

**ACID MINE DRAINAGE:
RECLAMATION AT THE RICHMOND HILL and GILT EDGE MINES,
SOUTH DAKOTA**

by

Thomas V. Durkin
Hydrologist
South Dakota Department of Environment and Natural Resources
Office of Minerals and Mining
Pierre, SD

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Introduction

Acid mine drainage (AMD) is defined as contaminated mine drainage that occurs as a result of weathering reactions between sulfide-bearing rocks, air and water that can lead to problems in the receiving environment. AMD is characterized by low pH, increased acidity, elevated heavy metals, sulfate and dissolved solids in the drainage emanating from the sulfide rock source. Various physical, chemical and biological controls can be used to prevent, minimize and treat AMD. The best environmental controls, and least expensive in the long run, are waste management practices that focus on "prevention" rather than "treatment".

In 1992, the South Dakota Department of Environment and Natural Resources (DENR) identified environmental problems associated with reactive sulfide rocks at a valley-fill waste depository at LAC Minerals' Richmond Hill gold mine in the northern Black Hills. This led to a shut down of the mine, a significant increase in the reclamation surety bond from \$1.2 million to \$10.7 million, a settlement of \$489,000 for permit and water quality standard violations, and the development of an AMD reclamation plan that is currently in the final stages of completion and exhibiting impressive results.

Numerous abandoned mine reclamation projects have been conducted by active mine operators in the Black Hills on a voluntary basis. These efforts have resulted in a net improvement to the environment while lowering the environmental liability posed by the abandoned mine sites. One of the more notable reclamation projects was conducted by Brohm Mining Corporation, which operates an active heap leach mine.

Case histories for these two mine waste remediation sites are presented in this paper.

Richmond Hill Mine

Physical Setting and Ownership

LAC Minerals' operates the approximately 400 acre Richmond Hill mine located in the northern Black Hills, four miles northwest of Lead, South Dakota. This surface gold mine, which is operated using conventional heap leach technology, was permitted by the State of South Dakota in 1988. At that time, the mine was owned and operated by St. Joe American, Inc. Successors included St. Joe Gold Corporation, St. Joe Richmond Hill, Inc., Bond Gold Richmond Hill, Inc, Bond Gold Corporation, and Richmond Hill, Inc., a subsidiary of LAC Minerals (USA), Inc.

The mine facilities are located at an elevation between 5,500 and 6,000 feet above sea level in an area of relatively rugged terrain. Annual and daily temperature variations can be extreme. Annual precipitation averages about 28 inches per year. The pit/waste facility is drained by Spruce Gulch, an intermittent tributary to perennial Squaw Creek which flows into perennial Spearfish Creek. The process facility is drained by Rubicon Gulch, an intermittent tributary of Spearfish Creek. Groundwater is confined to two systems: In the

shallow alluvium system, flow is predominantly controlled by topography; in the deep bedrock system, hydraulics are more complicated and flow is structurally controlled (1).

The mine pit and valley-fill waste rock depository are connected to the processing facility (crusher, leach pads) by a 1.5 mile haul road. The nearest area to the ore body that was sufficiently flat to construct the leach pads was 1.5 miles away. South Dakota requires a double liner system for leach pads and ponds, complete with leak detection, collection, and recovery systems (2).

Geology

The ore body is associated with a Tertiary breccia pipe that intruded into Precambrian amphibolites, forming a near vertical contact. Sulfide and oxide components of the breccia exist. Oxidation of the Richmond Hill ore deposit resulted in a well-developed hematitic-jarositic cap up to 260 feet thick. The oxidized cap closely follows the extent of the breccia pipe. Primary sulfide mineralization occurs below the oxide cap and consists of 70 to 80 percent feldspars, showing variable argillic alteration, and 10 to 20 percent pyrite and marcasite. Minor quartz, micas, carbonates, barite, rutile, apatite, zircon, and monazite account for the rest of the rocks. Traces of chalcopyrite, bornite, sphalerite, galena, and arsenopyrite are found in the major sulfide species. The protolith of this rock was determined to be the Precambrian amphibolites, with the sulfide mineralization replacing the original mafic minerals. Unaltered amphibolites contain little to no sulfides (3).

Discovery and Description of the AMD Problem

From the time operations began in 1988 until 1992, the mine was operated without any significant environmental problems. In 1988, several general conditions were written into the state mine permit that addressed AMD prevention as followup to preliminary indications that a small amount of sulfide rock may be encountered during mining. The mine operators encountered a significantly larger amount of sulfide rock, however, than was originally anticipated.

During a routine inspection in January 1992, the Department of Environment and Natural Resources (DENR) identified a 200,000 ton stockpile of sulfide ore on top of the Spruce Gulch waste rock depository as well as sulfide waste in the dump. Uncrushed sulfide ore had been stockpiled on the waste dump to allow it to oxidize and become more amenable to leaching, with the intent to later crush and leach it. This prompted a series of additional inspections and communications with mine personnel to field-document the potential for AMD from the sulfide ore and waste rock.

Richmond Hill's Spruce Gulch, valley-fill waste dump is located in the upper reaches of an intermittent drainage to perennial Squaw Creek, which is classified as a fishery. The Spruce Gulch dump contained about 3.5 million tons of waste rock. During the 1992 mid-winter inspections, no flow was exhibited at the toe of the dump, but pH measurements of

melting snow taken at the base of the sulfide ore stockpile on top of the dump were between 4.5 and 5. A very apparent odor of oxidizing sulfides was noted. As a result of spring runoff in April 1992, flow appeared at the toe of the dump; pH was 3.1 and heavy metals, sulfate and total dissolved solids (TDS) were elevated. Preliminary field observations indicated that AMD was a potential long-term problem, and an intensive environmental and economic assessment was undertaken.

Contamination of surface runoff at the toe of the dump (located above the treatment system described later under Short-term Mitigation Actions) continued from the discovery of the AMD problem in 1992 until this writing in mid-1995. Field pH levels on the order of 2.6 to 3.6 are typical; sulfate levels commonly range between about 700 and 3,400 mg/L, and TDS between about 800 and 5,700 mg/L. Isolated spikes above these levels have occurred on occasion. Elevated heavy metals include aluminum, copper, iron, manganese, and others. The short-term treatment systems described below are effective in removing most of the contamination from the water.

The chemical reactions involved with acid generation are exothermic. The predominant problematic sulfide mineral is marcasite. Marcasite in the Richmond Hill rock is extremely fine grained, exhibits a high surface area, and oxidizes rapidly. During the late summer and early fall of 1992, fumaroles (areas of escaping steam) were noted along the crest of the waste dump and in areas on top of the dump where backhoes disturbed the crust that formed from compaction due to heavy equipment traffic. The rate of acid generation was manifested in the temperatures recorded at the fumaroles. A temperature probe inserted just below the surface of one of the fumaroles recorded a temperature of 180 degrees Fahrenheit (4).

Temperatures of AMD water flowing from the toe of the dump were about 35 degrees Fahrenheit in the summer of 1992, when temperatures of water flowing from the base of non-acid-generating waste dumps in the Black Hills that had been subjected to similar waste disposal techniques were over 50 degrees Fahrenheit. An ice block had formed within the rocks at the base of the waste dump due to barometric pumping that pulled in cold air during the winter. Another reason for the lower temperatures of discharge water may be explained, in part, by endothermic reactions that occur as metals precipitate from solution as AMD enters the more neutral receiving environment.

Environmental/Economic Assessment

From 1992 through 1994, the company conducted an intensive environmental and economic assessment. Expert company consultants were brought in to conduct the assessments and to develop mitigative plans. The DENR brought in its own consultants to review the reports and plans, and to give advice that could be used in regulatory decisions. The Richmond Hill AMD mitigation plan has been subjected to the scrutiny of some of the world's leading experts in the field of AMD reclamation.

The environmental assessment included AMD predictive testing and geochemical analyses. Static testing included acid/base accounting (ABA) tests, net acid generating (NAG) pH tests, paste pH tests, and whole rock analyses. Kinetic testing included humidity cells, column leach tests, and mineralogical analyses. Samples were taken from drill core and cuttings, crusher composites, waste dump trenches, and pit walls.

Experts estimated that approximately 2.7 million tons of rock in the waste depository was acid-generating, representing all waste rock deposited in the dump since the end of 1989. Much of the exposed material in the pit was found to be acid-generating, contributing to contamination of shallow groundwater below the pit floor. Some of the spent ore on the leach pads and rock within certain ancillary facilities was also found to be reactive. Reclamation costs were estimated for the various components of the site.

Other environmental assessments included hydrologic impact studies, metals-loading evaluations and mass balance assessments, aquatic impact studies, and identification of contaminant migration pathways and associated environmental receptors. After considering several short-term and long-term mitigative options, the company chose a course of action to address the immediate problems and made plans to implement long-term closure requirements (1).

All water quality data and results of the various environmental assessments are on file at the South Dakota DENR Minerals and Mining Program in Pierre, South Dakota.

DENR Enforcement Action and Bond Increase

In December of 1992, the DENR issued two Notices of Violation (NOV) to Richmond Hill for violating the state mine permit and state water quality standards. Enforcement negotiations continued until March of 1992 when a Stipulation and Stipulated Order was signed. This included a settlement of \$489,000 for alleged violations and specific requirements for short term and long term mitigation, water quality and biological monitoring, and provisions for postclosure maintenance and financial assurance. The order required that a long-term AMD mitigation/closure plan be submitted in the form of a formal amendment to the state mine permit. Applications to amend mine permits undergo the public review process by the state Board of Minerals and Environment.

Richmond Hill's original reclamation bond before the acid problem developed, was \$1.1 million. In response to the economic assessment conducted after the acid problem developed, the bond was incrementally raised to \$10.7 million. The ten-fold increase in bonding is testimony to the financial liabilities of AMD and improper sulfide waste management.

Short Term Mitigation Actions

To counter the immediate problem of contaminated surface discharge down Spruce Gulch into perennial Squaw Creek in the early spring of 1992, a series of treatment ponds were

constructed at the toe of the waste dump to chemically treat the dump effluent. Contaminated discharge was first treated with an anoxic limestone drain that proved ineffective. The limestone became armored with iron hydroxide, which rendered it ineffective in neutralization. Below the treatment ponds, a retention pond designed to accommodate the 10-year, 24 hour storm event was constructed. Treatment was first accomplished by the addition of soda ash, and later the additive was changed to caustic soda. The resulting metal hydroxide sludges can be periodically removed.

Partially treated water in the retention pond is then pumped to Richmond Hill's large, lined stormwater pond located at the process facility that has a capacity to accommodate about 80 million gallons. The partially treated water undergoes significant dilution in the stormwater pond and is contained and made available for further treatment in a water treatment plant before discharge. Discharge to groundwater can be effected via land application, which is regulated through a state groundwater discharge permit or to surface water through a National Pollution Discharge Elimination System (NPDES) permit.

Other short-term mitigation actions included the following. The sulfide ore stockpile was removed from the waste dump and placed on the leach pads where resulting contamination could be contained. Diversion ditches were constructed around the Spruce Gulch waste dump to direct clean surface runoff from above the dump, around it. A certain amount of lime, limestone, and alkaline fly ash was added to the waste dump at key locations for further neutralization. A semisealant material called Entac was sprayed on the waste dump in 1992 in an attempt to minimize infiltration of precipitation.

Migration of contaminated groundwater was addressed by constructing a cutoff trench in the shallow alluvium across the valley below the waste dump. The resulting water is collected and directed to the treatment ponds.

Although all of the water in the retention pond is pumped to the lined stormwater pond, a certain amount of surface flow remains in Spruce Gulch below the retention pond. This water probably represents a combination of retention pond water seeping through the embankment and shallow groundwater that is not cutoff at the trench and that surfaces at springs just below the pond embankment where alluvium pinches out to bedrock.

These treatment processes effectively remove metals and buffer pH. Sulfate and TDS are not effectively removed by base addition to the Spruce Gulch treatment ponds. Comparisons can be made of water quality data representing samples taken from the toe of the waste dump above the treatment ponds and samples taken from Spruce Gulch below the treatment system to determine the effectiveness of the control measures. The water quality data indicates that the combination of short-term control methods have proven quite successful at improving surface water quality below the waste dump.

Long Term Mitigation Actions

After considering several remedial options, a long-term closure plan was chosen based on the tonnage calculations and identification of the locations of acid-generating rock obtained in the environmental assessment. System hydraulics, water balance, and other site specific logistics also were considered before deciding on a plan. The state Board of Minerals and Environment reviewed and conditionally approved the mitigation/closure plan in February of 1994.

The objective of the closure plan is to reduce the potential for long-term environmental risk to surface and groundwater, promote long-term hydrologic and geotechnical stability, and maintain acceptable post-closure land uses.

The reactive waste rock from the dump (2.7 million tons) will be removed from Spruce Gulch and backfilled in 3-foot compacted lifts in the pit impoundment. In addition to removing the reactive wastes, LAC Minerals decided to remove all 3.5 million tons of rock from the dump. A portion of the non-reactive waste rock will be used in the construction of the pit impoundment cap described below. Some of the acid-generating sulfide-spent ore will be removed from the leach pads in the same manner. As of this writing in June 1995, over 90 percent of the material from Spruce Gulch had been backfilled in the pit.

The determination as to what constitutes material to be removed to the pit impoundment is based on the following criteria: waste rock having a NAG pH of less than 3 indicative of an ABA of less than -5 tons/kiloton calcium carbonate, and a paste pH of less than 4.5.

After backfilling is complete, the waste rock and corresponding acid-generating pit surfaces will be graded to slopes between 3:1 and 6:1 and capped with a multi-media cover shown in Figure 1. The cap system overlying the compacted waste rock consists (from bottom to top) of the following: 6 inches of onsite crushed limestone, 18 inches of compacted low permeability manufactured soil, 4.5 feet of nonreactive crushed waste material for thermal/frost/root protection of the manufactured soil layer, and 4 to 6 inches of topsoil. The cap will be revegetated with a mixture of aggressive grass species to limit the establishment of deeply rooting woody species and trees that could damage the integrity of the soil liner. The cap will include a riprap-lined channel to manage runoff and control erosion.

The 18 inch low permeability layer (compacted, manufactured soil) is constructed in two 9 inch lifts and consists of nonreactive waste rock crushed to minus 1/2 inch and blended with about 13 percent bentonite to meet a field permeability criteria of 1×10^{-7} cm/sec. Natural onsite clay was considered, but was found to be of insufficient quantities and of too heterogenous a nature to consistently meet the permeability criteria. The bentonite-amended material is blended in a pugmill and provides material consistency that assures better quality assurance and quality control during construction.

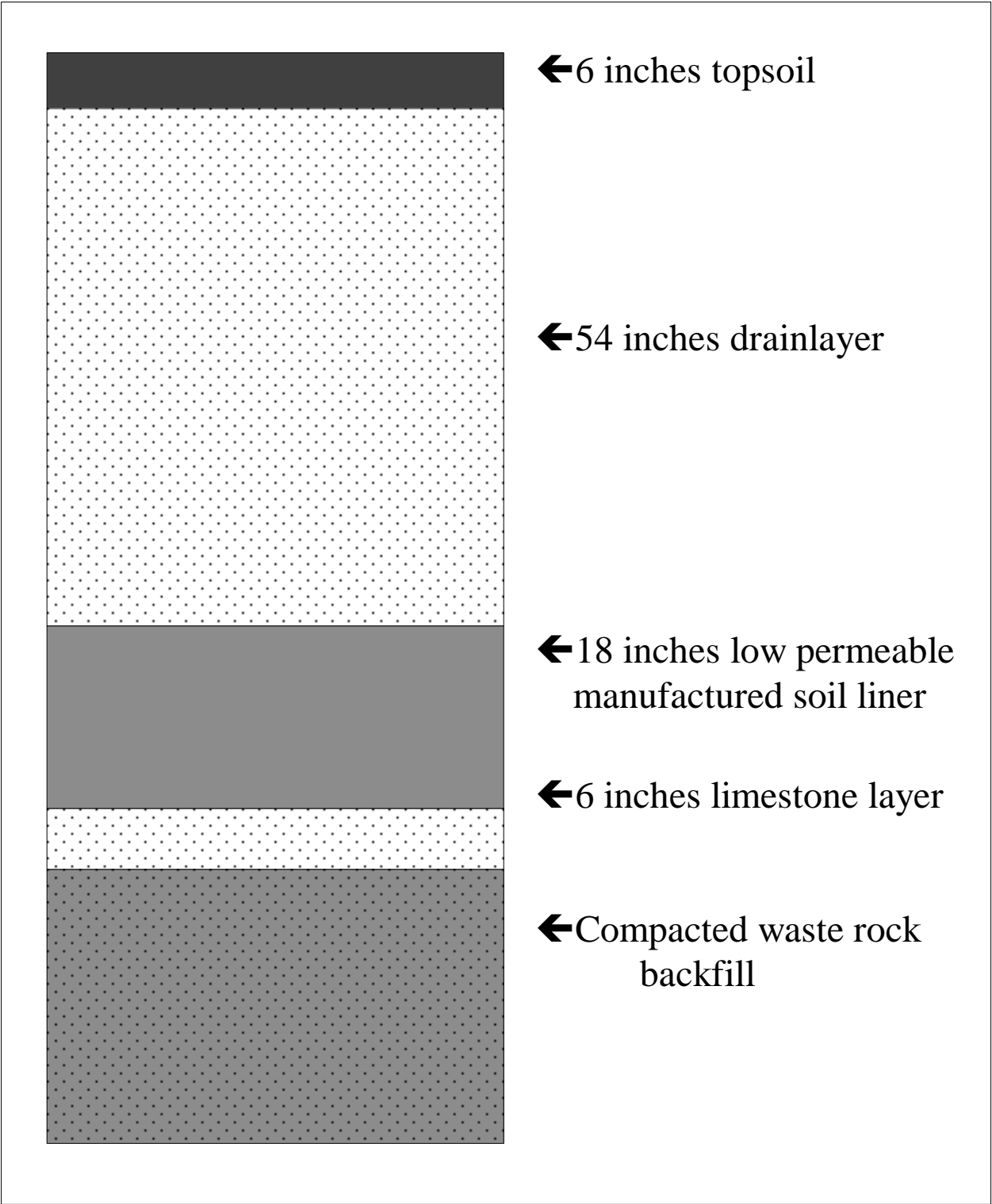


Figure 1. Cross Section of Richmond Hill Cap

At the time of the Board of Minerals and Environment hearing, a specific closure plan for the leach pads had not yet been developed. Preliminary AMD predictive tests indicated that a certain amount of acid-generating spent ore is present within the material that will remain on the pads. Limestone will be thoroughly mixed with reactive spent ore that remains on the leach pad. A condition of the permit amendment requires that an updated closure and postclosure plan for the leach pads be submitted to the DENR for approval prior to mine closure.

The details of the approved plans and specifications (P&S) and the construction quality assurance (CQA) plan for all components of the reclaimed facility required to have such plans (i.e., cap systems and waste rock placement in impoundment) are on file at the DENR Minerals and Mining Program.

This approach to long-term mitigation offers the best chance of a walkaway situation, or as close to it as is technically and economically feasible. The backfill option allows for control of site's water balance and avoids the need for perpetual water treatment of acid mine drainage. Extensive environmental data will be collected during the closure and postclosure period. Performance monitoring criteria are being developed to assess the success of reclamation and act as a trigger for initiating additional reclamation and/or maintenance work to assure compliance with long-term reclamation goals.

Postclosure

The postclosure period begins at the time of reclamation surety release (i.e., mine closure) and lasts for a period not to exceed 30 years, unless the state Board of Minerals and Environment determines that a longer or shorter period of time is necessary for compliance with performance standards or design and operating criteria.

The company will submit postclosure maintenance and monitoring plans to the DENR for approval prior to the start of the postclosure period. This includes contingency measures that could be taken to mitigate recurring AMD from any completed component of the reclaimed site. Such measures might include:

- * the addition of base material to waste rock.
- * capping or improvements to capping systems.
- * recovery and treatment of contaminated groundwater.
- * mitigation of acid-generating material at ancillary facilities.
- * removal of additional waste rock to the pit impoundment or other suitable location.
- * long-term water treatment of effluent from the pit impoundment or waste dump.

Cost estimates for implementing contingency measures will be included in the postclosure plan.

Prior to the start of the postclosure period, the company will submit a postclosure financial assurance in the amount of \$1.7 million to cover estimated postclosure care (this amount will be recalculated at the time of mine closure). Unless the postclosure period is altered, the financial assurance will be held for 30 years after reclamation surety release to ensure that the reclaimed site is stable and free of hazards; has self-generating vegetation, minimal hydrologic impacts, and minimal releases of substances that adversely effect natural resources; and is maintenance free to the extent practicable.

Performance Monitoring

During and after reclamation, the success of reclamation efforts will be assessed through certain performance monitoring indicators. The monitoring efforts will indicate whether each component of the reclaimed facility is functioning properly and whether additional touchup work is needed to meet closure objectives.

Performance monitoring will be based on results of surface and groundwater sampling, biologic testing, and outputs of various monitoring devices designed to assess the integrity of the capping systems and AMD reduction in the reclaimed waste material. Such monitoring devices include: lysimeters installed at key locations within the pit impoundment designed to measure AMD reduction and infiltration rates, temperature and oxygen probes in the backfill designed to monitor sulfide oxidation rates, and thermistors installed within the low permeability soil layer designed to indicate whether "heat of reaction" from acid generation within the backfilled waste or frost penetration below the thermal protection barrier are compromising the integrity of the low permeability layer.

Each year LAC Minerals, the DENR, and other appropriate regulatory agencies will meet to review the performance monitoring data acquired during the previous year and collectively assess the success of reclamation. Authorities recognize that closure and postclosure objectives, as determined through environmental monitoring results, will take some time to be reached. Reclamation efforts should not be expected to immediately reach these objectives. Regulatory flexibility must be maintained to allow for this and to assure that reclamation objectives are being approached over a reasonable amount of time. The annual performance meeting will allow for the identification of justifiable followup work to keep reclamation goals on track (4).

The Importance of the Link Between Company Operations and Corporate Environmental Policy

Often local mine operations are owned by larger corporations. In many cases, the larger corporations often have excellent environmental policies and advocate proper waste management practices and financial provisions for closure plans. LAC Minerals is such a

corporation. In fact, LAC has a history of being actively involved with Canada's Mine Environment Neutral Drainage (MEND) Program, an international leader in the field of AMD prediction, prevention, and abatement.

As is true in many arenas - government included - policy and practice may not always run in parallel. In a mining scenario, company-level practice may not be in proper communication with corporate environmental policymakers. This can be particularly damaging when it occurs with regard to the management of sulfide wastes because of the magnitude of the financial and environmental liabilities posed by AMD problems. Regulatory agencies can become keenly aware of such shortcomings and can be drawn in when problems develop. The issue is raised here in a general sense, and is respectfully offered for industry consideration.

Gilt Edge Mine

Numerous abandoned mine reclamation projects have been conducted by active mine operators in the Black Hills of South Dakota on a voluntary basis. These efforts have resulted in a net improvement to the environment while lowering the environmental liability posed by the abandoned mine sites.

One of the more notable reclamation projects was conducted by Brohm Mining Corporation, which operates an active heap leach mine in the northern Black Hills. Tailings from mining operations at Gilt Edge in the early 1900's were placed by the "old-timers" in the drainage of Strawberry Creek, a perennial stream in its middle and lower reaches. The Gilt Edge tailings were situated on property controlled by Brohm Mining, adjacent to one of the open pits associated with the active, permitted mine operation.

The relic tailings originally contained relatively high concentrations of sulfide minerals. As the tailings continued to erode, they produced severe acid mine drainage for many decades along Strawberry Creek. Bear Butte Creek, a perennial stream classified as a marginal fishery into which Strawberry Creek flows, was impacted by acid runoff for varying distances below the confluence, depending on the season and contaminant load. In the late 1980's a pH of 1.9 was recorded in Strawberry Creek immediately below the tailings pile (5). Static tests conducted on the relic tailings in 1993 showed that much of the sulfides had oxidized, leaving behind a significant amount of stored oxidation products (acidity and heavy metals) as a result of previous oxidation reactions (6).

In the fall of 1993, Brohm Mining removed approximately 150,000 tons of reactive tailings from the upper reaches of Strawberry Creek. The tailings were thoroughly mixed with alkaline fly ash from a local coal-fired power plant at a rate that provides sufficient neutralizing potential for contained sulfides. The amended tailings were placed in a "high and dry" disposal area in compacted, 12-inch lifts, graded to a maximum slope of 3H:1V, and capped with a low permeability cover. The fly ash was applied to the tailings in haul trucks and mixed again with bulldozers prior to compaction as it was spread out in the disposal area.

Water was added to the fly ash/tailings mixture, which allowed hydration reactions to occur. This resulted in achieving a pozzolanic (i.e., cementitious) behavior in the mixture, effectively isolating the reactive tailings from air and water. This type of AMD abatement procedure can be much more cost effective than using portland cement grout to achieve the desired reduction in permeability (7).

The tailings were amended with fly ash at a rate sufficient to ensure that the acid-neutralizing potential to acid-generating potential (ANP:AGP) ratio is greater than or equal to 3:1. The fly ash exhibited an average neutralizing potential of 467 tons/kiloton and was added to the tailings at an approximate rate of 25 tons/kiloton of tailings. This proportion was found to be sufficient to neutralize available acidity in the tailings and produce a net neutralization potential of 20 tons/kiloton in the amended tailings (6).

The amended tailings were capped with a low permeability clay liner in 1994. The requirements for the clay liner included that it be compacted in 6-inch lifts to at least 90-percent modified proctor density or 95-percent standard proctor density. No rocks, sticks, or other debris larger than 2 inches in size were allowed in the liner materials. The permeability of the clay liner had to be equivalent to a 12-inch layer with a maximum permeability of 1×10^{-7} cm/sec. Approved CQA personnel were required to be present on site at all times during the placement of amended tailings and clay liner.

A gravity fed, leachate collection system consisting of geosynthetic material was placed at the bottom of the tailings depository to detect seepage through the cap and amended tailings. Seepage has never been detected since the cap was installed. Considering the added benefit of the pozzolanic nature of the amended tailings, seepage is not likely to be detected in the leachate collection system.

In addition to removing the approximately 150,000 tons of eroding streamside tailings in upper Strawberry Creek, additional historic tailings that had accumulated behind several abandoned beaver dams further downstream were removed with a dozer and excavator. Removal with a vacuum truck was attempted but proved less efficient than the dozer and excavator.

In 1995, the South Dakota DENR made use of funds available through the Western Governors' Association and federal initiative to Develop On-site Innovative Technologies ("DOIT") to have the effectiveness of abandoned mine reclamation evaluated on a "watershed basis". As part of this watershed study, conducted by the South Dakota School of Mines and Technology, Strawberry and Bear Butte Creeks were monitored for water quality during and after tailings excavation activities. This monitoring was conducted to assess the effectiveness of the reclamation project. The results were related to preexisting water quality information. It was found that by employing a combination of best management practices (BMPs) during excavation work, increased sediment load downstream and exacerbation of AMD were kept to a minimum. BMPs included conducting the reclamation in the autumn low flow season, diverting Strawberry Creek

flow around work sites during excavation, ceasing excavation activities during precipitation events, and using adequate sedimentation and erosion control devices. Although a slight increase in total dissolved and suspended solids during remediation was noted, the increase was judged to be insignificant and showed little additional release of tailings downstream (8).

The tailings cleanup activities resulted in a significant improvement in water quality and aquatic habitat in Strawberry Creek. Total cost for the project was slightly over \$450,000. Reclamation was entirely funded by Brohm Mining. Discharges below Brohm's active mine operation, which had been of poor quality as a result of the historic tailings, are now in compliance with state Surface Water Discharge (i.e., NPDES) permit limitations.

Conclusions

Most aspects of modern mining in South Dakota have a history of proper regulation and pollution prevention. The only notable exception to this general rule concerns problems associated with acid-generating sulfide wastes.

AMD poses a significant threat to the environment and to the liability for sulfide mine operations, if not properly managed. Attention must be focused on preventing AMD at the source rather than mitigating impacts after the fact.

With the implementation of effective, and notably expensive, AMD reclamation practices such as implemented at the Richmond Hill facility, adequate environmental protection can be achieved. However, suitable mine waste management methods at active mine operations in the Black Hills demonstrating that acid-generating sulfide wastes can be handled properly from the start of operations, are yet to be incorporated into South Dakota's regulatory history. It is recognized that in some cases, sulfide rock is mined in South Dakota and AMD problems do not occur. In some situations, mined sulfide rocks contain sufficient natural buffering capacity to prevent acid generation; in others, reactive sulfides are identified early and kept to a subcritical volume in the mine plan. Before the permitting of additional operations that include sulfide rock of the problematic nature can be realistically expected in South Dakota, however, "preventative" waste management practices must be developed. These practices must be put in place during all phases of the mining operation from startup to closure.

The Richmond Hill AMD problem, with its regulation, enforcement, and subsequent reclamation work, is the most complex heap leach mining-related environmental issue that has arisen in the Black Hills. The reclamation work at the mine represents the culmination of exhaustive environmental planning. The work is progressing in an excellent fashion and with very promising results.

Backfilling, compacting, and capping the reactive waste in the Richmond Hill pit impoundment allows for control of the site's water balance and avoids the need for

perpetual water treatment of AMD. With the exception of a limited amount of performance monitoring, this approach toward long-term reclamation offers the best chance of a walkaway situation, or as close to it as is technically and economically feasible.

The cleanup of the acid-generating Gilt Edge tailings along Strawberry Creek represents one of the most significant abandoned mine cleanup efforts conducted in the Black Hills. This project is one of several such efforts undertaken by active mine operators in South Dakota to manage environmental problems caused by abandoned mines located on properties they control. Although South Dakota does not have an abandoned mine reclamation program, opportunities for cleanup of abandoned mine sites are pursued cooperatively as they arise. An intent to overcome regulatory barriers that might otherwise tend to stifle cleanup efforts has proven successful at keeping these reclamation projects out of the legal realm. This allows resources to be expended for on-the-ground site improvements, which is where they should be focused.

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