2000 Billings Land Reclamation Symposium

ACID REMEDIATION AT HOMESTAKE'S SANTA FE MINE USING A CHEMICAL CAP

D. A. Shay[1] and R.R. Cellan[2]

ABSTRACT

The Santa Fe Mine, located in west central Nevada, began leaching ore in 1988 and completed ore processing in 1995. Homestake Mining Company has completed final reclamation of the site, including remediation of waste dump acid conditions resulting from the oxidation of near-surface sulfide minerals. The production of acidity and the migration of acidity into coversoil became a significant detriment to previous revegetation success at the site. Acid geochemical conditions at the site indicated that the actual production and concentrations of acidity were relatively low, the result of low moisture regime, low biological activity, and limited oxidation of ferric ions. The oxidation of sulfides was a near-surface condition and the spread of acidity into coversoil materials was largely the result of chemical diffusion processes. After examining several remediation options, Homestake elected to construct a chemical cap on the waste dumps to prevent the diffusion of acidity into new coversoil materials. Monitoring data from the site has indicated that the chemical cap has been successful in preventing the diffusion of acidity into coversoil materials and the long-term goal of revegetation success is likely.

---

[1] Resource Investigation and Management Consultants, 309 Lariat Drive, Spearfish, SD 57783
[2] Homestake Mining Company, P.O. Box 98, Grants, NM 87020

INTRODUCTION

Hardrock mine plans in the early 1980's did not generally include provisions for managing waste rock containing pyrite or other sulfidic minerals. By the late 1980's, mine operators and regulators began to understand the potential problems associated with mining sulfidic rocks. As has been well documented, the oxidation of sulfides will result in the generation of significant acidity and the potential for the release of acid mine drainage. The sulfide oxidation process, and resultant acid production, has plagued many hardrock mines in recent years. The lack of planning for management of sulfidic rock during mine-planning and permitting phases resulted from the fact that most cyanide leach facilities developed in the early 1980's mined primarily oxide deposits. That is, the minerals in the deposits, including pyrite, were highly oxidized resulting in a deposit that is amenable to cyanide leaching. In addition, the majority of rock characterization was aimed at defining the ore reserve and less attention was paid to waste rock characterization. Waste rock was placed randomly in waste dumps and it was generally thought that the rainfall amounts in arid and semi-arid climates were not sufficient to cause environmental or reclamation concerns.

The Santa Fe Mine was developed in the late 1980's with ore processing completed in late 1995. Homestake Mining Company acquired the Santa Fe Mine in 1992 as part of a merger with another mining company. The operator began to reclaim the waste dumps in 1991 and 1992. The waste dumps were characterized by long angle-of-repose side-slopes and relatively flat tops, configurations common at the time for dumps constructed by end-dumping trucks. The original reclamation plans included the placement of 4 to 6 inches of coversoil on the tops and sides of the dumps, straw mulching, and seeding with a native seed mix. Initial revegetation growth was excellent with the establishment of a native grass, shrub, or forb community.

In 1997, revegetation monitoring and site observations indicated that the re-seeded vegetation was dying, leaving bare areas on the tops and side-slopes of the dumps. Examination of these areas confirmed that the oxidation of sulfides and the subsequent migration of acidity were responsible for the decline of vegetation. Homestake contracted with RIMCON to develop an acid rock remediation plan for the site and to assist Homestake in implementing that plan. Details of the remediation and results of first year monitoring are presented in this paper.

GEOLOGIC AND MINING BACKGROUND

The geologic setting and the mining practices at the Santa Fe Mine were typical of the mining operations and operational practices of the 1980's. The Santa Fe gold-silver deposit is located in the foothills of the eastern margin of Todd Mountain, within the south-central portion of the northwest trending Gabbs Valley Range in Nevada. The surface elevation of the mine site ranges from 5975 feet to 6160 feet above sea level. Three major rock units are present at the site. The oldest unit is the Triassic Luning Formation, which is intruded by a Mesozoic pluton. These rocks are overlain by, or in fault contact with, Tertiary volcanics and Quaternary to Recent alluvium (Fiannaca, 1987).

The Luning Formation comprises blue-grey, medium-bedded to massive brecciated limestone, micrite, and rare amounts of siltstone. These rocks are usually carbonaceous and

occasionally pyritic. Near intrusive margins, dull-green hornfels, whitish brown marble pods and calc-silicate skarns occur with pyrite as a common accessory mineral. The Tertiary volcanic rock unconformably overlies, or is in fault contact with the Luning Formation. This ash flow has a densely welded basal rhyodacite which grades upward into a partially welded rhyolite and both are generally non-pyritic (Fiannaca, 1987).

The gold and silver mined at the Santa Fe Mine came largely from the highly oxidized zones within the pit. As such, the rock placed on the heap leach pads did not contain appreciable concentrations of pyrite or sulfides and did not produce acidity upon leaching. Drill cuttings from the in-pit blast-hole drilling were analyzed for ore grade and oxidation state in relation to sulfides. Ore rock containing appreciable concentrations of pyrite (sulfide ore) was selectively handled and placed in a stockpile. This ore was generally not considered readily amenable to cyanide leaching and was stockpiled as a contingency for possible future processing.

Waste rock consisted of a combination of oxidized, mixed and sulfidic rock that was not mineralized. Waste rock dumps at the Santa Fe Mine were typical end-dump repositories. That is, the rock was dumped by trucks in piles and the piles were dozed flat to form a layer in the dump. This process resulted in long, angle-of-repose sideslopes and relatively flat tops. The mining process moved in and out of rock that contained pyrite and this process resulted in the sulfidic rock being placed randomly in the dumps. As stated previously, during this mining period, there was little concern by mining companies or regulators that the sulfides could create environmental or reclamation problems in the future. The Santa Fe Mine provides a case study of the types of remedial problems that can occur in an arid climate when pre-planning for management of sulfides has not occurred.

SITE GEOCHEMICAL CHARACTERIZATION

In 1997, Homestake personnel observed that vegetative cover was declining, significant bare areas were developing, and the bare areas appeared to be growing in number and size. Revegetation specialists examined the site and evaluated numerous agronomic characteristics to determine the cause of the dying vegetation. Based on their review and the subsequent field examination by RIMCON, it was determined that the majority of bare areas were the direct result of the oxidation of sulfides in the waste rock.

Since the waste rock was placed randomly in the dumps, the occurrence of the acid areas was also random and the location of other potential acid generating areas was difficult to predict. Numerous areas of the waste dumps exhibited classic symptoms of the sulfide oxidation process. That is, oxidation by-products, such as iron and manganese hydroxides and gypsum were present. Surfaces were crusted and exhibited telltale red, yellow-orange, and black colors. Where some of the acidity had been neutralized by adjacent limestone, clayey residues resulted, further enabling surface crusting as the materials dried. In some areas, the oxidation and weathering processes allowed for significant expansion or swelling of the waste materials creating a hummocky landscape.

The development of a remediation plan for the site depended on numerous factors including the sulfide oxidation mechanisms. The sulfide oxidation process is generally

complicated and involves both chemical and biological oxidation components. The rate of chemical oxidation is influenced by factors including pH, oxygen concentrations, temperature, moisture content and the ferrous/ferric iron equilibria. The chemical oxidation of pyrite is quite sensitive to the pH of the reaction media, particularly on the influence of pH on the ferrous/ferric iron equilibria. That is, at very low pH, ferric iron serves as an oxidant of ferrous iron resulting in a significant increase in both the rate and quantity of acid generation. If the oxidation process is limited and pH levels remain generally above 4.5, the oxidation of ferric iron will be limited (Sobek, etal., 1997).

Microorganisms also serve as catalysts to the oxidation process and are most active in the pH range of 2.0 to 4.5. The organisms have optimum temperature requirements and must have moisture to be active. Generally the organisms obtain their energy from oxidation of elemental sulfur and can actually regenerate ferric iron in the process. When bacteria are active, the generation of acidity may be increased 50-fold by increasing the rate of ferrous iron oxidation (Sobek, etal., 1987).

Table 1 summarizes some of the site geochemical characteristics from selected areas. The table has been divided into two sections, one summarizing data from areas that did not contain oxidizing sulfides and the other from areas that had oxidizing sulfides. As is typical of most acid generating materials, the sulfidic areas exhibited elevated iron, manganese, and sulfate levels. The sulfate concentrations for the sulfidic areas ranged from 100 to 880 ppm while the sulfate concentrations for the non-sulfide areas ranged from 6.6 to 64 ppm. Manganese concentrations for the sulfide areas ranged from 98 to 820 ppm as compared to the concentration range for non-sulfide areas of 3.3 to 46 ppm. The iron concentrations, often the most identifiable element associated with acid generation, ranged from 190 to 4600 ppm for the sulfide samples and ranged from 6.7 to 95 ppm for the non-sulfide samples. With the exception of one sample (5C), pH values for the sulfidic areas were greater than 4.5 and ranged up to 5.9. The sampled identified as 5C exhibited a very low pH value of 2.6.

Table 1. Waste dump geochemical characteristics.

Sample Site	pH	Iron mg/l	Manganese mg/l	Sulfate mg/l
Non-sulfides				
4A	7.6	13	7.4	64
15	7.0	79	46	39
16	6.9	95	24	41
17	7.9	8.2	3.8	6.6
21A	7.9	6.7	3.3	12
Sulfides				
13B	5.5	1000	320	180
4D	5.9	190	98	140
5C	2.6	4600	820	880
23C-1	4.5	2800	410	320
23C-2	5.6	1900	110	100

While the generated acidity was sufficient to degrade coversoil, the actual concentration of acidity was somewhat limited. Laboratory weathering tests of samples 5C and 23C-1 show that total titrateable acidity generated in the samples was only 380 and 420 mg/l,

respectively. These results can be compared to numerous other mine sites where total generated acidity often exceeds several thousand mg/l. This data, along with the observations described above and field observations, indicated that the relatively low acid generation was the result of several rate limiting factors, including low moisture regime, limited biological activity, and limited oxidation of ferric ions. This conclusion was very important for the selection of a cost-effective remediation plan.

REMEDIATION PLAN

Several factors resulted in the degradation of coversoil and vegetation at the Santa Fe Mine. Because precipitation is limited at the site (7 inch average), the generation of acidity was strictly a near-surface condition. Limited grading of the dump and dump settlement resulted in brief ponding and collection of rainfall runoff in low areas. This moisture was sufficient to allow for oxidation of near-surface sulfides and the production of low-level acidity. While the sulfide rock was often deposited in the vicinity of other waste rock derived from the Luning limestone, geochemical kinetics were limited and little neutralization of the acidity occurred. Generally, the acid generation process was very rapid and the limestone surface area was too large to allow for significant neutralization of the acidity. Additional field observations of acid areas showed typical iron hydroxide coating of the limestone, further restricting the ability of the limestone to neutralize the acidity. In areas where rainfall did not collect for extended periods of time, the sulfide waste rock had not yet began to oxidize and generate acid.

The migration and spread of acidity into the coversoil was the result of chemical diffusion rather than movement by convective flow. That is, the acid solute moved from areas of high concentrations to areas of lower concentrations without significant water movement. Because of this process, the final remediation design had to consider ways to prevent the diffusion of the acidity into new coversoil. Since many areas of the dump had sulfide waste that had not yet significantly oxidized, the plan had to be inclusive of these areas also. Covering the dumps with non-sulfide waste rock was not an option since mining had ceased, all waste rock was randomly mixed with sulfidic rock, and coversoil availability was also limited.

Since the oxidation was accelerated in low areas on the dumps, the final remediation plan involved grading the surface of the dumps to prevent ponding of the limited precipitation. The crests of the dumps were graded to prevent rainfall from flowing directly over the steep sideslopes creating rilling and erosion. In addition, drainage channels were designed into the plan to route precipitation from potential high rainfall events away from the dumps. While the grading plan may create a less diverse vegetative stand over time, the prevention of ponding was considered very important to preventing isolated high oxidation areas.

The final, and most important aspect of the remediation plan, was the construction of a chemical cap that was placed on the dump tops and sideslopes before coversoil application. Chermak and Runnells (1997) discussed the use of a chemical cap at an unamed Nevada mine site. They attempted to create a permanent chemical cap, or hardpan, by neutralizing surface acidity with lime. The chemical reactions produced gypsum and amorphous iron oxyhydroxides, which were produced in an attempt to limit water infiltration into the dump. Conversely, the Santa Fe Mine chemical cap function was to neutralize existing near surface

acidity and to serve as a barrier for diffusion of acid solutes. The chemical cap was placed over the entire surface of the dumps and selected areas of the sideslopes since the location of potentially new acid generating areas was difficult to locate even with intensive sampling.

The chemical cap consisted of the placement of 20 tons per acre of magnesite (magnesium carbonate) and brucite (magnesium hydroxide) mined in nearby Gabbs, Nevada. The application rate was significantly higher than was necessary to neutralize any potential acidity. The application rate was finally estimated by the ability of available equipment to apply the chemical uniformly over the dump surfaces. The chemical was not disked into the surface as is common but was left as a concentrated amendment, maximizing chemical gradient differences. A total of 1850 tons of magnesite and brucite were applied to the dumps. Following placement of the cap, 8 to 12 inches of coversoil, borrowed from a nearby native draw, was placed carefully over the cap and seeded with a native seed mix.

While used at times for water treatment, the use of magnesite and brucite as a chemical amendment for remediation of acid rock conditions is somewhat rarer. Theses chemicals had a total alkalinity of 1920 mg/kg and a neutralizing potential (NP) of 600 tons per 1000 tons CaCO3 equivalent. Laboratory observations indicated that the rate of chemical neutralization was slightly slower than for calcium carbonate due to a slower dissolution rate. However, the magnesite and brucite had significant buffering capacities and the fact that the materials were mined very close to the site made them an extremely cost-effective and technically sound amendment.

REMEDIATION RESULTS

Construction of the chemical cap and coversoil placement was finished in late 1997 and revegetation efforts on the remediated dumps were completed by spring 1998. The site was visited in late April 1999 to monitor the effects of the chemical cap and to make general observations of the site conditions. Vegetation monitoring has been conducted separately from this study.

Monitoring procedures consisted of hand-dug holes to a depth below the chemical cap. Monitoring sites were selected randomly throughout the tops and sideslopes of the waste dumps. A total of 21 monitoring holes were dug and observations of coversoil depth, coversoil pH, waste pH, chemical cap conditions, and other general observations were recorded. Photographic documentation of the monitoring holes was also performed.

Table 2 and Table 3 summarize the results of those field observations for the east and west waste dumps. In all cases, where sulfidic waste was noted below the cap, no diffusion of acid solutes has occurred. One site, identified as site W-9 showed evidence that the coversoil, chemical cap, and sulfidic waste had been disked and thoroughly mixed. While oxidation by-products were clearly visible in the materials, field pH measurements indicated that neutralization of the acidity had occurred as evidenced by a 6.9 pH value. The mean pH of all coversoil immediately above the chemical cap was 7.2 with a range of 6.9 to 7.6. The mean pH of the sulfidic waste present immediately below the chemical cap was 5.5 with a range of 4.7 to 5.9.

At this point in time, rainfall quantities have not been sufficient to reach the chemical cap. The 8 to 12 inches of coversoil is sufficient to store all of the moisture received during a normal rainfall year. In the absence of sufficient moisture to allow for convective movement of acid solutes, conditions are ideal for chemical diffusion to occur. The presence of the chemical cap has prevented the diffusion of acidity into the coversoil and it is likely that the chemical gradient created by the cap will result in long-term mitigation of any potential diffusion.

Table 2. West waste dump chemical cap monitoring observations.

Location	Coversoil Depth - in.	Coversoil pH	Waste pH	Visual Observations
W-1	11	7.6	5.9	No visible acid by-products in coversoil; amendments visible
W-2	13	7.5	4.9	No visible acid by-products in coversoil; amendments visible
W-3	8			Non-sulfidic waste; amendments visible
W-4	9			Non-sulfidic waste; amendments visible
W-5	10			Non-sulfidic waste; amendments visible
W-6	8	7.2	5.9	No visible acid by-products in coversoil; amendments visible
W-7	12			No visible acid by-products in coversoil; amendments visible
W-8	8			No visible acid by-products in coversoil; amendments visible
W-9*	0	6.9	6.9	Coversoil/waste mixed; small area; acidity neutralized
W-10	8			No visible acid by-products in coversoil; amendments visible
W-11	10			No visible acid by-products in coversoil; amendments visible
W-12	10			Non-sulfidic waste; amendments visible
W-13	8	7.1	5.9	No visible acid by-products in coversoil; amendments visible
W-14	8			No visible acid by-products in coversoil; amendments visible
W-15	8			Non-sulfidic waste; amendments visible
W-16**	12	7.4	4.7	No visible acid by-products in coversoil; amendments visible
W-17	8	7.1	5.8	Side slope site; no visible acid by-products in coversoil
W-18	8			Side slope site; no visible acid by-products in coversoil

* Coversoil, waste, and amendments have been disked together at this location. Acidity has been neutralized.
** Location in area of intense weathering and oxidation before remediation. Area was very wet and generating steam on cold days. Amendments were applied at a rate of 40 tons/acre.

Table 3. East waste dump chemical cap monitoring observations.

Location	Coversoil Depth - in.	Coversoil pH	Waste pH	Visual Observations
E-1*	24			No visible acid by-products; amendments not reached
E-2	9	7.3	5.9	No visible acid by-products in coversoil; amendments visible
E-3	11			No visible acid by-products in coversoil; amendments visible
E-4**	12	7.1	2.7	No visible acid by-products in coversoil; amendments visible
E-5	8			Non-sulfidic waste; amendments visible
E-6	9			Non-sulfidic waste; amendments visible
E-7	8			No visible acid by-products in coversoil; amendments visible
E-8	8	7.0	5.9	No visible acid by-products in coversoil; amendments visible
E-9	8			No visible acid by-products in coversoil; amendments visible
E-10	10	7.2	5.8	No visible acid by-products in coversoil; amendments visible
E-11	10			No visible acid by-products in coversoil; amendments visible
E-12	8	7.0	5.2	No visible acid by-products in coversoil; amendments visible
E-13	8			

* For unexplained reasons, this sampling site is very deep and amendments were not reached.
** This location is the site of significant acid generation compared to other areas. The chemical cap is functioning at this severe site.

ECONOMIC CONSIDERATIONS

Table 4 summarizes the costs associated with the acid remediation plan and does not include the internal management expenses encountered by Homestake. In addition to the

expenses noted in Table 4, Homestake also had internal site review costs, remediation plan development and review costs, on-site construction management costs, and site maintenance costs.

As can be seen from Table 4, Homestake's voluntary waste dump remediation efforts cost the company in excess of $775,000 not including their internal costs. These costs are a case study of a relatively uncomplicated remediation plan, the result of low precipitation levels. Many sites that have developed acid problems, including acid mine drainage, are faced with remediation costs that often exceed several million dollars. In fact, acid remediation construction costs at two mines in South Dakota that are of similar size to the Santa Fe Mine are estimated in excess of $12,000,000 each, not including post-remediation water treatment and management costs (SDDENR, 1999).

Table 4. Santa Fe Mine remediation and reclamation costs.

Expense category	Cost
Mobilization, demobilization, site grading, and drainage construction	$146,000
Chemical amendment purchase, haulage, and application	$139,000
Coversoil haulage, application, and revegetation	$442,000
Engineering and construction management	$ 50,000
Total	$776,000

CONCLUSION

The selection of the chemical cap technology for remediation of acid conditions at the Santa Fe Mine was cost-effective. Other alternative options, such as a combined physical and chemical cap, would have cost significantly more than the chemical cap. The voluntary effort by Homestake to improve the revegetation success of the site appears to have been very successful. This project is indicative of Homestake's desire to be proactive in the reclamation and management of all of their mine sites.

REFERENCES

Fiannaca, M. 1987. Geology of the Santa Fe gold-silver deposit, Mineral County, Nevada, In Johnson, J.L. ed., bulk Metal Deposits of the Western United States, Geological Society of Nevada. 1987 Symposium, p. 233-239.

Chermak, J.A. and D.D. Runnells. 1997. Development of chemical caps in acid rock Drainage environments. Mining Engineering. P. 93-97.

Sobek, A. A., Hossner, L.R., Sorenson, D.L., Sullivan, P.J. and Fransway, D.F. 1987. Acid-base potential and sulfur forms. In Reclaiming mine soils and overburden in The western United States, R. Dean Williams and Gerald E. Schuman, editors, Soil Conservation Society of America, Ankeny, IA, p.223-258.

South Dakota Department of Environment and Natural Resources, Minerals and Mining Division. 1999. Personal communication, Pierre, SD.

2000 BILLINGS LAND RECLAMATION SYMPOSIUM

ALTERNATIVE MINE WASTE REPOSITORY DESIGN TO ALLOW FOR REDEVELOPMENT AND REUSE OF LAND IN BUTTE, MONTANA

Chuck Stilwell, P.E. and Brad Archibald, P.E.[1]

ABSTRACT

Reclamation of mine waste areas and design of mine waste repositories and covers must take into consideration regulatory, technical, and end-use issues. Presented here is a case study of a site in Butte, Montana, where a unique approach was taken to design and construct a mine waste repository and municipal landfill that met all regulatory requirements while allowing the redevelopment of the site into a multi-functional recreational complex for the community.

The Clark Tailings were a historic tailings impoundment approximately one mile southwest of Butte, Montana. The 60-acre (24-hectare) site contained approximately 1,000,000 cubic yards [yd^3] (765,000 m^3) of mine waste and is adjacent to the old Butte municipal landfill. A combined remedy for the mine waste and landfill was performed under RCRA jurisdiction. Also, 850,000 yd^3 (650,000 m^3) of mine waste from another site in Butte were consolidated at the site. The waste placement and repository cover designs considered plans for future redevelopment into a recreational complex, which included large irrigated areas for turf-grass ballfields, play areas, Park buildings, and parking areas. Though the cap was designed to meet the prescriptive regulatory requirements, many alternative features were incorporated, including using locally available soil to meet strict infiltration barrier requirements. Waste placement and the final cover were designed in 1997 and constructed in 1997 and 1998. Park improvements are scheduled for construction in 1999 and 2000.

Introduction

A combination of conditions and concerns related to several/mine waste reclamation projects and a recently closed, previously used municipal solid waste landfill near Butte provides an opportunity for a creative solution to all. This paper describes how the challenge of cleaning up two sites, a mine waste site and a landfill in an urban setting, while creating a recreational amenity for the community in the process was met.

[1] Chuck Stilwell, Environmental Manager, ARCO Environmental Remediation, L.L.C, 307 East Park Street, Suite 400, Anaconda, Montana 59711, and Brad Archibald, Senior Engineer, Pioneer Technical Services, Inc., P.O. Box 3445, Butte, Montana, 59702

Background

The Clark Tailings, located in southwest Butte, are wastes generated by the William Clark's Timber Butte zinc mill, operated between 1914 and the 1930s. The historic tailings impoundment containing approximately 1,000,000 yd^3 (765,000 m^3) of tailings on a 60 acres (25 hectares) site was partially reclaimed in the mid-1980s, but concerns remained regarding their possibility to impact the surrounding area. The once remote site, now has residential and light industrial development adjacent to it, and was to be studied to determine the need for further, more permanent reclamation.

Adjacent to the west of Clark Tailings was the old Butte municipal landfill, operated between the 1960s and 1995. Groundwater contamination detected in 1994 precipitated a Corrective Measures Assessment for the landfill. The landfill was closed in the mid-1990s in accordance with applicable Subtitle D regulations. The closure included a soil cover and grading to achieve positive drainage from the waste areas, the surface revegetated with native grasses, and a landfill gas venting system installed to mitigate groundwater contamination present beneath and downgradient of the landfill. Though the closure was complete, no foreseeable active land use was likely - as with many closed municipal landfills - due to the uncompacted fill, methane generation and site maintenance issues.

A second area impacted by mine waste called the Lower Area One (LAO) site was located one mile north of the Clark Tailings and Butte landfill sites. Approximately 1.2 million yd^3 (917,000 m^3) of tailings were to be removed from a historic floodplain and wetland setting, which was causing significant metals impacts to the Silver Bow Creek surface and groundwater. LAO was in the process of being remediated, which involved an action of removing much of the accessible tailings from the Silver Bow Creek floodplain for a span of about a mile of the stream and disposed of them via rail 25 miles away in the Opportunity tailings ponds, near Anaconda, MT. The LAO tailings removal was already underway, with approximately 400,000 yd^3 of dry, unsaturated tailings already moved to the Opportunity Ponds. What tailings remained was to take up to six years to remove and haul, given the originally selected mode of transportation - rail. This lengthy construction schedule was due specifically to lack of rail car availability and capacity and the distance and time to haul 25 miles away. Under isolated conditions, a six-year project length could have been accommodated. Yet in the case of LAO, this project's schedule was interrelated with other planned remediation in the Butte area. If the LAO project took another four to six years to complete, the Butte area clean-up effort would likely have been delayed the same length of time.

Finally, an unrelated need existed in Butte - Butte had a lack of modern community recreational facilities. The prospect of a publicly funded facility was unlikely due to an uncertain economic tax base similar to many Montana communities. By working together, ARCO, which was performing much of the reclamation in Butte Butte's local government, State, and Federal Agencies overseeing mine waste and landfill reclamation, conceptualized a creative solution to these issues.

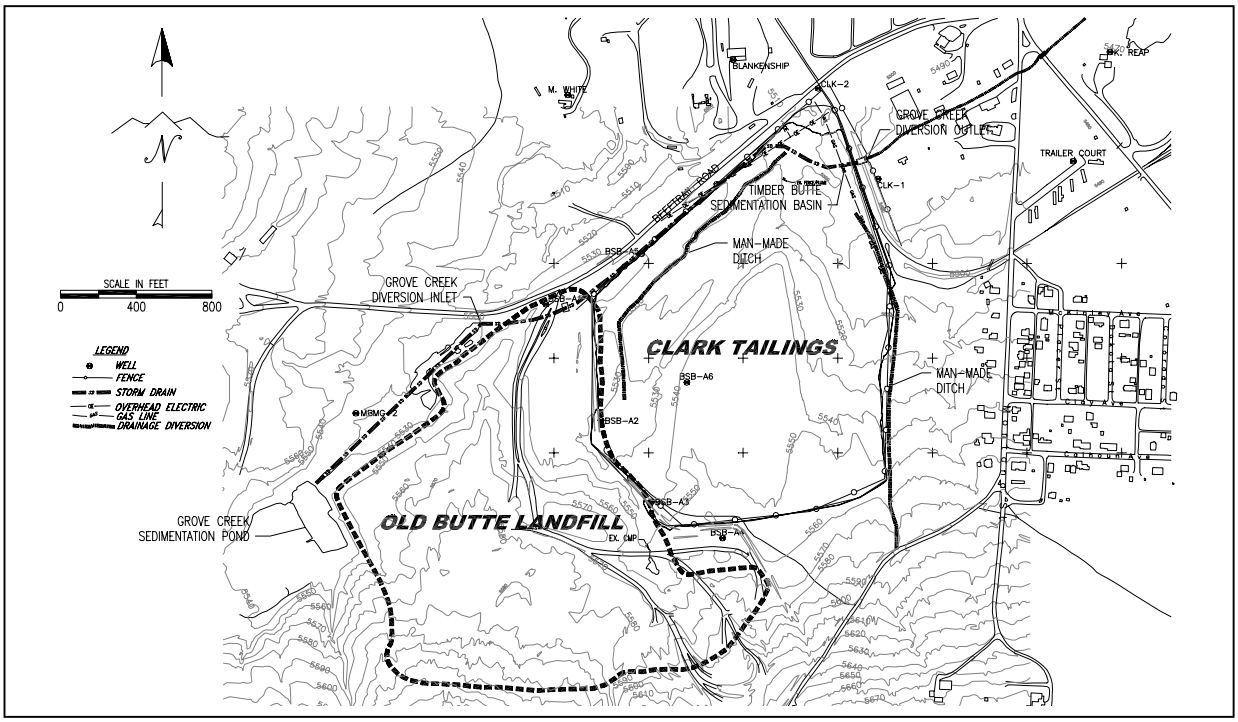

Figure 1. Pre-Remediation Site Map.

Conceptual Plan

The prospect of a protracted remediation schedule at LAO if the Opportunity Ponds disposal site continued to be used initiated a study to find a closer alternative repository site which would be environmentally acceptable for the long-term and would allow a safe haul operation during construction. Though several sites were potentially available near Butte, Clark Tailings provided several advantages, including:

- proximity (approximately one mile away from LAO);
- a likely off-road large truck haul route (for safe haul off public roads using high capacity 35-50 ton trucks);
- shorter schedule (hauling in 35-ton trucks to Clark Tailings would allow the LAO tailings removal and disposal to be completed in two years); and
- the possibility of combining the closure of the partially reclaimed Clark Tailings at the same time as the LAO remediation.

Several advantages also existed in reclaiming the Clark Tailings and Butte's old landfill as a consolidated waste management unit. The landfill had impacted groundwater downgradient of the site, and there were elevated metals in the groundwater downgradient of the Clark Tailings. Closing, monitoring, and managing the groundwater impacts as part of a consolidated waste management unit offered a efficient and effective solution to both of the groundwater issues.

One small disadvantage of hauling to Clark Tailings was having the off-road haul trucks cross public streets frequently (every 2 to 10 minutes during work hours) at two locations over several months. Another concern was the public perception of "new" waste being brought into a part of town which had an adjacent residential neighborhood, commonly called the "Not in My Backyard" issue. To accommodate these concerns, it was agreed that a "brownfield"-type remediation was appropriate. Specifically, the site could be reclaimed and re-developed for functional use as a multi-purpose recreational facility to benefit the community at large. A recreational facility had several advantages – both technical and social. First, waste fills - such as newly placed mine tailings - are typically relatively unconsolidated and material settling over time is inevitable. Allowing commercial or residential buildings would require costly building foundations. Secondly, no future land use which would be incompatible with a closed mine waste repository should be allowed. This would not allow any activity which disturbed the repository cap or vegetation and exposed the tailings underneath.

A dedicated recreational facility with limited building structures, ball fields which would tolerate minor consolidation expected of the newly fill placed tailings (and the newly stressed historical tailings) and ample open space was very compatible with maintaining the repository. Also, a public dedicated development would more likely be better-maintained and be subjected to less unauthorized uses (dirt bikes, etc.), than an inactive and fenced repository. Finally, the recreational facility, or Park, in itself offered the community a new, modern public amenity. The combined repository/closed landfill/park idea was formalized in a Conceptual Plan, which was conditionally approved by the representative Agencies as long as the regulatory requirements for both landfill and mine waste repository closures were met.

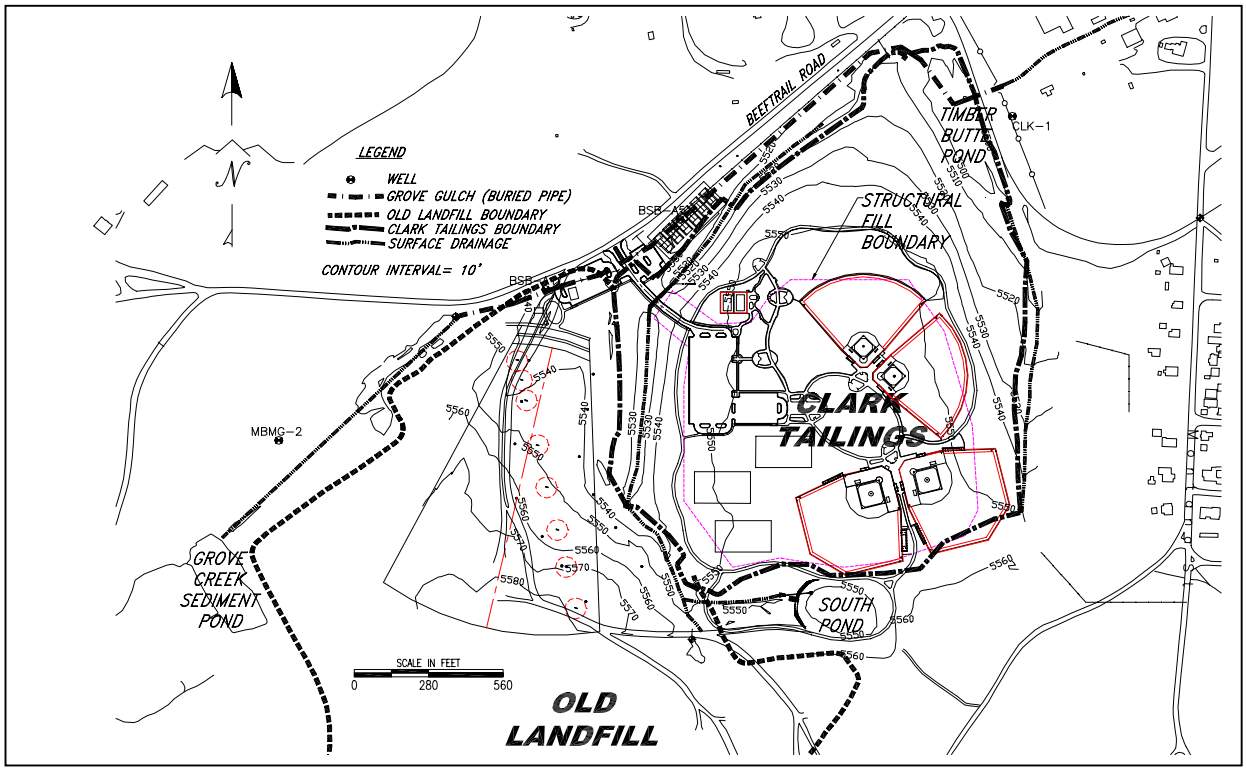

Figure 2. Site map for Post-Remediation with Park Features shown.

Repository and Park Design

With the Conceptual Plan set to build a recreational facility at the Clark Tailings once the Colorado Tailings from LAO were placed there, detailed design of the repository could begin. Designing a tailings repository cap before all the tailings materials are placed and knowing its end land use offered many advantages to having to close an existing tailings pond which was created during a mine processing facility's operation. To integrate the recreation facility's (Park's) design and repository design, both the primary repository design requirements (and objectives) and Park design features had to be understood.

Repository Design Requirements - Primary requirements for the repository were established by the Montana Department of Environmental Quality's Solid Waste Program (MDEQ/SW) who regulates municipal and hazardous waste repositories in Montana. The MDEQ/SW was also the authority overseeing the old Butte landfill's closure, adjacent to the Clark Tailings. Two memoranda of agreement between federal Environmental Protection Agency (EPA) and MDEQ/SW (EPA, 1995 and MDHES, 1995) transferred the Superfund (CERCLA)[2] authority to the MDEQ/SW related to placing LAO's tailings at Clark Tailings and closing the old Clark Tailings as a consolidated waste facility closure with the old Butte Landfill. All solid and hazardous waste regulatory requirements had to be met in this consolidated closure. The presence of groundwater contamination dictated the need for a Corrective Measures Assessment (Pioneer, 1997) for the combined site. The assessment included developing a closure plan to show which requirements must be met and how they were to be achieved.

The primary requirements to ensure the Clark Tailings repository would be constructed and maintained to be permanently protective were established using a risk-based approach. This risk-based approach recognized certain realities of such a mine-waste closure, but with the ultimate goal of reducing significant risk to the human population living in the repository area, as well as the local environment. The realities at Clark Tailings were tailings in an uncontrolled condition with the potential to pose continued risk via direct contract and as a source of surface and ground water running through the site. In fact, the groundwater beneath and immediately downgradient of the site contained highly elevated levels of zinc, on the order of 100 ppm (Pioneer, 1997). Though groundwater was contaminated immediately adjacent to the site, groundwater further downgradient (within ¼ mile) was not. Groundwater beyond the site's perimeter, which was used by the local community, contained zinc levels well below regulatory standards.

The basic plan to eliminate significant risk of further exposure to from metals at the Clark Tailings was to: 1. Consolidate the waste; 2. Isolate the waste; and 3. Monitor the groundwater to show that groundwater downgradient of the site does not get worse and shows steady improvement over time. The specific design features needed to achieve this plan are summarized below:

[2] Comprehensive Environmental Response Compensation Liability Act, 1980

1. Consolidate the Waste – Tailings from LAO and historic Clark Tailings, which had been spread out at the site by wind and water, were to be consolidated in a main repository within the existing "foot-print" of the Clark Tailings Site. This foot-print was approximately 60-acres (24 hectares), and contained an estimated 1,000,000 yd^3 (765,000 m^3) of consolidated tailings. The new repository at Clark Tailings has a 53-acre foot-print.

2. Isolate the Waste – Isolating the waste from exposure pathways was the primary challenge that was to be met. The waste had to be isolated to prevent further exposure to surface water or groundwater flowing near and through the site. This was done through meeting several design objectives:

a. Cap the Waste with Engineered "Prescriptive" Cover – Once consolidated, the approximately 1,850,000 yd^3 (1,414,000 m^3) of waste must be capped with cover intended to isolate the waste from surface exposures via direct contact of the waste, and more importantly, mitigate the potential for further infiltration of water to and through the waste. This was to be achieved with an engineered cover intended to meet the technical requirements determined in the Corrective Measures Assessment and the prescriptive requirements of RCRA and related MDEQ/SW regulations. The cap consists of a multi-layered soil and geosynthetic cover, that limited infiltration, as shown on Figure 3. The layers included from the top down: a. 18 inches of topsoil (fine-textured, locally available soil) to allow vegetated growth; b. geotextile, which is a non-woven, needle-punched fabric intended to keep fine-grained materials from penetrating from the cover soil into the gravel layer; c. 4.5 inch gravel layer to allow any water infiltrating through the topsoil to freely drain laterally off the site, rather than continue infiltrating vertically and to provide a capillary break, increasing the water-holding capacity of the overlying topsoil and preventing the upward migration of acid from the underlying tailings; d. infiltration barrier consisting of 18 inches of native clay/silt materials with a maximum hydraulic conductivity of 1×10^{-7} cm/sec to reduce further infiltration; and e. compacted, low permeability tailings material of depths varying from 2 to 20 feet, which in itself deters significant water infiltration.

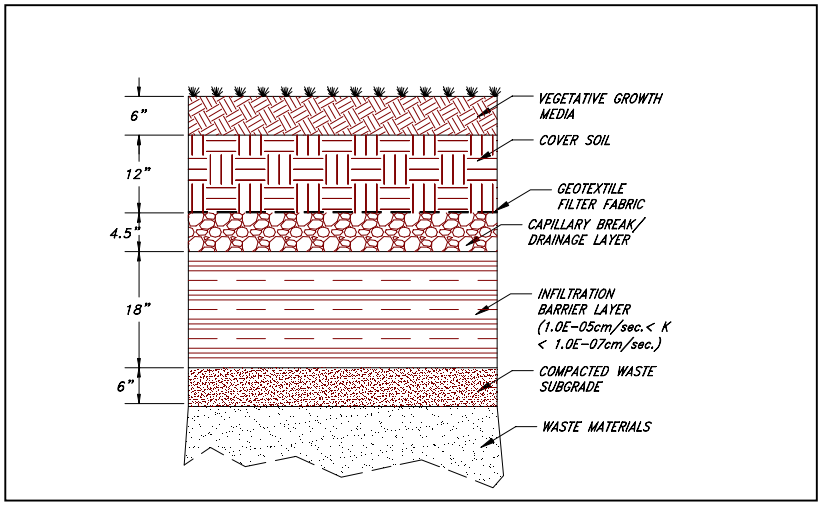

Figure 3. Typical Cap Cross-Section.

b. **Control Surface Water Run-on and Run-off** – By managing the surface water flowing onto the site so that it does not contact the waste or is allowed to collect and infiltrate into the waste, surface and groundwater exposures are largely cut off at the site. Historically, surface water flowing off of Timber Butte above the site was allowed to flow onto the Clark Tailings, washing the tailings via surface erosion and infiltrating to exacerbate poor groundwater quality conditions. Under the closure plan, all surface water running on the site would be routed around the perimeter of the repository via lined open channels. All surface water generated from precipitation falling on the site would be routed to these same channels.

c. **Clean and Line Timber Butte Sediment Pond** – A primary suspected pathway of historic groundwater contamination was an unlined sediment pond which collected all run-off from the Clark Tailings before it entered the surface drainage, Grove Gulch, running adjacent to the site. The unlined pond collected surface water and sediment with elevated metals from the site and likely allowed active infiltration to the downgradient groundwater. The only downgradient well in which groundwater quality standards were exceeded was directly downgradient of this pond. By controlling run-on and run-off of surface water and capping tailings to eliminate water from direct tailings exposure, the water reaching the Timber Butte sediment pond would be of much-improved quality. By cleaning out existing sediment and consolidating it into the new repository, then lining the pond, a significant source of infiltration of poor quality water would be likely eliminated.

d. **Site Grading –** Positive drainage was required for the entire final surface of the repository to promote run-off of precipitation on the site. Also, a maximum of 4:1 (horizontal to vertical) surface grade was allowed to ensure the revegetated surface would not be subjected to significant erosion and final slopes were stable under static and dynamic conditions. As further discussed below under Park Design, the design team was able to work within those grading constraints to develop a functional and aesthetically pleasing Park design.

3. Monitor the Groundwater – The two major engineering actions of consolidating and isolating the wastes are intended to eliminate future pathways of surface and groundwater contamination. To confirm that these actions actually achieved their objectives, a simple yet effective groundwater monitoring program was established for the site. After all surrounding and onsite groundwater was characterized, it was determined that two wells immediately downgradient of the site (CLK-1 and CLK-2) would be monitored. CLK-1 well was the closest well (115 feet east (downgradient) of Timber Butte Pond/Clark Tailings boundary) and showed highly elevated zinc levels (120 mg/L, mean value) (Pioneer, 1999). The CLK-2 well was also very close to the perimeter of the Clark Tailings, but was not immediately downgradient of the Timber Butte Pond. It showed much less zinc impacts (.050 mg/L, mean value) (Pioneer, 1999). By monitoring these two wells on a semi-annual basis, it is expected that a trend of improvement will be established, given the engineered improvements to reduce metals flux to the groundwater. This trend is expected to be realized over a time period of 15 to 50 years, given the hydrogeologic setting that dictates groundwater velocities and flow. These time frames

to allow improvement are acceptable, since the groundwater under or immediately adjacent to the site would not be available for use and all groundwater data further downgradient showed no exceedences of groundwater quality standards, as mentioned above.

These primary design features were laid out in a detailed repository design and constructed as the haul and disposal of LAO tailings at the Clark Tailings was completed between 1997 and 1998.

Other Repository Design Elements

In the completion of the repository at Clark Tailings several unique or site-specific variations on the primary design were used which both met the design's requirements and offset some of the additional costs of constructing the repository to allow a Park to be built on it.

Infiltration Barrier Material - The specification for the infiltration barrier was meeting or exceeding a $1x10^{-7}$ cm/sec permeability requirement. Normally, this specification is met using a natural true clay material or a geomanufactured geosynthetic product. With Clark Tailing's new repository size (49 acres) and barrier layer depth (18 inches), a volume of approximately 120,000 yd^3 (74 ac-ft) of natural clay or geosynthetic clay (GCL) liner material would have been required. Given the geology around Butte, little or no large sources of true clay exist, but there was a silt-clay material that had the potential as a low-permeability material. A procedure to test the locally-available silt-clay was approved by MDEQ/SW, so that the infiltration barrier specification could be met using the available silt-clay material. The ability to use the locally-available material, rather than importing natural clay or purchasing a geosynthetic liner product, saved the project approximately $500,000.

Parking Lot as Barrier – Knowing the Park layout as the repository was being designed offered several advantages. An important example of this was allowing a variation to the infiltration barrier layer of the cap in the 2.3 acre area where the Park's main parking lot was to be located. The parking area, with its asphalt cover, would be impervious to infiltration; therefore, the normal infiltration layer was not required under the parking lot area.

Park Design

Once it was decided a park would be the permanent future use of the new Clark Tailings repository, a detailed design for the Park which was fully integrated with the repository design was required. Being able to design the Park prior to the completion of the repository allowed for more effective integration of repository's and Park's designs. Though there are numerous examples of this, several of the more important integration elements are discussed here.

Park Grading, Landform – One of the most important issues in integrating the Park's design with the repository was the placement, shaping and grading of the tailings within the repository to accommodate the needs of the Park. The primary landform need of the

Park was a large, relatively flat surface where the ballfields, parking lot, and support facilities would be located. In its existing condition, the Clark Tailings had only a few contiguous flat acres, and being on the side of the Timber Butte hill this offered an interesting challenge. To achieve a relatively flat area for the primary Park area of approximately 25 acres, the repository's design had to include a fairly precise fill and grading plan for the tailings imported from LAO. The repository "fill plan" generally provided that a 25 acre bench would be created with fill depths (all requiring 90% compaction to minimize differential setting) of up to 20 feet at the northern edge of the site. In addition, the tailings had to be placed in some locations to be a suitable foundation for buildings and other structures. These structural fill areas were identified in advance and only tailings with the material strength to hold structures were placed there.

A second design objective related to the grading of the repository was creating a landform which was more natural-looking than the conventional engineered repository. Often repositories, as with many engineered earthworks, have square or rigid planforms, 3:1 side slopes and a flat top. Though the Clark Tailings repository needed to be relatively flat for the Park's design, the side slopes which generally faced northeast toward the town were designed to be more natural-looking and blend into the surrounding landscape. A basic maximum slope of 4:1, instead of 3:1, was chosen. Then actual slopes on the northeast side (the most visible side) were varied from 4:1 to 10:1, interjecting some subtle ridges and depressions extending from top to bottom of the slopes. The subtle ridges and depressions offer a more natural foothill-looking landform as well as ultimately allowing vegetation to mature with more diversity given a slight variation of water availability from the ridges to the depressions.

Park Structures and Cap Penetrations – The Park's design called for several buildings, shelters, five ballfields with associated fences and backstops, and other minor structures which all required foundations. These foundations, as well as the necessary underground utilities, required construction at depths below the ground level within the repository's cap. For all Park construction requiring cap penetration, a design was required which provided a retrofit around the penetration with an equivalently protective cap. Figure 4 shows one such design for a fence post.

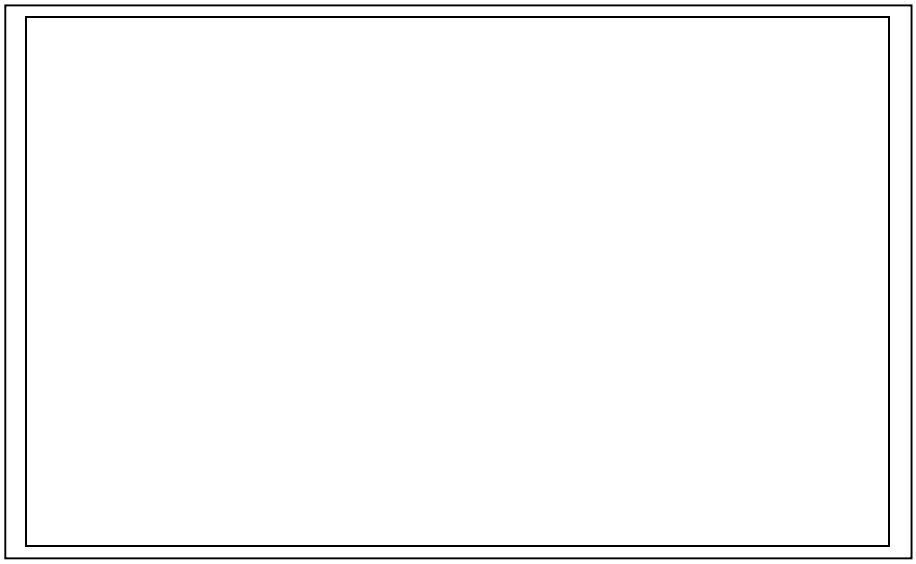

Figure 4. Typical Cap Penetration (example shown for a fence post).

Use of Adjacent Landfill in Park Design – Though the primary Park elements were designed to be on the new Clark Tailings repository, Butte's closed municipal landfill adjacent to the site was integrated into the Park's design. Given its unconsolidated and unlevel fill, its suitability was limited. Yet, it was generally acceptable as a landing area for a golf driving range. With appropriate grading and infrastructure design of tee areas where the public would access, a golf driving range was designed as a compatible future option to the Park.

Summary

By planning and designing the Park in tandem with the repository, they could be integrated and coordinated much more effectively and efficiently. The repository was constructed as designed between 1997 and 1998. The Park will be constructed between 1999 and 2000. The Park will be available for community use by spring of 2001. Groundwater monitoring to track the groundwater's quality at the downgradient edge of the site will continue to ensure the repository remains protective of the aquifer downgradient of the site.

This project provides an example of how industry, a community, and regulatory agencies can coordinate well to successfully meet an environmental challenge. Though the circumstances described herein precipitating the creation of a municipal Park from an old mine tailings area was somewhat unique, many of the technical designs and regulatory decisions leading to the successful redevelopment of Clark Tailings mining site are applicable elsewhere.

REFERENCES

EPA, 1995. Letter from John Wardell, EPA to Jack Lynch, Butte-Silver Bow County (3/1/95).

MDHES, 1995. Letter from Bob Robinson, MDHES, to Jack Lynch, Butte-Silver Bow County (3/23/95).

Pioneer, 1997. Butte-Silver Bow Landfill/Clark Tailings Corrective Measures Assessment (January, 1997, final addendum, February, 1997). Prepared by Pioneer Technical Services, Butte, MT.

Pioneer, 1999. August 23, 1999 letter from Shawn Bisch to Pat Crowley regarding semi-annual groundwater monitoring results. Data on file at Montana Department of Environmental Quality.

On-Site Repository Construction and Rehabilitation of the Silver Crescent Abandoned Mine Site, Shoshone County, Idaho

J. K. Johnson

The Silver Crescent abandoned mine and mill site is located in Idaho's Silver Valley near Kellogg. The mine produced lead, zinc, and silver ore which was initially processed by gravity separation in a jig mill, while a subsequent ball mill at the site also served as a custom processor for ore from other sources. Approximately 92,000 cubic meters of tailings and waste rock were deposited in the floodplain of the east fork of Moon Creek which is a tributary to the south fork of the Coeur d'Alene River. The actively eroding tailings impoundments and waste rock dumps have been a source of heavy metal contamination in the surface and ground water at the site. The U.S. Forest Service began a non-time crtical removal action under CERCLA authority at the site in 1998. Goals of the removal action include reduction of dissolved and particulate metal loading into the east fork of Moon Creek by incorporating the tailings and waste rock dumps into an on-site capped repository. Soft foundation engineering of the repository includes the use of a geoweb mattress to provide stability and compensate for settling of the tailings. The Silver Crescent project is currently active and should be completed in early 2000. Methods and results will be discussed as part of the symposium presentation.

Key Words: cadmium, aluminum, revegetation, reclamation, adit closure, portal closure, shaft closure

---

Jeff K. Johnson, Geologist, United States Forest Service - Idaho Panhandle National Forest, Coeur d'Alene, ID 83814

2000 Billings Land Reclamation Symposium

ALTERNATIVES ANALYSIS FOR MINE WASTE RELOCATION REPOSITORIES

B. Grant, M. Cormier, W.H. Bucher[1]

ABSTRACT

The Streamside Tailings Operable Unit, Silver Bow Creek/Butte Area, Montana NPL site requires disposal of mine and milling waste materials in mine waste relocation repositories. The Record of Decision (ROD) for the site requires that the mine wastes be amended with lime and revegetated, and that the repositories be sited in a protective location, potentially near Silver Bow Creek. If the near-stream setting for repositories are not sufficiently protective of human health and the environment, then the ROD provides for locating the repositories off-site where conditions would be more protective. An analysis was completed for the purpose of comparing the near-stream and off-stream settings, as well as to assess what types of design elements could be incorporated into the repository to raise the level of protectiveness to the environment. The completed analysis explored liner system alternatives, leachate generation rates, synthetic leachate characteristics, soil attenuation characteristics, estimated contaminant concentrations (particularly arsenic) in groundwater, and the cost associated with each of the alternatives.

[1] Maxim Technologies, Inc., Helena, Montana

INTRODUCTION

The Streamside Tailings Operable Unit (SSTOU) is one of several Operable Units that make up the Silver Bow Creek/Butte Area NPL Site. This NPL Site encompasses the historic mining and milling operations within the vicinity of the town of Butte, Montana as well as the mining and milling wastes present in Silver Bow Creek from its headwaters to the terminus of the site where Silver Bow Creek leaves the Warm Springs Ponds system. The SSTOU is defined as Silver Bow Creek, its present stream channel, current and historic floodplain, and railroad beds and embankments adjacent to the floodplain, and extends from the edge of Butte to the Warm Springs Ponds, a distance of about 40 km. Numerous studies have been completed to date as part of remedial investigation activities. Among others, soil sampling has documented the extent and magnitude of waste materials and levels of metals and arsenic in the waste and revegetation studies have been conducted to evaluate lime amendment methods and plant establishment techniques.

The remedial action for the SSTOU consists of removing mine and milling waste from the floodplain and areas adjacent to the stream. Mine waste relocation repositories (MWRRs) are a central component of the remedial action. The Record of Decision (MDEQ, 1995) for the site requires that the mine wastes be amended with lime and revegetated and that the MWRRs be sited in a protective location, potentially near Silver Bow Creek.

The evaluation which this paper presents was completed to study whether placing the MWRRs near Silver Bow Creek was a viable remedial action, or if locating the MWRRs further away from the stream in a more upland setting would provide a higher level of protectiveness that the near- stream setting could not afford. Determining the exact sites and design requirements for MWRRs was not a specific goal for the study. The evaluation was completed for Subarea 1 of the SSTOU which includes the upper reaches of the stream (Figure 1) in which six proposed, near-stream MWRRs were located. Total waste to be removed within the subarea is estimated at 380,000 m^3.

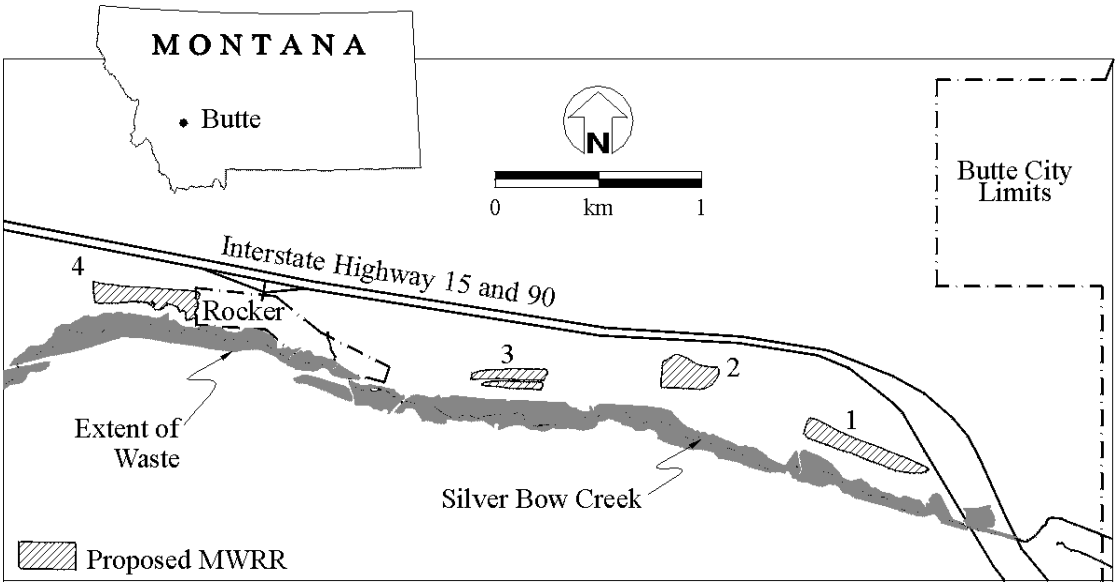

Figure 1. SSTOU, Subarea 1, Upper Reach

The waste is characterized as a silty sand, with elevated levels of copper, lead, zinc, cadmium and arsenic, which has been fluvially deposited within the approximate 100-year floodplain of the creek.

Design criteria used to evaluate near-stream and off-site settings included geology, surface water hydrology, groundwater hydrology, community impacts and land use. The principal criterion was groundwater quality. Discharges to groundwater may not exceed Montana DEQ Circular WQB-7 standards for groundwater (Table 1). The arsenic concentration goal is quite low in comparison to the U.S. EPA maximum contaminant level for drinking water supplies of 50 µg/l.

Table 1. Groundwater Standards

Constituent	Concentration (µg/l)
Copper	1000
Lead	15
Zinc	5000
Cadmium	5
Arsenic	18
Mercury	0.14

METHODS

Essential components of the evaluation were determining leachate quality from the tailings waste and adsorption characteristics for soil which will underlie the repositories. Methods used for assisting in determining these characteristics are described in this section.

To approximate leachate quality, a synthetic leachate was derived. Waste material used to derive the leachate was acquired by obtaining a composite sample prepared from selected soil depth intervals from 9 test pits. Test pit locations and sample depths were determined using an existing database for 435 test pits. Preparation of the composite was patterned toward the average soil grain size (silty sand) and metal and arsenic concentrations that would approximate the third quartile levels of all samples collected from the 435 test pits. The composite sample was analyzed for saturated paste pH, arsenic, metals and several other analyses for determining the lime amendment rate.

Synthetic leachate solutions were prepared for amended waste and for unamended waste. Preparation of the synthetic leachate for unamended tailings was performed following EPA Method 1312 using a 60/40 mixture of nitric and sulfuric acid at an unbuffered pH level of 4.2. Preparation of the synthetic leachate for the lime amended waste was performed using reagent grade deionized water since the lime amended tailings are expected to produce a buffered leachate. Each synthetic leachate was prepared in triplicate batches with the extract fluid from each filtered and analyzed for pH, arsenic and metals.

Sorption testing was completed on subsurface soil materials from Settings 1 and 2 (discussed below). The Setting 1 sample was a composite sample collected from a boring located at proposed MWRR-2. The Setting 2 sample was collected from beneath the surface of an excavation cut immediately north of Rocker. Developed soil horizons were excluded from each soil sample. The sorption testing consisted of introducing 800 milliliters of synthetic amended tailings leachate at dilutions of 0, 50, 75 and 90 percent to 40 grams of soil. The tests were conducted in a manner similar to the leaching test by placing the solution and soil in a rotating drum for 18 hours. The extract fluid from each test was filtered (0.45

micron filter media) and the filtrate analyzed for total arsenic and copper.

DEVELOPMENT OF ALTERNATIVES

The process used to develop alternative repository designs is similar to the feasibility study process outlined in EPA guidance documents for evaluating National Priority List sites (USEPA, 1988). The first step of the process was to complete an initial screening of potential design components. These design components provided the building blocks for several different design options which were then applied to a selected set of environmental conditions. The initial screening of design components brought forward only the most likely components that could potentially meet or exceed repository design and siting criteria, either separately or in combination with other components.

Repository Design Components

The general elements of a waste repository include a cover system, the waste materials, and a leachate collection system. Design components were developed for each of these three elements during the initial screening process, with several components being selected for use above and below the mine wastes. The design components selected for incorporation into design options are described below.

Cover System

The function of a cover system is to protect the waste material enclosed within the repository from climatic effects of wind and precipitation. The major concerns associated with these effects are infiltration and erosion. The design components for a cover system that passed the initial screening are the following: 1) directly amending waste materials with lime and revegetating; 2) placing a cover soil over the waste to promote evapotranspiration; and, 3) constructing a low permeable cover using geosynthetic materials. In regards to the first component, revegetation studies have shown that the amended tailings material can be revegetated (RRU and Schaefer & Assoc., 1993). For the third component, a cover design using a geosynthetic clay liner (GCL) with an overlying drainage layer was selected.

Waste Material

For design components, only treatment or non-treatment of waste materials were considered for inclusion in the design options. Treatment would consist of incorporating a lime amendment with waste materials to reduce the mobility of metals

Leachate Collection System

Low permeability liner systems at the base of a repository are often used to intercept and collect leachate percolating down through the waste material. The leachate collection system design component would consist of a drainage layer overlying a low permeable base liner constructed with HDPE. The leachate collected would be disposed of by evaporation, incineration, or transported to an approved waste management facility.

Repository Design Options

Several designs options were constructed using the design components described above (Figure 2). The design options include the repository design as described in the ROD and presented in an Intermediate Design Report (ARCO, 1997) along with four alternate designs. The following discussion explains the components of each design option.

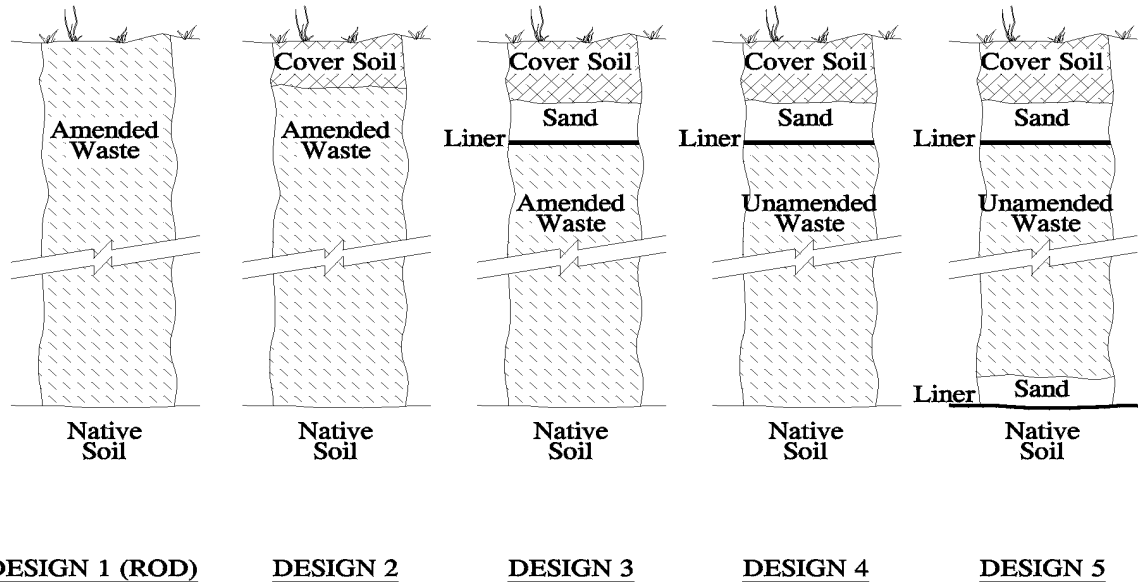

Figure 2. Repository Design Options

- Design 1 - Revegetated Amended Waste Material (ROD Design) - Waste material would be amended with lime and placed in the repository. Amended waste material at the surface of the repository would be revegetated to reduce infiltration and erosion.

- Design 2 - Improved Cover, Amended Waste Material - A soil cap consisting of at least 18 inches of borrow soil would be placed over the amended tailings. The use of 18 inches of soil cover was selected for this design to provide adequate rooting depth and to improve soil moisture storage capacity in the cap.

- Design 3 - Improved Cover with Low Permeable Liner, Amended Waste Material - This design is similar to Design 2 but incorporates a low permeable liner in the cover system to reduce infiltration into the repository.

- Design 4 - Improved Cover with Low Permeable Liner, Unamended Waste Material - This design is similar to Design 3 but evaluates placing unamended tailings in the repository. In this design, higher metal concentrations may be produced in leachate since the waste is unamended.

- Design 5 - Improved Cover with Low Permeable Liner, Unamended Waste Material, Leachate Collection System - This design is similar to Design 4 but includes a leachate collection system.

Site Environmental Settings

In order to evaluate the alternative MWRR designs, two potential site settings were assumed to be the most likely for siting the repositories. The differences between the two site settings is primarily subsurface soil texture, depth to ground water, and distance from the 100-year floodplain. The following describes the general environmental conditions expected to be encountered at the two sites.

- Setting 1 - Near-Stream Repository Site. Near-stream repository sites would be located immediately adjacent to the 100-year floodplain as propsoed in the ROD. A typical setting for these sites is on moderate slopes adjacent to Silver Bow Creek. Hydrogeologic characteristics are:

  - Soil Type — medium sand
  - Saturated Permeability — 10^{-2} cm/sec
  - Groundwater Gradient — 0.01 m/m
  - Depth to Groundwater — 3 m

- Setting 2 - Off-stream Repository Site. These sites are located in an upland setting underlain by Tertiary sediments and located well away from the 100-year floodplain. Tertiary sediments north of Silver Bow Creek typically exhibit a higher content of silt and clay than near-stream sites. Hydrogeologic characteristics for this setting are:

  - Soil Type — sandy silt
  - Saturated Permeability — 10^{-4} cm/sec
  - Groundwater Gradient — 0.01 m/m
  - Depth to Groundwater — 12 m

Number of Repository Sites

The ROD identified six near-stream locations for MWRRs within Subarea 1. Figure 1 shows the location of four of the MWRRs. Designing numerous repositories in a near-stream location minimizes haul distances and reduces cost but has disadvantages as well, such as greater area to volume ratios, requiring more land to be overlaid with tailings and greater disturbance area for construction. The numerous repositories will require an increase in the amount of vegetation needed for erosion protection and, if the design includes a low permeable cover, greater construction material quantities and associated costs. In addition, higher monitoring and maintenance costs may result from numerous repositories with lesser volumes of tailings per repository.

In the near-stream setting (Setting 1), construction of three repositories for designs other than Design 1 was selected to provide a balance between cost of construction, hauling tailings a greater distance, and maintenance of the repositories. In the off-stream setting (Setting 2), two repositories were selected by extension of the reasons given for Setting 1.

Repository Design Alternatives

Repository design alternatives were developed by combining the various design options with the two environmental settings (Table 2). Design 4 was not considered to comply with the ROD if placed in Setting 1 without a base liner. Design 5 was not

considered for Setting 2 because Setting 2 is considered to provide an added depth to groundwater and offered native materials that could provide attenuation of metals and arsenic in leachate.

Table 2. Repository Design Alternatives

Alternative No.	Design/Setting	No. of Sites	Alternative No.	Design/Setting	No. of Sites
1	Design 1/Setting 1	6	5	Design 2/Setting 2	2
2	Design 2/Setting 1	3	6	Design 3/Setting 2	2
3	Design 3/ Setting 1	3	7	Design 4/Setting 2	2
4	Design 1/Setting 2	2	8	Design 5/Setting 1	2

GROUNDWATER PROTECTION ANALYSIS

Physical and chemical characteristics associated with each of the alternatives affect metal and arsenic concentrations in groundwater downgradient of the MWRR. The repository designs are analyzed with respect to their effectiveness in protecting groundwater quality. To perform the analysis, information on leachate characteristics was obtained. The various repository designs are then evaluated with respect to contaminant loading to the subsurface and attenuation of metal and arsenic concentrations by soil sorption and dilution/dispersion in groundwater.

Leachate Characteristics

Amending tailings material placed in the MWRR would result in minimizing the potential for acid conditions to develop. Most mobile metal cations in the tailings (Cu, Pb, Zn, Cd) would form relatively stable precipitates as a result of the lime addition. At high pH levels, similar to which may be found in the amended tailings, arsenic may exhibit an increase in solubility (Dragun, 1988).

Table 3 presents metal and arsenic concentrations in the composite waste sample, which was used for preparing the synthetic leachates, along with statistical data for these elements collected across the site (ARCO, 1995a). The pH of a saturated paste made from the waste was 4.5. Table 4 compares metal concentrations for fluids from amended waste obtained from recent SSTOU studies and from the synthetic leachate study. Arsenic concentrations in leachate are approximately one order of magnitude greater than the WQB-7 standard; cadmium is only slightly elevated above the standard.

Table 3. Metal Concentrations in Composite Waste Sample (mg/kg)

Description	Copper	Lead	Zinc	Cadmium	Arsenic
Composite tailing sample	1717	2243	3337	22	1059
Subarea 1, mean values	739	540	2400	8	278
Subarea 1, third quartile	2458	1048	3560	17	491

Table 4. Metal Concentrations in Leachate from Amended Tailings Material (µg/l)

Sample Location	Copper	Lead	Zinc	Cadmium	Arsenic
Lysimeter 07D14; 40 and 90 cm depth, collected 1991 and 1992; mean concentrations[1]	121	2.5	1530	9.6	208
Lysimeter SPW3-S, depth 45 cm, mean concentrations [2]	182	7	717	9	175
Synthetic Leachate, Amended Tailings	130	<150	<30	<15	210

WQB-7 Standards	1000	15	5000	5	18

Data Source: [1] RRU and Schaefer, 1993; [2] Schaefer, 1997

Table 5 presents pore water metal concentrations from lysimeters in unamended tailings and from synthetic leachate. The unamended tailings exhibit higher concentrations of several elements with exceedances of WQB-7 standards possible for copper, lead, zinc, cadmium and arsenic. With the exception of arsenic, amendment of the tailings with lime results in a noticeable improvement in leachate quality.

Table 5. Metal Concentrations for Leachate Solution from Unamended Tailings (µg/l)

Sample Location	Copper	Lead	Zinc	Cadmium	Arsenic
Highest measured concentrations in lysimeters installed within Clark Fork River untreated test areas, collected 1992 [1]	1050	nm	222	nm	23
Lysimeter SPW3-D, depth 45 cm, mean concentrations [1]	3076	7	15,225	60	135
Synthetic Leachate, Unamended Tailings	35,500	3820	28,300	39	350
WQB-7 Standard	1000	15	5000	5	18

nm = not measured
data source: [1] Schaefer, 1997

Performance Evaluation of Alternative Designs

An evaluation of the alternative designs was completed using the generalized hydrogeologic characteristics for the two types of settings to gain an understanding of what effects leachate metal and arsenic concentrations may have on groundwater quality. This evaluation was performed for the two types of hydrogeologic settings defined.

Leachate Production Estimates

Each of the MWRR designs was evaluated using the Hydrologic Evaluation of Landfill Performance (HELP) model, version 3.05 (Schroeder, et. al., 1994) to predict the amount of leachate which would percolate through the base of each design. The results are summarized in Table 6. The model was run using 100 years of local precipitation data.

Table 6. Leachate Production Estimates

Design No.	Leachate (cm/yr))
1	5.5
2	1.6
3	0.08
4	0.08
5	0.02

Attenuation of Metals by Sorption

Metal cations and arsenic anions in leachate flowing through the subsurface will be attenuated by sorption which includes the processes of adsorption, fixation and precipitation. Sorption testing was performed using the amended tailings synthetic leachate for soil samples collected from Settings 1 and 2. Fluid from the testing was analyzed for copper and arsenic because only these two elements were present at significant concentrations in the synthetic leachate. Sorption testing was not completed using unamended tailings synthetic leachate.

Figure 3 presents the isotherms generated from the sorption testing using Cs (sorbed mass) versus Ce (equilibrium concentration) graphs. The arsenic isotherms indicates that the soil sorption affinity decreases at lower equilibrium concentrations and that the Setting 1 soil more readily adsorbs arsenic than Setting 2 soil. Arsenic sorption did not appear to occur at concentrations below about 0.024 mg/l for the Setting 1 sample and 0.018 mg/l for the Setting 2 sample. The lower limit of arsenic sorption in the test are similar to arsenic concentrations observed in a nearby background well (well C-15) which exhibits an arsenic concentration near 11 µg/l (ARCO, 1995b). The copper isotherms indicate that the metal is adsorbed to the soil. Several of the copper equilibrium concentrations were below laboratory detection.

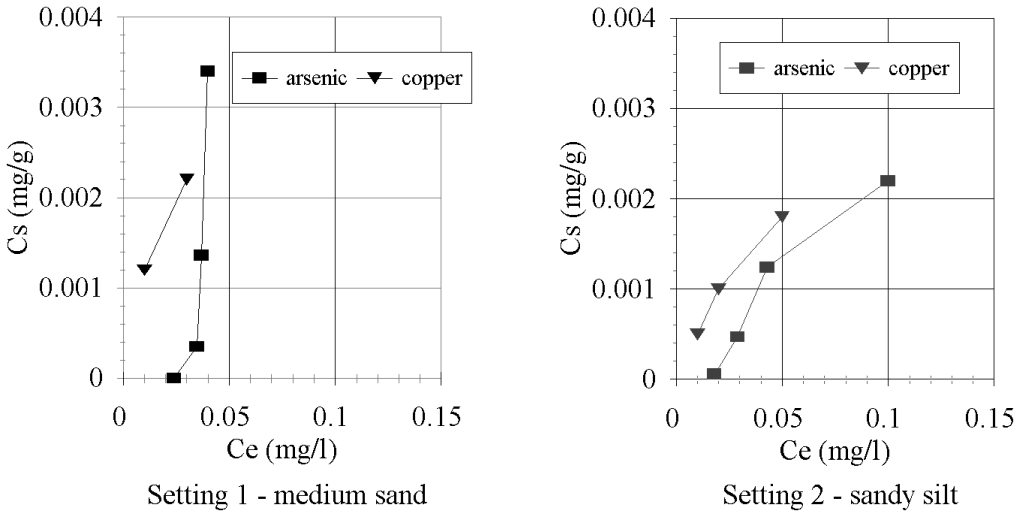

Figure 3. Sorption Isotherms

Dispersion/Dilution

Leachate which enters the groundwater system beneath the repository will be dispersed and diluted. Leachate and attenuation test data indicate that repositories constructed with amended tailings will show relatively low concentrations of arsenic in the leachate which reaches groundwater. Copper, lead, zinc, and cadmium will not likely be present due to amendment of tailings with lime and/or sorption of the metals with soil. Table 7 presents estimates for arsenic concentrations in groundwater for Alternatives 1 through 6 (amended waste). To prepare these estimates we assumed that the repository is 4 ha in area with a length to width aspect of 1:1 and that leachate is mixed within the uppermost 3 m of the aquifer. Estimates of arsenic in leachate reaching the groundwater were obtained from the attenuation testing of synthetic leachate (24 and 18 µg/L), and to demonstrate the sensitivity of the mixing calculation, estimates were also prepared under the assumption that attenuation of arsenic is relatively ineffective in the subsurface and the leachate contains 100 µg/L or 200 µg/L of arsenic. This could be the case if very little attenuating material is located under the repository or if the arsenic attenuation capacity of the subsoil is exhausted over time. A background arsenic concentration in groundwater was selected using data for an

upgradient well.

Table 7. Estimated Arsenic Concentration in Groundwater After Dilution/Dispersion of Leachate (µg/l)

Alternative No.	Setting 1 As=24 µg/l	Setting 2 As=18 µg/l	Setting 1 As=100 µg/l	Setting 2 As=100 µg/l	Setting 1 As=200 µg/l	Setting 2 As=200 µg/l
1	13	--	21	--	31	--
2	12	--	14	--	17	--
3	11	--	12	--	12	--
4	--	17	--	93	--	185
5	--	16	--	79	--	156
6	--	12	--	25	--	40
7	na					
8	na					

WQB-7 Standard = 18µg/l
Background Groundwater = 11.4 µg/l

-- not applicable, the alternative does not apply to this setting
na = not analyzed (unamended tailings)

Results shown in Table 7 indicate that arsenic may not exceed WQB-7 groundwater standard provided certain design components are added to the repository. For Setting 1 and using the attenuation test results, incorporation of a low permeable liner into the repository cover system does not appreciably affect arsenic concentrations as indicated by the 2 µg/l difference between Alternative No. 1 and Alternative No. 3. As compared to Setting 1, the Setting 2 alternatives result in higher arsenic concentrations in large part because of slower groundwater velocities and therefore less dilution of the leachate. For Setting 2 (Alternatives 4, 5, 6) inclusion of a liner in the cover shows a more distinct advantage in lowering arsenic concentrations in groundwater.

It is interesting to note the sensitivity of this calculation to the leachate quality. If we assume that leachate has 100 µg/L or 200 µg/l of arsenic, only Alternatives 2 and 3 provide sufficient protection to meet the Circular WQB-7 standard after mixing. This analysis demonstrates the value of the improved cover designs within Setting 1 if attenuation capacity can not be relied upon to reduce arsenic concentrations.

SUMMARY

The most significant points resulting from the evaluation include the following.

- Arsenic appears to be the only constituent in the amended tailings case which has the potential to exceed regulatory levels in groundwater downgradient of the repositories.

- Alternatives 1, 2 and 3 (Setting 1) appear to provide adequate protection to groundwater resources as compared to Alternatives 4, 5, 6 and 7 which are located off-site (Setting 2).

- Alternatives 2 and 3, which provide an improved repository cover over Alternative 1, do not substantially reduce the arsenic concentration in groundwater because of elevated background arsenic concentration in groundwater. However, cover improvements contained in Alternatives 2 and 3 do reduce the contaminant load reaching the groundwater system and provide greater assurance that groundwater quality standards will not be exceeded.

- Alternative 1 includes several repositories some of which are smaller in size than the size evaluated by this study (4 ha). The smaller repositories are less prone to result in arsenic exceedances in groundwater due to a smaller area over which leachate is entering groundwater. One of the main disadvantages of this alternative is the smaller repositories are less efficient in storing tailings so that more land area is disturbed. The overall area for Alternative 1 repositories is approximately 24 to 28 ha and the overall area for Alternatives 2 through 8 repositories is approximately 6 to 8 ha.

The calculations of leachate production, leachate loading, attenuation, and groundwater mixing completed in the study are subject to a number of limitations due to limited data on which the analysis is based and the inherent uncertainty in geochemical and hydrogeological parameters used in the calculations. Because of limitations in data and uncertainties in calculations, the quantitative results of the evaluation were used more to gauge the relative protectiveness of the alternatives rather than their absolute capabilities.

REFERENCES

Atlantic Richfield Company (ARCO) 1997. Silver Bow Creek/Butte Area NPL Site (NPL). Streamside Tailing Operable Unit. Intermediate Design Report. July 1997.

_____1995a. Silver Bow Creek/Butte Area National Priorities List Site (NPL). Streamside Tailing Operable Unit. Draft Remedial Investigation Report. January 1995.

_____1995b. Silver Bow Creek/Butte Area NPL Site. Streamside Tailings Operable Unit. Draft Feasibility Study Report, Revision 2.

Dragun, J., 1988. *The Soil Chemistry of Hazardous Materials*. Silver Spring, Maryland: Hazardous Materials Control Resources Institute

Montana Department of Environmental Quality (MDEQ), 1995. Record of Decision, Streamside Tailings Operable Unit of the Silver Bow Creek/Butte Area National Priorities List Site.

Reclamation Research Unit of Montana State University (RRU) and Schaefer & Associates, 1993. Streambank Tailings and Revegetation Studies, STARS Phase III Final Report. Montana Department of Health and Environmental Sciences. Helena Montana.

Schaefer & Associates, 1997. Clark Fork River Governor's Demonstration Monitoring (1993 1996). Final Report.

Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W., & Peyton, R.L.,

1994 *The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3*, EPA/600/9-94, U.S. Environmental Protection Agency Risk Reduction Engineering Laboratory, Cincinnati, OH.

USEPA 1988. *Draft Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA*. Office of Emergency and Remedial Response and Office of Solid Waste and Emergency Response.