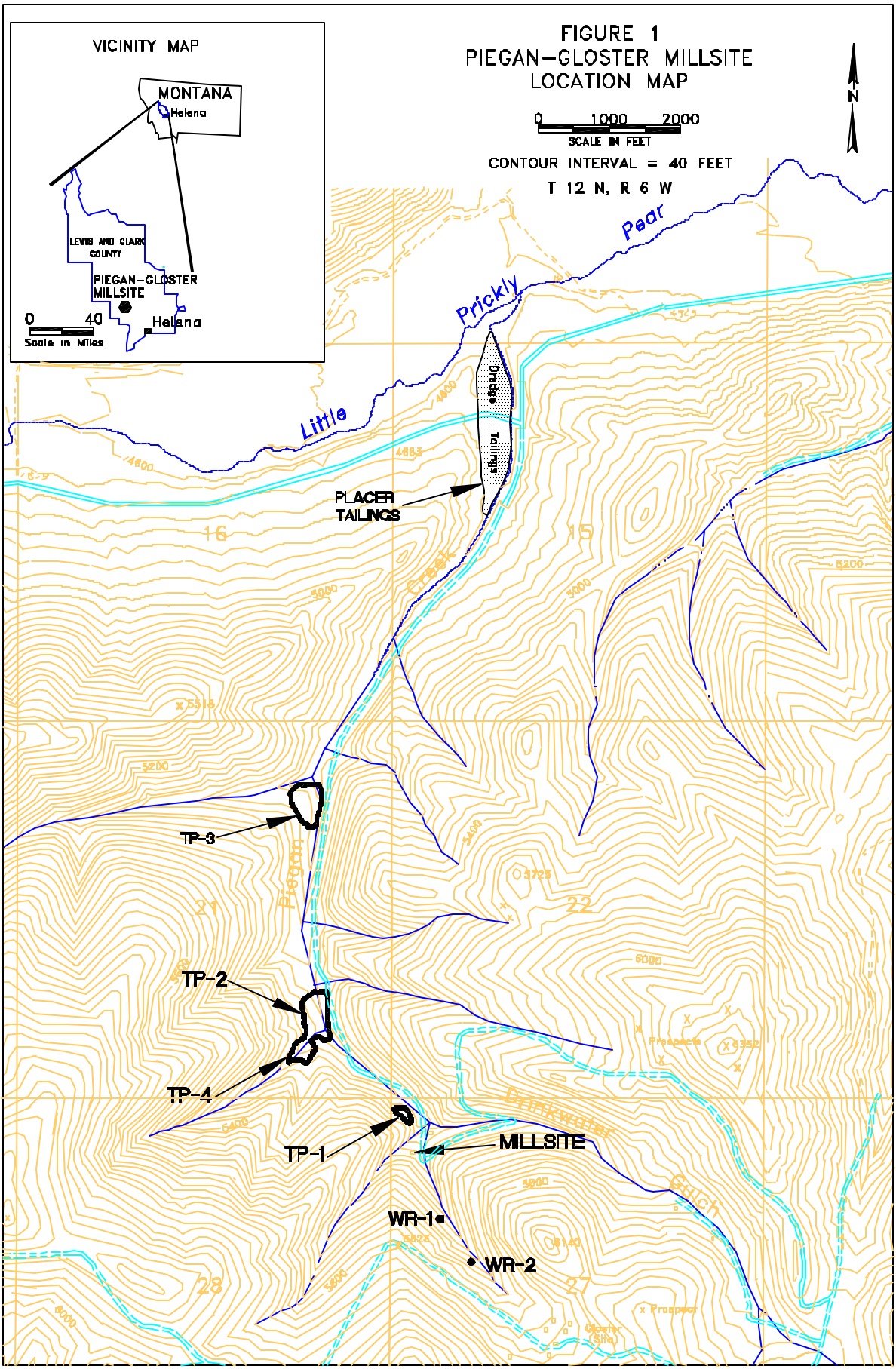


FIGURE 1
PIEGAN-GLOSTER MILLSITE
LOCATION MAP
0 1000 2000
SCALE IN FEET
CONTOUR INTERVAL = 40 FEET
T 12 N, R 6 W
N
VICINITY MAP
MONTANA
Helena
LEWIS AND CLARK COUNTY
PIEGAN-GLOSTER MILLSITE
Helena
0 40
Scale in Miles
Little Prickly Pear
Tailings
PLACER TAILINGS
Creek
Piegan
TP-3
TP-2
TP-4
TP-1
MILLSITE
WR-1
WR-2
Drinkwater Gulch
Prospects
Prosper
Gloster (Site)
16
15
24
22
28
27

Table 1. Mine/Mill Waste Mean Chemistry, Area and Volume Summary

Media	Area (Acres)	Volume (CY)	pH (SU)	ABP t/1000t $CaCO_3$	Total Cyanide (mg/kg)
TP-1	0.595	1,887	7.80	21.38	3.5
TP-2	4.85	99,983	8.56	95.73	7.1
TP-3	4.43	70,483	7.88	88.04	8.7
TP-4	1.88	48,884	9.70	85.91	1.2
Waste Rock	0.95	14,778	7.95	36.38	ND
Placer			8.37	51.31	ND
Native Soil					ND

Media	As (mg/kg)	Cu (mg/kg)	Hg (mg/kg)	Mn (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
TP-1	51.2	61.3	0.86	1123	267.1	579
TP-2	61.5	170	0.10	4438	1340	1740
TP-3	70.8	377	0.24	3783	2738	3248
TP-4	68.9	168	0.45	6590	898	1317
Waste Rock	24.1	93.3	0.63	811	84.4	122.7
Placer	51.8	21.6	0.54	640	30.0	70.3
Native Soil	14.5	17.3	ND	532	14.6	64.8

ND = not detected

exposure risk via direct contact and airborne emissions. The only physical hazard identified was the dilapidated Piegan-Gloster mill. The results of the site characterization indicated that tailings piles TP-2, TP-3 and TP-4 posed the greatest risk to human health and the environment. Metal and cyanide-bearing tailings from these facilities were being eroded and released to Piegan Creek during storm water and snowmelt runoff events resulting in surface water quality degradation and impacts to stream sediments.

ENGINEERING EVALUATION/COST ANALYSIS

An Engineering Evaluation/Cost Analysis (EE/CA) included: residential/recreational risk assessments, development and screening of reclamation alternatives, evaluation of eight reclamation alternatives and a proposal for a preferred alternative.

The mill tailings in TP-2, TP-3 and TP-4 are the principal waste source contributing to environmental impacts at the Piegan-Gloster Millsite. Waste rock sources do not appear to be a problem at the site. The mill tailings base metal chemistry is, for the most part, significantly lower than most mill tailings and these tailings, after nearly 100 years of exposure, show no evidence of acid rock drainage (ARD) characteristics. The tailings are alkaline and this has limited the solubility of most metal constituents in the tailings piles, with the exception of arsenic. Although arsenic is generally more soluble under neutral to alkaline conditions, its impact to the environment is limited because the maximum concentration of arsenic in the tailings is less than 100 mg/kg. The principal source of ground water in the Piegan-Gloster site area is bedrock where ground water movement is most likely fault and fracture controlled. The bedrock in the tailings areas is predominantly

shales and limestones that may or may not be metamorphosed depending on their proximity to the quartz diorite stock near the headwaters area of Piegan Creek. The subsurface geology in the area of the tailings piles is a positive factor for limiting the downward migration of contaminants into a bedrock aquifer because of the low permeability of the shale and the neutralization potential of the limestone.

The greatest risk to human health and the environment in the Piegan-Gloster Millsite area is the release of tailings sediment into Piegan Creek and in its unnamed tributary containing tailings pile TP-4. Erosion cuts up to 24 feet deep were observed in some of the tailings piles. Metal contaminants of concern are predominantly transported as suspended sediment by surface water mainly during storm water and snow melt runoff events. Direct contact with the tailings also presents a significant risk to human health and the environment. Metals contained in the exposed tailings are subject to ingestion and dust inhalation.

Table 2 summarizes the five reclamation alternatives that were evaluated in detail for the Piegan-Gloster Millsite. Based on the conclusions of the detailed analysis and comparative analysis of alternatives, Alternative 3 - In-Place Containment was selected as the preferred alternative for the Piegan-Gloster Millsite. This alternative is considered the most appropriate and cost-effective means to reduce risk to human health and the environment to an acceptable level.

Table 2. Summary of Reclamation Alternatives and Cost Estimate

Alternative	Description	Cost Estimate ($)
1	No Action	0
2	Institutional Controls	150,671
3	In-Place Containment	1,298,486
4	On-site Disposal in Constructed Repository	3,585,105
5	Partial 0n-site Disposal/In-Place Containment	2,359,683

DESIGN AND IMPLEMENTATION OF THE RECLAMATION ALTERNATIVE

The primary design objectives were to provide long-term stabilization of the tailings by controlling surface water and reducing erosion and sedimentation, to reduce exposure via a soil cap and to reconstruct Piegan Creek and its unnamed tributary in the vicinity of the reclaimed tailings piles.

The Piegan Creek drainage basin occupies an area of 5.02 square miles of generally steep, forested terrain with some open parks. Piegan Creek and its tributaries occur in narrow canyons with valley floors usually less than 200 feet in width. Elevation differences from the valley floors to adjacent ridges is on the order of 800 feet. The Piegan Creek stream channel is generally less than 10 feet wide. Piegan Creek has a moderately steep gradient for most of its length with an average gradient of approximately 6% in the area of the tailings impoundments. The stream has a low sinuosity, low width/depth ratio, and the channel materials are predominantly cobbles with a mixture of sand, gravel and some boulders. Based on these parameters, Piegan Creek, in the vicinity of the tailings, is an A3 stream according to the Rosgen classification system (Rosgen, 1996). The unnamed tributary to

Piegan Creek that flows through tailings pile TP-4 has a gradient exceeding 10% and is a Rosgen class A3a+ stream.

A hydrologic study of the Piegan Creek Basin was completed and the data used in the stream channel design and to estimate the volume of tailings that would require removal from the channel/floodplain area in the vicinity of each tailings impoundment. USDA Soil Conservation Service TR-55 methods were used to estimate peak flows (Table 3) at tailings impoundments TP-2, TP-3, and TP-4. The rainfall events used in the TR-55 calculations were taken from the NOAA (1973), and are as follows: 2-year, 24-hour (1.2 inches), 5-year, 24-hour (1.6 inches), 10-year, 24-hour (1.9 inches), 25-year, 24-hour (2.2 inches), 50-year, 24-hour (2.6 inches) and the 100-year, 24-hour (2.8 inches).

Table 3. Peak Discharge Estimates for Tailings Impoundments TP-2, TP-3, and TP-4

Location	Peak Discharge, cfs					
	2-year	5-year	10-year	25-year	50-year	100-year
TP-2	<1	6	22	47	96	143
TP-3	<1	10	32	64	137	198
TP-4	<1	5	10	20	45	59
Mouth of Piegan Creek	<1	19	54	103	225	316

A riprap channel lining was selected to provide long-term stabilization of the tailings because of the steep channel gradients and because the natural stream above and below the tailings is largely cobble-size material, which is similar to riprap. Figure 2 shows tailings piles TP-2 and TP-4 before and after reclamation, and a typical channel cross section. The TP-2 stream channel was lined with 12-inch minus riprap and a geotextile filter fabric. The riprap was blended with soil to provide a growth medium for vegetation and the channel banks were seeded with grasses. The stream channel through tailings pile TP-4 was reconstructed with several riprap-lined drop structures with riprap up to 28-inch diameter. The drop structures were designed as cascading chutes. Tailings pile TP-3 (Figure 3) was also designed with small drop structures.

Open-channel flow assessments indicated that the following channels should contain the discharge from the 100-year, 24-hour rainfall:

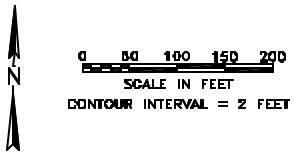
Location	Depth (including freeboard)	Base Width	Side Slopes
TP-2	4 ft	6 ft	2H:1V
TP-3	4 ft	10 ft	2H:1V
TP-4	2 ft	6 ft	2H:1V

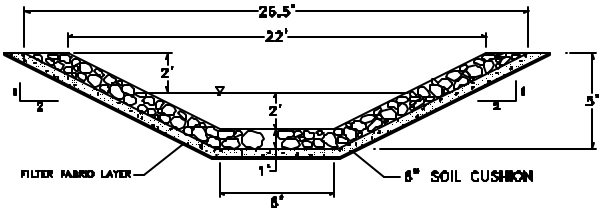
Tailings contained in the active stream drainage were excavated and relocated on areas of the tailings piles away from the creek. Piegan Creek is a mountain stream with youthful stream valley characteristics in that it is developing its channel in the vertical and shows very little meandering. Examination of the tailings bank erosion cuts verify vertical channel development.

FIGURE 2
TAILINGS PILES TP-2 AND TP-4

PRE-RECLAMATION

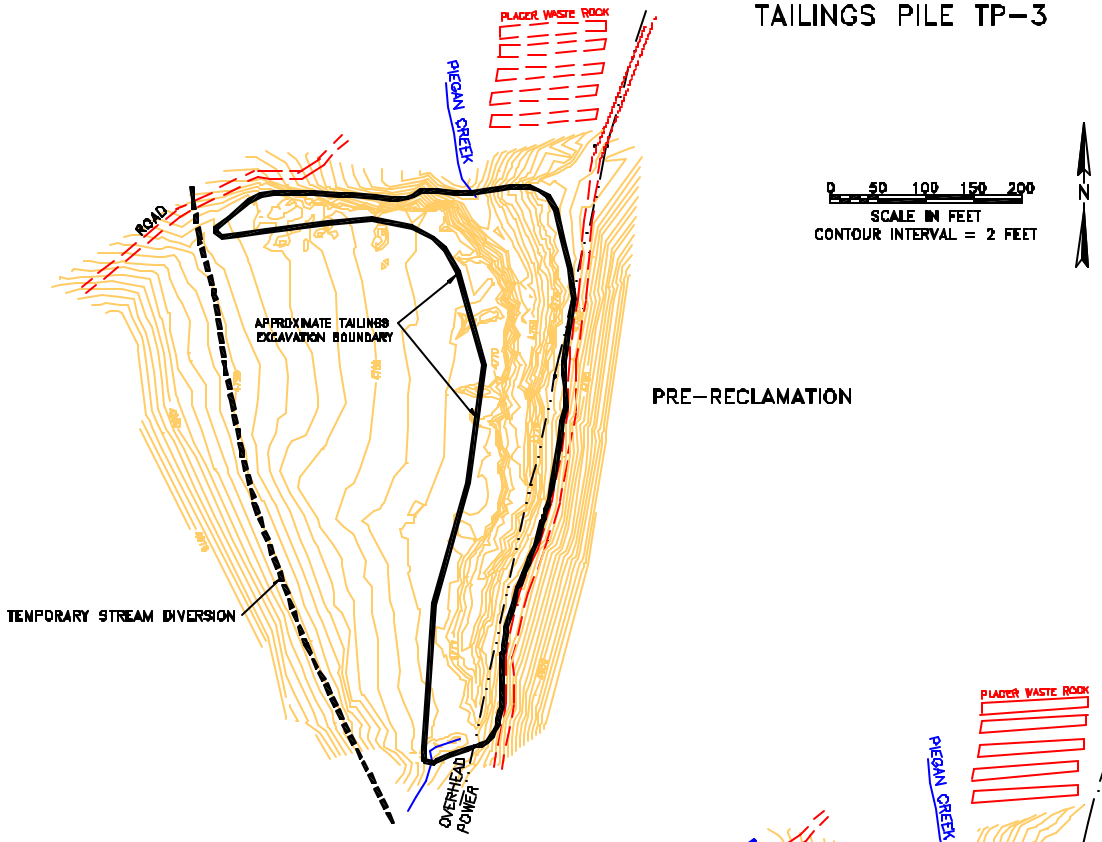
POST-RECLAMATION



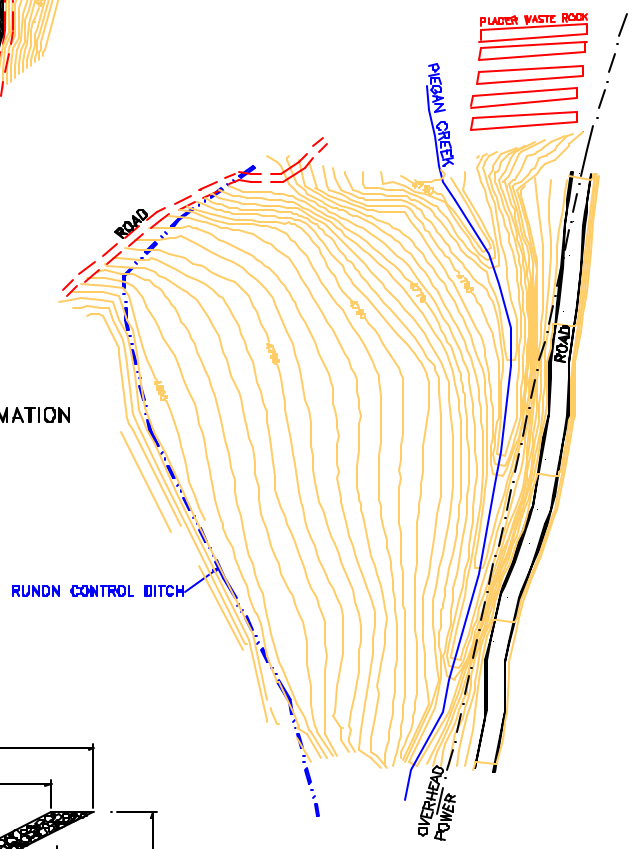


TP-2 TYPICAL CHANNEL CROSS SECTION

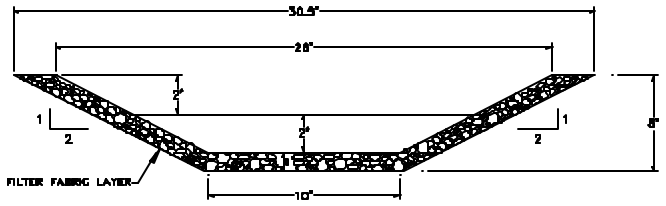
FIGURE 3
TAILINGS PILE TP-3



PRE-RECLAMATION



POST-RECLAMATION



TP-3 TYPICAL CHANNEL CROSS SECTION

Tailings pile TP-1 has naturally revegetated with grasses and shows almost no erosion effects. Erosion has been minimized by the fact that Piegan Creek does not flow through the pile, grades are gentle and abundant grass cover is present. Because acid rock drainage is not a problem, lime amendment was not required. On the other tailings piles, erosion was controlled by reconstructing stream channels, a grading plan and stormwater diversion controls. To accelerate the growth of a self-sustaining plant community, a 1.5-foot thick soil cap was applied to provide a suitable medium for establishing vegetation. Cover soil, channel backfill and riprap borrow sources were acquired on site by using native soil, selected placer tailings and quartz diorite talus.

The general construction steps used for implementing the In-Place Containment reclamation alternative were as follows:

- construction of temporary surface water diversion structures to divert flow during construction activities;
- excavation and relocation of tailings from the stream channel and floodplain in the area of tailings piles TP-2, TP-3 and TP-4;
- excavation and redistribution of material from the tailings dam faces to reduce the slopes to 3H:1V or less;
- backfilling of appropriate fill material and riprap to stabilize the channel in the vicinity of the tailings piles;
- grading of the tailings piles (typically 4H:1V or less) to reduce erosion from surface water run-off;
- constructing surface water diversion ditches strategically located to control water run-on during revegetation;
- covering the tailings with a 1.5-foot thick soil layer derived from placer tailings and other sources;
- establishing vegetation on the covered tailings piles by seeding (five grasses and three forbs) and fertilizing;
- mulching of the seeded areas; and
- constructing a four-strand barb wire fence around the reclaimed tailings and stream channel areas.

In addition, the wood and steel debris from the Piegan-Gloster mill was removed and buried on site to mitigate the physical hazard posed by the dilapidated structure.

FINAL RECLAMATION COST SUMMARY

Table 4 presents a summary of the actual costs incurred for the various phases of the Piegan-Gloster Millsite reclamation project. The project took 24 months to complete the tasks from the initial reclamation work plan through final construction.

Table 4. Summary of Reclamation Costs

Task	Cost ($)
Reclamation Work Plan, Field Sampling Plan & Supporting Documentation	25,432.37
Site Characterization	81,963.41
Engineering Evaluation/Cost Analysis	21,391.00
Engineering Design and Bid Specification Preparation	26,630.14
Construction Engineering	46,540.08
Subtotal	201,957.00
Reclamation Construction	637,033.00
Total	838,990.00

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2000 Billings Land Reclamation Symposium

CLOSURE OF THE ABANDONED SKOOKUM SLOPE MINE

Ginger Kaldenbach and Michael Bailey, P.E.

ABSTRACT

This presentation describes closure and reclamation of the Skookum Slope Mine, a complex of underground coal mines which operated for more than 70 years prior to abandonment around 1950.

Reclamation included closure of open shafts and tunnels, preservation of historic structures, and wetlands and stream protection. Permitting and construction was complicated since most of the mine workings are flooded and discharge through open shafts into a wetland, beaver ponds and an adjacent stream which has a protected fisheries status. Eleven permits required for the reclamation were obtained from local, state and Federal agencies. Reclamation is complete including monitoring of wetland revegetation.

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2000 Billings Land Reclamation Symposium

HIGH ORE CREEK STREAM SIDE TAILINGS RECLAMATION

M. F. Browne[1] and J.D. Belanger-Woods[2]

ABSTRACT

Metal-mining wastes and mill tailings from the Comet Mine have eroded into High Ore Creek for over 80 years. Thirty-two thousand cubic yards of stream side tailings and 5,800 cubic yards of waste rock were distributed throughout the 3.7 mile High Ore Creek flood plain below the Comet Mine. The stream side tailings is the largest mine waste source of concern because of high contributions of metals and sediment to the surface water. Concentrations of antimony, arsenic, cadmium, copper, iron, lead, manganese, silver, and zinc were significantly elevated above background concentrations (>3X) in the flood plain and surrounding area (BLM, 1999). An Expanded Engineering Evaluation/Cost Analysis was used to present the detailed analysis of reclamation alternatives in accordance with the National Contingency Plan. This analysis was then used to select the preferred alternative for the reclamation of High Ore Creek based on the amount of risk reduction with each alternative. The reclamation alternatives for High Ore Creek varied from complete tailings removal and flood plain reconstruction to partial or no tailings removal and some stream bank reconstruction where no tailings were present. Stream side tailings were classified, for the purpose of site assessment and reclamation, into three types of tailings impacted areas. Areas with no vegetation growing on the tailings were classified as High Impact Areas. Areas where tailings were visible with some vegetation were classified as a Medium Impact Areas. Low Impact Areas represent all remaining areas of the flood plain where vegetation was prominent with little to no effect from the tailings. The reclamation of metal-mining wastes in the High Ore Creek drainage basin in Jefferson County, Montana is expected to reduce the detrimental impacts to water quality and riparian vegetation as well as reduce the adverse impacts to human health and the environment. Not all tailings have been removed from High Ore Creek. The necessity to remove all tailings rather than partial removal of tailings cannot be adequately assessed until post reclamation monitoring has been completed following reclamation.

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INTRODUCTION

High Ore Creek is located NW of Boulder, Montana in Jefferson County. High Ore Creek flows through the Comet Mine site and into the Boulder River approximately two miles northeast of the town of Basin.

The Comet Mine and Millsite is one of the oldest abandoned hardrock mine sites in the Basin/Cataract Mining District. The site was first mined in about 1880 by the Alta-Montana Mining Company. The majority of the production from the Comet occurred from 1883 to 1893 while owned by the Helena Mine and Reduction Company. The Basin Montana Tunnel Company acquired the Comet in 1926 and constructed a 200-ton flotation mill to process Comet ore as well as custom mill ores from other mines in the district. The mill was closed and dismantled in 1941. The Basin/Cataract Mining District produced large quantities of gold, silver, lead, and other metals with an estimated total value of $11,000,000. Production consisted of 129,000 ounces of gold; 5,600,000 ounces of silver; 35,000,000 pounds of lead, and 27,000,000 pounds of zinc (MBMG, 1960).

The High Ore Creek Stream Side Tailings Reclamation project begins below the Comet Mine site and continues to the creek's confluence with the Boulder River. The stream side tailings reclamation includes approximately 32,000 cubic yards of stream side tailings and 5,800 cubic yards of waste rock that is distributed throughout the 3.7 mile High Ore Creek flood plain below the Comet Mine. Forty-three percent of the lands on High Ore Creek are Public Lands administered by U.S. Department of Interior, Bureau of Land Management (BLM) and 57% of the land is private property belonging to 20 landowners with 34 patented mining claims. Nine County, State, and Federal Agencies along with numerous consultants, contractors and interested parties worked together to investigate, characterize, design, and mitigate environmental impacts on High Ore Creek.

ABANDONED MINE LAND RECLAMATION, BLM, WESTERN MONTANA

The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) requires the BLM to complete removal site evaluations for releases or threatened releases identified for possible Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) responses on Public Lands (40 CFR, §300.410 (b)). The BLM is also responsible, under the guidance of the National Environmental Policy Act (NEPA), for making decisions that are based on an understanding of environmental consequences, and taking actions that protect, restore, and enhance the environment. The Butte Field Office's Resource Management Plan/Environmental Impact Statement (RMP/EIS) requires soils to be managed to maintain productivity and minimize erosion. The BLM (1983) is required to maintain or improve water quality in accordance with State and Federal standards.

The High Ore Creek Stream Side Tailings Reclamation project was considered a non-time critical removal action under the NCP. In accordance with the NCP, a Expanded Engineering Evaluation/Cost Analysis (EEE/CA) for the High Ore Creek Stream Side Tailings Reclamation Project was completed and used to present the detailed analysis of reclamation

alternatives. The site background, waste characteristics, applicable or relevant and appropriate requirements (ARARs), risk assessment, and preliminary development and screening of reclamation alternatives was included in the EEE/CA. The detailed analysis of alternatives and additional background information provided in the EEE/CA was used to determine the preferred alternative for the reclamation of High Ore Creek.

HIGH ORE CREEK RECLAMATION

Stream side tailings deposits from the Comet Mine and mill site (Figure 1) eroded into High Ore Creek for many years. These tailings, deposited throughout the High Ore Creek flood plain are the largest mine waste source of concern because they are one of the highest contributors of metals and sediment to the surface water. These tailings severely affect the vegetation in the flood plain of High Ore Creek.

Figure 1 - Comet Mine and Tailings

In 1990 the Montana Department of Fish, Wildlife, and Parks (FW&P) sponsored reconstruction of a pre-existing creek diversion (Fig. 2) around the waste rock piles and mill tailings at the Comet Mine. The FW&P also reconstructed the existing sedimentation ponds to control the release of mine waste sediments from the tailings impoundments into High Ore Creek.

Figure 2 - High Ore Creek Diversion

The Montana Department of Environmental Quality, Mine Waste Cleanup Bureau (MWCB) inventoried the Comet Mine in 1993 for inclusion on the Abandoned Hardrock Mine Priority List (DEQ/MWCB-Pioneer, 1995). The Comet scored 10 th out of 276 sites using the Abandoned and Inactive Mines Scoring System (AIMSS). The MWCB conducted interim reclamation activities at the mill site in 1995 and 1996 to improve erosion and sediment control from the tailings in preparation for full-scale reclamation of the site (DEQ/MWCB-Pioneer, 1996). The MWCB initiated the first phase of the Comet Mine and Mill Site reclamation in 1997. The first phase of the Comet Mine and Mill Site reclamation required the construction of a mine waste repository at the location of the original glory hole. Approximately 500,000 cubic yards of waste rock and tailings were removed from the flood plain and placed in a constructed repository at the Comet mine site (Figure 3). The second phase of the Comet Mine reclamation will take place in the year 2000. This reclamation will involve removal of approximately 15,000 cubic yards of tailings and waste rock material beneath the High Ore Creek diversion channel and placement of these materials into the BLM repository located 1 mile SE of the Comet

Figure 3 - Comet Mine Repository

Mine. Reclamation will also involve reconstruction of the High Ore Creek stream channel in the bottom of the drainage, placement of cover soil and topsoil over the Comet Repository, and revegetation of any reclaimed or disturbed lands associated with the reclamation of the Comet Mine.

The Montana Bureau of Mines and Geology (MBMG, 1997) and the BLM (BLM, 1999) found concentrations of antimony, arsenic, cadmium, copper, iron, lead, manganese, silver, and zinc were significantly elevated above background concentrations (>3X) in soil and water samples in the flood plain and surrounding area. Preliminary findings by the U.S. Geological Survey also indicate that sediments, fluvial tailings and water from High Ore Creek are significant contributors to water quality degradation of the Boulder River below Basin, Montana (USGS, 1999). In 1998 the BLM initiated the reclamation of High Ore Creek with the development of the Expanded Engineering Evaluation/Cost Analysis (EEE/CA) to evaluate reclamation alternatives.

Objective

The objective of reclamation in the High Ore Creek drainage basin is to reduce the detrimental impacts to water quality and riparian vegetation as well as the impacts to human health and the environment. Reclamation is expected to restore riparian vegetation; allow High Ore Creek to function properly; improve water quality; and potentially establish a healthy, diverse biotic community and fisheries. The necessity to completely remove all of the tailings rather than partial removal of tailings will be evaluated and assessed after post reclamation monitoring has been completed on High Ore Creek. The High Ore Creek reclamation is expected to bring the BLM into compliance with the requirements of the NCP, the Butte Field Office's RMP/EIS , and the Clean Water Act.

Site Assessment

Site assessment began with the initiation of the EEE/CA in February 1998. Site assessment, in addition to the EEE/CA, included: 1) Owner/Operator History Report, 2) Community Relations Plan, 3) Quality Assurance Project Plan, 4) Laboratory Analytical Protocol, 5) Health and Safety Plan, 6) Cultural Inventory Report, and 7) Engineering Design/Construction Bid Specification Package.

The stream side tailings was the largest mine waste source of concern because of high contributions of metals and sediment to the surface water. Reclamation first required the

identification of mine waste types, location, volumes, and impacts to human health and the environment. The BLM conducted a stream inventory on High Ore Creek in 1998 to identify stream reach segments that required reclamation. Twenty-one reaches with 45 sub-reaches were identified that required reclamation as a result of mining impacts or poorly functioning riparian areas. The stream side tailings were separated into three types of tailings impacted areas. Areas with no vegetation growing on the tailings (approximately 21 acres) were classified as High Impact Areas (Figure 4). Areas where tailings were visible with some vegetation were classified as Medium Impact Areas (Figure 5). All remaining areas of the High Ore Creek flood plain were considered Low Impact Areas (Figure 6). Vegetation was prominent in these areas with little or no effect from the tailings. Some Low Impact Areas required stream bank reconstruction to return riparian areas to a functioning condition. Discrete and composite samples, from separate sampling events, in the High Ore Creek flood plain were collected by Pioneer Technical Services Inc. (Pioneer), the MBMG, and the BLM. Thirty-seven discrete samples and one composite sample were collected for X-ray Fluorescence Spectrometer (XRF) analysis, while three composite samples were collected for analysis of total metals, Acid Base Accounting (ABA), agronomic and Toxicity Characteristic Leaching Procedure.

Figure 4 - High Impact Areas

Figure 5 - Medium Impact Areas

Figure 6 - Low Impact Area

Risk Assessment

Stream side tailings were separated into three types of tailings impacted areas to assist with the analysis of alternatives based on the following criteria: 1) the relative protectiveness of human health and the environment provided by the alternatives; 2) the long-term effectiveness provided by the alternatives; and 3) the estimated attainment of ARARs for each alternative. An alternative screening summary, Table 1, was used to determine alternatives retained for detailed

analysis. Table 2 is a summary of overall cost comparisons between the Alternatives based on the amount of Human Health (HH) and Ecological Risk Reduction (E).

Table 1
Alternatives Screening Summary (BLM, 1999)

ALTERNATIVE DESCRIPTION	EFFECTIVE-NESS	IMPLEMENT-ABLE	EST. COST	RETAINED FOR DETAILED ANALYSIS
Alt. 1: No Action	NA	NA	$0	Yes
Alt. 2: Institutional Controls	Low	Yes	$390,000	No
Alt. 3: In-Place Containment of Wastes With Cover soil	Low-Medium	Yes	$674,298	No
Alt. 4a: Partial Removal/Disposal in Constructed Repository and Partial In-Place Containment (bottom liner and drainage layer)	High	Yes	$1,139,602	Yes
Alt. 4b: Partial Removal/Disposal in Constructed Repository and Partial In-Place Containment (no bottom liner)	High	Yes	$1,020,211	Yes
Alt. 5a: Removal/Disposal of all Solid Waste Material in a Constructed Repository (bottom liner and drainage layer)	High	Yes	$1,529,393	Yes
Alt. 5b: Removal/Disposal of all Solid Waste Material in a Constructed Repository (no bottom liner)	High	Yes	$1,343,786	Yes

Table 2
Alternative Cost-Effectiveness Comparison Summary (BLM, 1999)

ALTERNATIVE	Ecologic Risk Reduction (E)	Human Health Risk Reduction (HH)	Total Present Worth Value	Cost per 1% Reduction in Risk ($)
Alternative 1	0%	0%	$1.14 Million	NA
Alternative 4a	72%	94%	$1.02 Million	$15,833 (E) $12,128 (EH)
Alternative 4b	72%	94%	$1.02 Million	$14,167 (E) $10,851 (HH)
Alternative 5a	76%	100%	$1. 53 Million	$20,132 (E) $15,300 (HH)
Alternative 5b	76%	100%	$1.53 Million	$17,632 (E) $13,400 (HH)

Alternative 4b was selected as the preferred alternative for the reclamation of High Ore Creek. This alternative should protect human health and the environment by removing the highest risk mine wastes in the High Ore Creek watershed. This alternative consists of excavating selected solid waste material from the High Ore Creek flood plain and disposing of it in a modified RCRA repository constructed about 1 mile southeast of the Comet Mine site. The repository design includes a multi-layered cap with no bottom liner. This alternative is expected to reduce risks to human health by 94% and ecological risks by 72%. The long-term effectiveness of this alternative is expected to improve the water quality protect human health and the environment.

Figure 7 - Tailings Removal, Channel, & Flood Plain Reconstruction

Reclamation

The construction bid package for reclamation was administered for the BLM by the U.S. Army Corp of Engineers (USACE) and contained the reclamation engineering design, project plans and specifications prepared by Pioneer. Schumaker Trucking and Excavating (Schumaker), from Great Falls, MT, was awarded the construction contract and issued a Notice to Proceed by the USACE in September 1999. Schumaker began construction in September, 1999 and was shut-down by weather on December 15, 1999.

The reclamation of High Ore Creek in 1999 included: areas with complete tailings removal, channel, and flood plain reconstruction (Figure 7); areas with partial tailings removal and flood plain reconstruction (Figure 8), areas with only stream bank reconstruction ; and areas with no tailings removal or stream bank reconstruction. The construction contract involved removing waste adjacent to High Ore Creek and disposing of these materials in a constructed repository located approximately 1 mile southeast of the Comet Mine and Mill site.

Figure 8 - Tailings Removal and Flood Plain Reconstruction

Reclamation completed in 1999 included:

- Clearing, grubbing, and constructing a six acre borrow area/repository and improving the existing access road to the repository,
- Stockpiling 34,000 cubic yards of cover soil to be used by the MWCB for Phase 2 of the Comet Mine reclamation,

- Excavating and hauling 31,155 cubic yards of stream side tailings and mine wastes to the BLM repository,
- Installing 4,127 lineal feet of stream protection structures,
- Installing 12,246 lineal feet of silt fence,
- Reconstructing 3,459 lineal feet of High Ore Creek stream channel,
- Reconstructing flood plain with 14,276 cubic yards of clean cover soil,
- Backfilling flood plain with 18,103 cubic yards of clean, organically amended cover soil (topsoil) following waste removal,
- Constructing streambed including steps, pools, and grade control structures,
- Installing 4,612 square yards of Type A bank stabilization fabric,
- Installing 8,442 square yards of Type B erosion control mat,
- Installing willow cuttings and 833 lineal feet of willow fascines on stream banks, and
- Seeding and mulching reconstructed and stabilized streambanks.

Project Start-Up is expected to begin on May 1, 2000 to complete the remaining portions of the reclamation contract. Construction to be completed in the spring of 2000 includes:

- Construction of the repository cap:
  1. Installation of 19,000 square yards of a geotextile cushion over the uppermost lift of compacted mine wastes,
  2. Installation of 19,000 square yards of Geosynthetic Clay Liner,
  3. Installation of 19,000 square yards of a Geonoet and filter fabric geocomposite,
  4. Apply and grade 12,225 cubic yards of organically amended cover soil,
  5. Apply and grade salvaged topsoil, and
  6. Seed and mulch.
- Construction of repository run-on/runoff control ditches,
- Replace and install four properly sized culverts on High Ore Creek,
- Complete installation of Type A fabric along stream bank stabilization reaches. This includes seeding, mulching, installing willow fascines, etc. and
- Obliterating and reseeding temporary haul roads and the existing access road between the Comet repository and the new BLM repository.

To-date the construction cost for this project is $939,885.00. The total construction contract for this reclamation project is $1,520,837.

CONCLUSION

The necessity to completely remove all tailings rather than partial removal of tailings can not be adequately assessed until post reclamation monitoring has been completed following the completion of this reclamation project. The High Ore Creek Stream Side Tailings Reclamation project will not be completed until the summer of 2000. Water quality and re-establishment of vegetation will be closely monitored for the next 3-5 years to determine the success of this reclamation project.

Preliminary and unpublished results for this project seem to indicate that visual observation and subsequent removal of stream side tailings may be adequate for determination of metal contaminated tailings. X-ray Fluorescence Spectrometer and/or lab analysis of tailings to be removed should continue to be used to validate visual observations.

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2000 Billings Land Reclamation Symposium

Tailing Pond Flow Modeling Used To Predict Long-Term Tailing Seepage

T. Stein[1], K.-C. Hsu[2], and R. Schmidt-Petersen[3]

ABSTRACT

Characterization of the hydrogeology and geochemistry of tailing ponds is necessary to design effective closure plans for these facilities. A seepage investigation was recently conducted for a tailing pond in the Southwest United States to determine the current quantity and quality of seepage, evaluate the controlling factors affecting seepage, and predict long-term seepage flow from the facility. The results of the flow modeling are being incorporated into a hydrogeochemical model to predict the future quality of seepage from the tailing pond. Ultimately, the seepage flow and transport models will be used in conjunction with cover design studies to evaluate various closure alternatives for the tailing pond.

Based on a pond construction model developed from historical records and field characterization results, a conceptual model of flow in the tailing pond was developed for a period of active tailing deposition and a period after tailing deposition ceased. A two-dimensional, variably saturated, finite-difference code (VS2D) was used to simulate seepage flow within and beneath one tailing pond (Lappala et al., 1987; Healy, 1990). For the modeling, the tailing pond was divided into three areas based on the tailing surface topography and material characteristics. For each of the three areas, multiple representative two-dimensional cross-sectional models were developed to account for localized differences in underlying drainage patterns and geology. The model was calibrated using in-situ water levels, matric potentials, and antecedent water contents obtained from nested wells installed in the tailing pond.

The simulation results indicate that approximately 15 percent (2.4 inches) of average annual precipitation (16 inches) at the site infiltrates into the tailing pond in an uncovered scenario. Steady-state flow conditions are predicted to occur following a 50 to 70 year period of transient drainage. Once steady-state flow conditions are established, the estimated residence time for a particle of water entering the pond surface ranges between 45 and 317 years. In addition, the vast majority of the seepage (between 97 and 100 percent) migrates preferentially into alluvium lying within pre-existing surface water drainages.

Conservative estimates of water seepage from the alluvial drainage(s) into an underlying bedrock unit were obtained using the Green-Ampt infiltration model (Stephens, 1996). With a bedrock saturated hydraulic conductivity (K_s) of 1.61×10^{-7} cm/s, the seepage flow was estimated to be approximately two percent of the average annual precipitation at the site.

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2000 Billings Land Reclamation Symposium

EFFECTIVE MAINTENANCE TECHNIQUES TO DETERMINE LONG-TERM SUSTAINABILITY OF MINING RECLAMATION AT UPTOWN BUTTE, MT[1]

C.M. Mayn

ABSTRACT

Mining began at Butte, Montana, in 1864 and still continues today. Consequently, millions of cubic yards of low pH, high sulfide, and metal contaminated mine wastes were stockpiled at various locations across uptown Butte. The large-scale mining of the Butte area has created the largest EPA superfund site in the northwest. Mine wastes with high metal concentrations located in residential areas pose serious threats to human health and the environment. Storm water runoff events continually load Silver Bow Creek with sediments containing high metal concentrations. As a result, mine waste piles must undergo reclamation by complete removal and/or recontouring and capping with coversoil. The coversoil must be properly revegetated to stabilize reclamation and reduce erosion. Reclamation of mine waste began in the early 1980's. Since initial reclamation attempts, vegetation is currently failing live plant cover standards on many reclaimed areas. Incorporation of effective maintenance techniques must be performed to ensure the long-term sustainability of vegetation on these reclaimed areas.

A total of nine treatment combinations implementing both organic and inorganic nitrogen additions will be researched for two growing seasons to determine effects on existing vegetation and inter-seeded species. An introduced species seed mixture and a native species seed mixture have been inter-seeded among existing vegetation to determine if successional components drive long-term success of reclaimed soil cap stability. Daubenmire frame measurements of vegetative canopy cover and density by plant species will be collected during peak stand of two growing seasons. Vegetative biomass data will be gathered at the end of the second growing season. Soil analyses were performed prior the to treatment plot construction and will be performed after the second growing season to determine chemical and physical changes in soil structure. Currently, coversoil data for fourteen reclaimed areas and treatment plot vegetative data for the first growing season have been collected.

[1] Funding for this research was provided by the Atlantic Richfield Company, Anaconda, MT

BACKGROUND

The intensive, 130 years of copper mining in Butte, Montana, has produced serious impacts to the environmental integrity of the area. Associated with copper extraction were enormous volumes of waste rock, tailings, and smelter emissions. Immense volumes of mine waste containing low pH overburden with high sulfide and iron pyrite concentrations were stockpiled at various locations across uptown Butte. In addition to low pH and sulfides, the mine waste contains high concentrations toxic metals (As, Pb, Zn, Cd, Mg, Fe, and Cu) hazardous to human health and the environment.

A number of Comprehensive Environmental Response Compensation and Liability Act (CERCLA) superfund sites were identified in the Butte/Anaconda area by the Environmental Protection Agency (EPA). In Butte alone, several Time Critical Removal Actions (TCRAs) have been instituted to ensure the reclamation of various mine waste dumps. The EPA TCRA guidelines for Butte reclamation included that all mine waste be removed and/or recontoured to slopes of 3:1 or less. The contoured areas must then be capped with a 2 inch lime rock layer (approximately 350 tons/acre) and a minimum of 18 inches of coversoil to protect human health and the environment. The site is then seeded with a suitable seed mixture and straw mulched at 2 tons/acre.

ARCO began the reclamation of mine waste dumps at uptown Butte in 1985 and have been on going and improving since. However, vegetation productivity on many reclaimed areas is not meeting 35% live plant cover standards adopted by the local Butte Silver Bow county government. Coarse textured sandy loams weathered from decomposed granite have been used for reclamation at uptown Butte. The sandy loams possess poor water holding capacity and are often deficient in nutrients, organic matter, and microorganisms essential for healthy and productive vegetation.

Many reclaimed areas at uptown Butte have slopes of 3:1 with south facing aspects. The Butte area receives only 12 – 14 inches of precipitation annually. The combination of slope, hot and dry aspect, coversoil with limited nutrients and plant available water, and limited annual moisture hinders the establishment of vegetation capable of providing 35% live plant canopy cover. Sites with unproductive vegetation often succumb to excessive erosion, ultimately requiring complete reconstruction of the reclaimed cap.

RESEARCH PROCEDURES

The research project has been performed in a two-phase process. Phase I involves the evaluation of uptown Butte reclamation characteristics of initial site construction, vegetative performance, and coversoil properties. Phase II involves the implementation of field test plots to research the effects of nitrogen fertilization, organic matter incorporation, inter-seeding, and various combinations to determine effective vegetation establishment methods. Vegetative measurements for the first growing season were collected in July 1999. Second year measurements will be performed in late July 2000.

Phase I

Fourteen reclaimed areas at uptown Butte, Montana, were selected for coversoil evaluation using data collected from Environmental Protection Agency (EPA) reclamation assessments performed in 1992 and 1996. The EPA assessments noted vegetation characteristics, erosion, signs of disturbance, and mass instability on various reclaimed areas. In addition, results from Butte Hill Revegetation Monitoring 1994 – 1997, vegetation monitoring reports performed by Rich Prodgers of Bighorn Environmental, were also referenced. Site variables such as slope, aspect, source and depth of borrow material, institutional controls, and original seed mixtures were also considered when selecting the fourteen reclaimed sites for coversoil evaluation. Initial reclamation of the fourteen areas was performed from 1989 to 1991.

The coversoil evaluation involved the collection of three replicate soil samples from the 0 – 10 cm depth increment and the 10 – 40 cm depth increment from fourteen reclaimed areas. The three replicate samples at each depth were consolidated to form two separate composite samples in order to identify differences within the reclaimed cap possibly created by the lime rock barrier and/or the underlying toxic mine waste. Soil sample analyses were performed at the Montana State University Soils Laboratory. Analyses of soil chemical properties included total metals (Cu, Fe, Zn, Pb, Cd, Mn, and As), DTPA extractable metals (Cu, Fe, Zn, Pb, Cd, Mn, As, Cr, and Al), exchangeable acidity, Total Kjedahl Nitrogen (TKN), pH, EC, KCl extractable nitrate and ammonium, Olsen's phosphorus, and extractable potassium. In addition, soil physical features including saturation percentage, course fragment percentage, water holding capacity, texture, and organic matter percentage were determined.

Phase II

The field research involved the implementation of nine different treatments replicated three times on two selected reclaimed areas at uptown Butte, Montana. The two reclaimed areas selected for treatment plot construction were the Poulin Waste Dump #53 and the Washoe Sampling Works #135. An area that contained homogeneous plant cover and soil properties within each reclaimed area was selected for treatment plot construction. The nine treatment combinations consist of inter-seeding, organic nitrogen treatment, and inorganic nitrogen treatment, and varied combinations (Table I).

Table I. Treatment Combinations

Inter-seeding Seedmix		Control (No Nitrogen Treatments)	Inter-seeding Seedmix		Inorganic Nitrogen Treatment (50 lbs N/acre)	Inter-seeding Seedmix		Organic Nitrogen Treatment (Compost)
1. None	+	None	**4.** None	+	2 Applications	**7.** None	+	Compost
2. ARCO 97	+	None	**5.** ARCO 97	+	2 Applications	**8.** ARCO 97	+	Compost
3. Native	+	None	**6.** Native	+	2 Applications	**9.** Native	+	Compost

The treatment applications consisting of inter-seeding, inorganic nitrogen fertilization, and organic nitrogen addition (compost) focus on remedying the low nitrogen and low organic matter contents found at many uptown Butte reclaimed areas. The treatments selected will test three different views for creating healthy and diverse plant communities:

- the nitrogen treatments will improve soil nutrient conditions for existing plant communities;
- the inter-seeding treatments will create plant communities that are adapted to the infertile conditions at the sites; and/or
- a combination of improving soil nutrient conditions and matching plant communities adapted to the improved conditions will improve vegetation performance.

The experimental design is a completely randomized configuration with each square treatment plot covering 4 m^2. Twenty-seven treatment plots are randomly organized on each reclaimed area as shown in Figure 1.

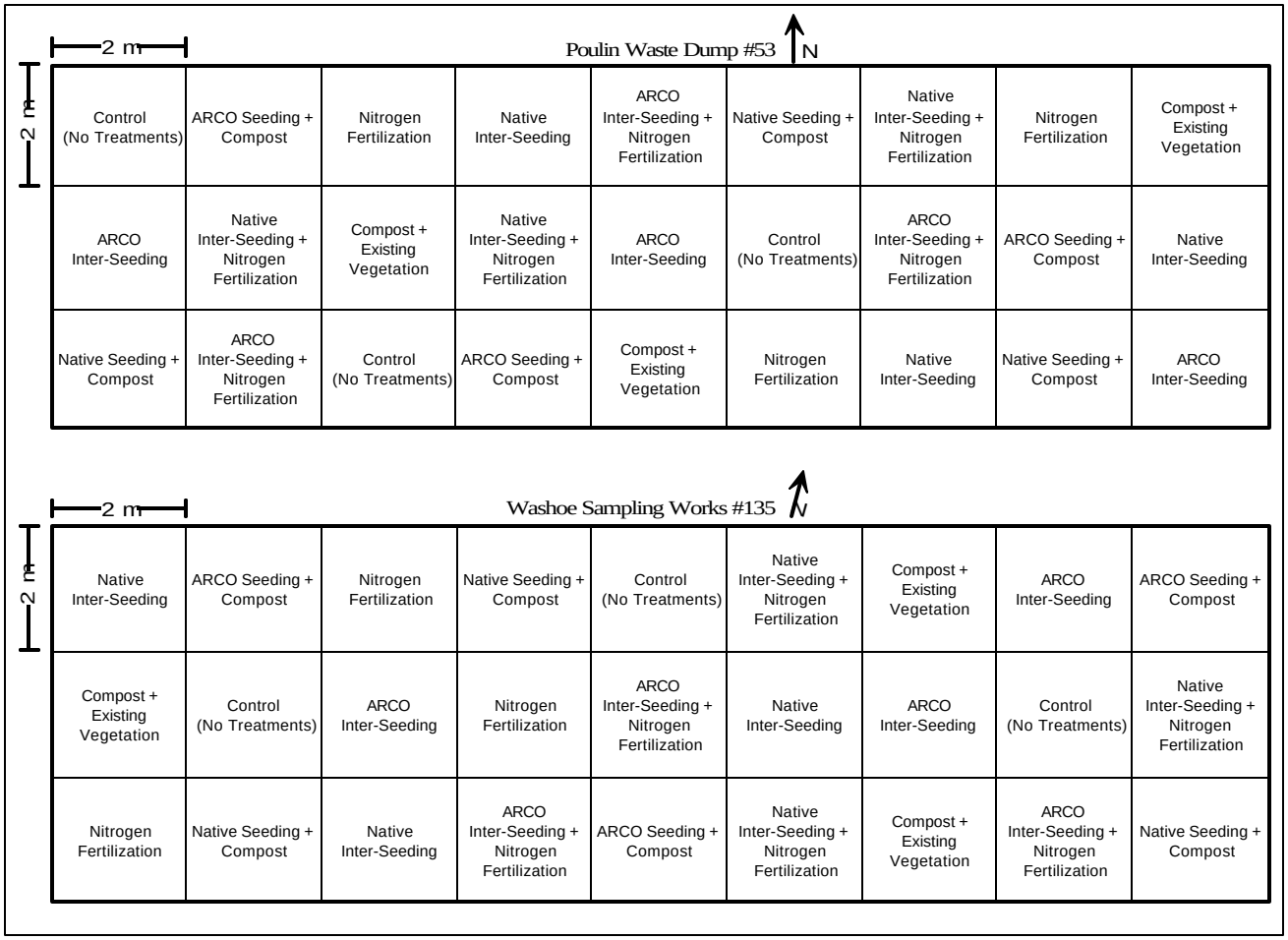

Figure 1. Randomized Treatment Design on each Reclaimed Area

Inter-seeding

Bare soil, which is highly susceptible to erosion and invasion by exotic species, is frequently encountered on many reclaimed areas at uptown Butte. Several different seed mixtures were assessed for inter-seeding methods on the treatment plots. The seed mixtures chosen for research consist of the ARCO 97 Primary seed mixture (currently used for all reclamation at uptown Butte) and a mixture of native perennial grasses and forbs. The broadcast seeding method was utilized; therefore, the recommended drill-seeding rate for each plant species was doubled to ensure initial

establishment (*Sheley, Jacobs, & Velagala, 1999*). Seeding rates are displayed in pounds of pure live seed per acre (PLS#/acre) in Table II.

Table II. Inter-seeding Seed Mixtures

Control	ARCO 97 Primary Seed Mixture	Seeding Rate (PLS/ac)	Native Seed Mixture	Seeding Rate (PLS#/acre)
No inter-seeding was performed on these selected treatment plots.	Slender wheatgrass	3.0 x 2	Yarrow	0.2 x 2
	Thickspike wheatgrass	2.0 x 2	Sandbergs bluegrass	0.2 x 2
	Sheep fescue	2.0 x 2	Bluebunch wheatgrass	1.4 x 2
	Crested wheatgrass	1.0 x 2	Indian ricegrass	0.6 x 2
	Ladak alfalfa	1.0 x 2	Prarie sandreed	0.8 x 2
	Red clover	2.0 x 2	Lewis flax	0.3 x 2
	Canada bluegrass	1.0 x 2	Mountain brome	1.7 x 2
	Bird's Foot trefoil	1.0 x 2		
	Total	**13.0 x 2 = 26.0**	**Total**	**5.2 x 2 = 10.4**

Reclaimed areas with low nitrogen and organic matter contents have great difficulty supporting highly productive introduced species without the addition of nutrients and intensive management. Undisturbed, native sites with impoverished soils found throughout many landscapes often have high plant species diversity and productivity without the need for added management practices and chemical inputs (*Huston 1993*). Therefore, the seed mixture consisting of native species is being explored to determine vegetative success in these low nutrient environments.

Inorganic Nitrogen (Urea Fertilization)

Two incremental urea (46-0-0) applications were performed on selected treatment plots. One application was performed early June and the second application in early July. The fertilizer was applied at 50 lbs nitrogen/acre during each application. Granular urea fertilizer was completely dissolved in water and applied with a hand held sprayer to ensure that all nitrogen was absorbed into the soil immediately. The fertilizer applications will be continued during the second research year.

Organic Nitrogen Addition (Compost Incorporation)

Compost was incorporated on designated treatment plots at an application rate of 1.68 % organic amendment. The application rate was calculated on a dry weight basis for incorporation into the upper six inches of cover soil. The compost was mixed to the six-inch depth with a small tractor and roto-tiller. Compost incorporation destroyed all existing vegetation on treatment plots where seeding treatments were also applied. Conversely, to assess the effects of compost on the existing species, a garden claw tool was used to mix the compost into the soil. The garden tool effectively mixed the compost with the soil without posing adverse effects to the existing species. Compost application was performed during initial treatment plot construction and will not be applied again throughout the research.

Measurement of Response Variables

First year measurements of each treatment plot included the quantification of individual and total plant species densities, individual species and total live plant canopy cover, litter, bare ground, and moss and lichen coverage. Quantification of the response variables was performed with the use of a 2 x 5 dm Daubenmire frame (*Daubenmire 1959*). The Daubenmire frame was randomly placed within each treatment plot at fifteen different locations. An analysis of variance (ANOVA) was used to statistically evaluate the data collected from the treatment plots. During the second year of research, plant densities, canopy cover, seed relation, and mortality of inter-seeded species will be measured by individual plant species. Treatment plot soil properties will be measured after the second field season to determine alterations produced by treatment conditions.

PHASE I RESULTS

The analyses of soil samples collected from the fourteen uptown Butte reclaimed areas indicate that soil chemical properties are most likely not phytotoxic to vegetative growth. However, average total metal concentrations for copper, lead, and zinc are considerably higher than suitable coversoil criteria adopted for the Butte area (*Alice Dump Response Action Design Report, February 14, 1999*) displayed in Table III.

Table III. Comparison of Criteria & Measured Total Metal Concentrations in Butte Coversoils

Metal	*Acceptable Total Metal Conc.* (mg/kg)	*Maximum Measured Conc. (mg/kg)*	*Average Measured Conc. (mg/kg)*
Arsenic	<97	50.00	23.64
Cadmium	<4	5.60	1.97
Copper	<250	631.00	191.36
Lead	<100	692.00	103.96
Zinc	<250	1588.00	313.82
Manganese	400 – 1000*	2536.00	1484.64
Iron	Criteria not established	5.48	4.00

*Phytotoxic data from Kabata-Pendias and Pendias, 1992

Excess copper concentrations can cause observable tissue damage and depressed plant growth, seedling development, and root development (*Tiller and Merry, 1981*). Copper concentrations in soil that lead to phytotoxic plant conditions are highly variable and complex. Elements within the soil form complex interactions with copper that can be both favorable and toxic to vegetative processes. The toxicity of the complexes depends upon the elements involved and their associated concentrations (*Kabata-Pendias and Pendias, 1992)*. Observable copper toxicity of plants was not observed during sampling. Unproductive plant growth is more likely associated with coarse textured soils and limited available water.

Elevated zinc concentrations can cause depressed plant growth and chlorosis of new growth; however, zinc is not considered to be highly phytotoxic and only select sensitive plant species (cereals and spinach) at various growth stages show effects of poisoning (*Davis 1979*). Upper toxic

levels of zinc have been measured at 500 ppm in plant tissues, a small fraction of the total zinc concentrated in the soil.

Lead contamination of soil negatively affects microbial activities important for nutrient cycling and organic matter decomposition (*Tyler 1976)*. On the other hand, elevated soil lead concentrations tend have limited effect on plants. Soil lead is often unavailable to plant roots and studies have shown that much less than 1% of the total lead in soil is taken up by plants (*Wilson and Cline, 1966*).

Total manganese criteria concentrations have not been established for Butte coversoil; however, analyses of reclaimed area soil samples detected considerable manganese concentrations. The tolerance of plants to manganese is dependent upon the proper manganese to iron ration within plant tissues. However, the ratios and effects differ greatly among species and their growth stages (*Kabata-Pendias and Pendias, 1992).*

Soil physical properties of reclaimed area coversoils are a major limitation to plant growth. The sandy loam soils contain an average clay concentration of 11.8%, corresponding to low average values of complete saturation (18.58%), field capacity (11.74%), and wilting point (6.05%). Coarse fragments comprise an average of 32.55% of the soil volume. Average plant available nitrogen concentrations are also notably low. Surprisingly, the average soil organic matter (OM) percentage is 0.36%. The organic matter percentage is very low, yet higher than anticipated for the coarse textured cover soils. Suitable coversoil criteria (*Surface Mining and Coal Reclamation Act, 1977*) and measured average, maximum, and minimum levels are displayed in Table IV.

Table IV. Acceptable Coversoil Criteria & Measured Levels

Parameter	*Suitable Levels*	*Average Measured Levels*	*Maximum Measured Levels*	*Minimum Measured Levels*
pH	5.5 – 8.5	7.65	8.40	6.40
Conductivity (mmhos/cm)	< 4.0	0.20	0.32	0.08
Soil Nitrogen (mg/kg)	> 17 mg/kg	3.33	9.50	0.80
Soil Olsen's Phosphorus (mg/kg)	> 4 mg/kg	11.10	25.90	1.90
Soil Potassium (mg/kg)	> 75 mg/kg	159.00	442.00	62.00
Saturation percentage	25 – 90 %	18.58	24.54	9.72
Coarse Fragments	< 20%	32.55	58.50	19.90
% Water at 1/3 Bar	Unverified	11.74	17.00	7.70
% Water at 15 Bar	Unverified	6.05	8.80	3.60
Organic Matter %	Unverified	0.36	1.06	0.08
Carbon to Nitrogen Ratio	< 18	5.53	10.00	1.92

Based upon the criteria presented in Table IV, reclaimed area coversoils sampled only meet acceptable limits for pH, conductivity, Olsen's phosphorus, and potassium. Coarse fragments for many of the reclaimed areas are well above 20%, correlating to very low saturation percentage values (< 25%). Water holding capacity is extremely poor and is most likely the largest limiting factor to productive plant growth. A moist climate could compensate for poor water holding capacity; however, uptown Butte received only 4.86 inches of precipitation from May 1, 1998 to August 15, 1998.

PHASE II RESULTS

In general, treatment values for total plant cover, litter accumulation, and bare ground are very similar on both sites. Major vegetation differences noted between the sites appear to be highly dependent upon the plant communities present before treatment plot construction. The Poulin Waste Dump vegetation consisted of a diverse community of species, largely weedy. Noxious weeds such as *Centaurea maculosa* (Spotted knapweed), *Verbascum thapsus* (Common mullein), and *Trapogon dubius* (Yellow salsify) were a major component of the plant community. Vegetative species dominant prior to the treatment plot construction on the Poulin Waste Dump have continued to play a major role, greatly affecting the first year of treatment results. Vegetation on the Washoe Sampling Works consisted of primarily *Festuca ovina* (Sheep fescue), and *Melilotus alba* (White sweet clover). Some weedy species such as *Verbascum thapsus* (Common mullein) were present, but did not play a dominant role. Inter-seeding treatments appear to have more success among this existing plant community. Germination rates of inter-seeded species were relatively abundant on both sites, yet actual species establishment rates are difficult to accurately assess prior to the second growing season.

The vegetation that existed on the Poulin Waste Dump prior to experiment implementation has essentially controlled the treatment plot plant communities. Weedy species dominated the site prior to the treatments and have continued dominance through the first growing season. The invasive species are a major concern for establishing vegetation; therefore, a weed management strategy must be developed for the research plots that will not alter the current treatments. Spot spraying weeds with herbicide and mowing the plots are two alternatives considered. Spraying poses large risks to broadleaf inter-seeded species and could drastically alter the current treatment effects. Mowing is a cost-effective alternative that will not significantly pose harm to the inter-seeded species, yet it is not always effective and must be continued throughout strategic points in the growing season and for consecutive years. If chosen, the mowing treatment will be performed early in the second growing season to reduce early weed competition and possibly during mid-growing season if weedy species still dominate the plant community.

CONCLUSIONS

The coversoil used for reclamation at uptown Butte, Montana, does contain some elevated heavy metal concentrations; though, concentrations present are not phytotoxic to the perennial grasses and forbs. Average plant available nitrogen and organic matter percentages are greatly limited on many reclaimed areas at less than 3.33 mg/kg and 0.36% respectively. The calculated average carbon to nitrogen ratio is 5.53 indicating mineralization is providing some plant available nitrogen (*Sylvia, D., et al 1998*). Poor coversoil physical properties are the utmost limiting factor to plant growth. The sandy loam coversoils contain an average of 32.55% coarse fragments that can hold only 18.58% percent water at complete saturation. Limited annual precipitation combined with south facing hot and dry aspects pose great challenges to healthy plant community establishment.

The treatment plot vegetation data collected for the first growing season demonstrate that plant species existing prior to the treatment plot construction continue to remain dominant over inter-seeded species. Invasive weedy species are highly competitive and are most likely benefiting the greatest from the added nitrogen treatments. A mowing strategy will likely be developed for the

second year of research to reduce weed competition and increase perennial grass and forb performance. The inter-seeding treatments had greater effect upon the Washoe Sampling Works site where few invasive species were present and a large percentage of bare ground provided adequate safe sites for vegetation establishment. Inter-seeding treatment effectiveness would be much greater if invasive species were reduced or eliminated prior to seeding. Forthcoming data from the second growing should provide greater insight on treatment plot effects of nitrogen addition (compost and fertilizer) and species establishment from the ARCO 97 and native inter-seeding mixtures.

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