HARD-ROCK MINE CLOSURE CASE STUDY - CYPRUS COPPERSTONE MINE[1]

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Abstract: This paper presents a case study of permitting and issues associated with hard rock gold mine closure. A mine closure design for the Cyprus Copperstone Mine in Arizona was prepared and submitted to State and Federal agencies for review and comment. Issues addressed as part of the mine closure design included: open pit stability; heap leach pad detoxification; tailings impoundment closure; and, waste rock disposal area closure. The mine closure was designed to minimize long-term environmental impacts, reduce physical hazards, and return the area to the pre-mining land uses.

Introduction

This paper presents a case study of recent planning and ongoing activities for hard-rock precious metals mine closure at the Cyprus Copperstone Mine (Copperstone) in Arizona. This paper discusses the general environmental and permitting issues involved in hard rock mine closure, as well as the site-specific operational and physical conditions at Copperstone. Successful mine closure and permitting require the following elements--

- Accurate prediction of site water balance, including capacity for stormwater retention and/or discharge, evaporation, and process requirements.
- Accurate prediction of geochemical behavior of waste rock, tailings, ore heaps, open pit, or underground workings when exposed to an oxidizing environment.
- Adequate physical and geochemical stabilization of mine waste materials through operational or reclamation activities.
- Adequate environmental and operational monitoring to identify changes in initial design assumptions.

It is further very beneficial if the mine has a clean operating history and complete monitoring history.

This paper reviews the issues addressed during the ongoing Copperstone closure and is organized into the following sections:

- Copperstone site and project description.
- Open pit stability and waste rock disposal area closure.
- Mine contractor's compound closure.
- Heap leach pad detoxification and regrading.
- Plant closure
- Tailings impoundment closure.
- Compliance point monitoring and postclosure activities.

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The objectives of successful mine closure are to provide long-term environmental protection to surface and ground water resources, establish a stable physical setting, return the site to premining or other land uses, and develop a low-maintenance or "walk-away" situation for the mining company. A period of postclosure monitoring is typically required by the existing permits, and is recommended for the mining company to verify successful closure.

Cyprus Copperstone Site and Project Description

The Copperstone Mine is located approximately 18 miles south of Parker, AZ, on unpatented mining claims administered by the U.S. Department of the Interior's Bureau of Land Management (BLM). The Copperstone Mine operated under the following Federal and State approvals and permits: Plan of Operations (Federal, administered by BLM); Groundwater Quality Protection Permit (State, administered by Arizona Department of Environmental Quality, ADEQ); and, Air Quality Operating Permit (State, administered by ADEQ).

The Copperstone Mine is situated on the northern portion of the La Posa Plain, a desert basin located between the Plomosa Mountains to the east and the Dome Rock Mountains to the southwest. The project site is on a relatively flat desert surface water drainage divide with local northeast trending stabilized sand dunes. Surface elevations range from 725 to 899 ft above mean sea level (msl).

The surficial materials are Quaternary eolian and alluvial sands which overlie the Pliocene-aged Bouse Formation. The Bouse Formation is comprised of lenticular deposits of clay, sand, and gravel, which are generally moderately to highly cemented with calcium carbonate.

The mine consists of an elliptical-shaped open pit excavation. The mine pit walls expose alluvial materials 0 to 170 ft thick, which are underlain by faulted and altered quartz latite and basalt. Below the quartz latite, Paleozoic-aged limestones and clastic rocks are exposed locally in the northern portion of the open pit. Mining was completed to an elevation of 350 ft above msl with an ultimate mine pit depth of approximately 540 ft below the original ground surface.

Mining was performed by drilling, blasting, loading, and hauling. Unmineralized rock and overburden were hauled and deposited in waste rock disposal areas. Ore was hauled to the processing area, which consisted of rock crushing and milling equipment and a carbon-in-leach (CIL) processing plant. Ore was crushed using a two stage crushing system, ground with ball mills, and then cyanide-leached. Spent ore was piped, in slurry form, to two separate lined tailings facilities for final deposition. The first area, cell A, was constructed and used for the ore processed beginning in 1987. Cell B was subsequently constructed in 1988 for additional tailings storage capacity. The reclaimed water from the tailings impoundment flowed to a double-lined reclaim pond and was subsequently pumped to the plant. Reclaim water was recycled into the process facilities. The site facilities are shown on figure 1.

A cyanide heap leach facility was constructed on top of deposited tailings solids in cell A in 1991. Pregnant solution from the heap leach facility was collected in a pond located near the center of the heap leach pad in cell A. During heap leach operation, reclaim solution from the tailings was used as barren make-up water for the heap leach operation. Pregnant solution was pumped to the CIL plant for gold extraction.

Cyprus Copperstone Mine was designed, constructed, and operated as a zero-discharge facility. Process solutions utilized for heap leaching or tailings management during operations were recycled and contained in the lined tailings impoundments, lined heap leach facility, curbed process facilities, and lined solution transfer channels for piped solution conveyance. During closure, to maintain the zero-discharge requirement, process solutions were pumped to the tailings impoundment for evaporation. Heap leach pad rinse solutions were detoxified and recycled prior to evaporation.

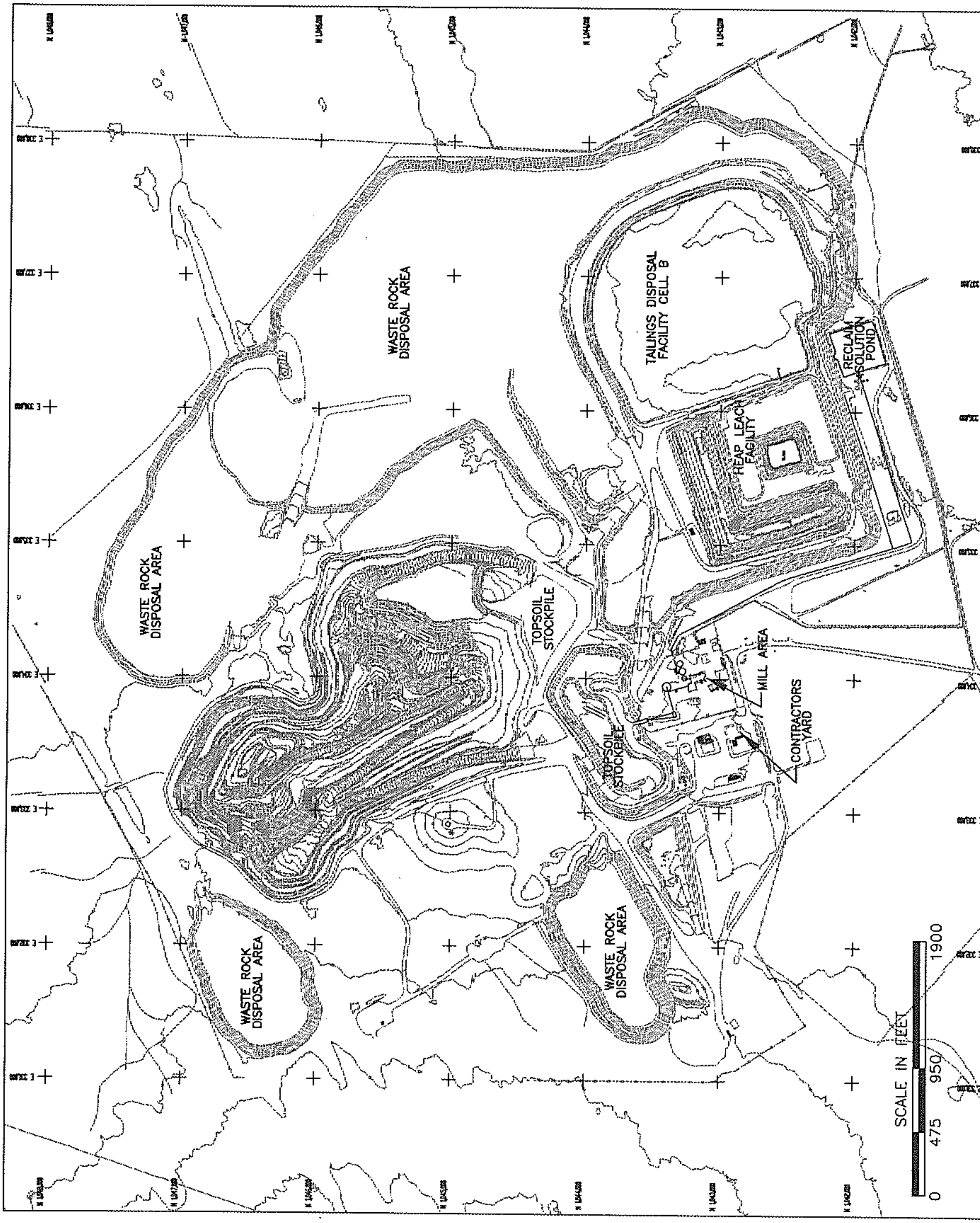

Figure 1. Site facility map.

Mine and Waste Rock Disposal Area Closure

The mine pit configuration near the end of operation is shown on figure 1. The pit wall has been excavated to between 47° and 63° slope angles. Some minor slope failures occurred during operation, mostly related to the geologic structure of the bedrock. Additionally the exposed slopes in the alluvium have failed locally. The bottom of the pit (at elevation 350 ft above msl) is approximately 20 ft above the local ground water level.

It is expected that the pit slopes will ultimately ravel to an overall 1.5H:1V in the alluvial overburden, while some future failures may occur in the structurally controlled rock faces. Because of the potential for future slope failures a rock berm was constructed on the surface around the predicted outer limits of the eventually stabilized pit rim. The berm was constructed of waste rock and excavated native soils. The berm is approximately 4 ft high with angle of repose sideslopes.

The waste rock disposal areas consist of a large contiguous rock pile on the east side of the pit, a north waste rock disposal area, and a south waste rock disposal area (fig. 1). These waste rock disposal areas were constructed in lifts through end dumping and dozing. The final lift was placed as loose "plug" dumps, creating a hummocky topography. The hummocky topography provides a more natural appearance as well as helping to collect wind-blown seeds, eolian silts, and moisture. Waste rock generated during the final stages of mining has been deposited in the southern part of the pit.

Geochemical Characterization

The mine pit overburden is comprised of both alluvium and bedrock. The bedrock is a quartz latite ranging from a massive to laminated texture and locally brecciated along faults. Adjacent to the ore zones, the quartz latite becomes sericitically or chloritically altered to various degrees. The altered zones contain minor amounts of barite, chrysocolla, hematite, and magnetite. The waste rock and ore contain only insignificant amounts of sulfide mineralization, and as such are not expected to have a potential for generation of acid drainage. A conformational geochemical testing program was developed to predict the geochemical behavior of the waste rock. This program consisted of the following four phases--

- Phase 1. - Identification of waste rock domains.
- Phase 2. - Selection of representative pit wall samples.
- Phase 3. - Acid-base accounting laboratory tests.
- Phase 4. - Meteoric water leach tests of waste rock samples.

The 57 million st of barren rock in the waste piles that will remain after closure were shown to be geochemically inert through the acid-base accounting and meteoric water testing program. Because these materials do not represent a potential source of contamination to surface or ground water, no treatment or discharge control is anticipated. No limitations on future land or water uses will be created as a result of the facility closure.

The closure plan presented for the mine pit and waste rock disposal areas is consistent with the State air quality and water quality permit requirements. This closure plan also meets the objectives established by the BLM including--

- Stabilized waste rock disposal areas against water and wind erosion.
- A confirmational geochemical evaluation determined no potential impact to ground water from infiltration of precipitation through the waste rock disposal areas
- Postmining land use consistent with the surrounding area except for the pit area.

Mine Contractor's Compound Closure

Cyprus Copperstone employed a private contractor to perform the mining operations. The contractor set up a compound with offices, maintenance facilities, refueling area, and storage yard in the contractor's compound area shown on figure 1. The fuel storage area consisted of a number of diesel tanks in a containment berm. The base of the contained area under the front end of the diesel tanks was lined with a 60-mil polypropylene liner.

The mine contractor's compound has been closed and reclaimed by removing equipment, followed by sampling and analysis, and finally by covering with topsoil. Some buildings will remain as the property of the claim holder, as these facilities have been purchased and bonded. All other equipment related to the mine contractor's compound was dismantled and removed for future use elsewhere.

Quantities of petroleum-contaminated soil from the mine contractor compound and plant area were identified based on the analytical results of a soil survey. The petroleum-contaminated soils have been excavated and are being bioremediated on-site.

Heap Leach Facility

The heap leach facility containing 1.2 million st of ore was constructed on the cell A tailings area (fig. 1), thus taking advantage of the existing buried liner under the tailings. Ten feet of waste rock was placed on the Cell A tailings impoundment with an overlying 20-mil PVC liner prior to construction of the heap. The heap was constructed in 20-ft lifts consisting of ore crushed to minus 5/8 in. Leaching was carried out with solution containing about 2 lb of free cyanide per ton of water delivered through drip emitters. The pregnant solutions were collected in a pond located in the center of the heap.

The heap leach pad closure requirements established in the operating permits are as follows: rinseate to be sampled from the pregnant solution pond should contain 0.2 mg/*l* or less total cyanide; the operator must assure that all solids will be properly capped (at least 2 ft of nontoxic native rock and solids) or that the constituent concentrations are less than or equal to the concentrations listed below.

Constituent	Limits, mg/*l*
Cyanide	20
Arsenic	5
Barium	100
Cadmium	1
Chromium	5
Lead	5
Nitrate	10
Selenium	1
Silver	5

The three options evaluated to potentially achieve the 0.2-mg/*l* total cyanide rinse effluent standard following detoxification included--

- Semicontinuous and partial low volume fresh water rinsing.
- Continuous rinsing with high volumes of recycled treated water.
- Natural attenuation using recycled water containing either indigenous or augmented microbial populations, both with possible nutrient addition.

A fourth closure option was considered that involved recontouring the 1.2-million-st heap without treatment and covering the solids in place with a cap. Although the treatment cost of this option was obviously less than the costs of the other three, it was less appealing owing to increased capping costs. As a result, the focus remained upon the three initial closure options.

Although the evaporation rate at the mine is high in comparison with precipitation, the use of large volumes of fresh water rinse and continuous rinsing to achieve the desired effluent standard is not practical. Thus, the preferred approach involved rinsing and enhancement of natural attenuation biological treatment to either eliminate or reduce the residual total cyanide content.

The use of biological treatment for destruction of cyanide is well known and has been applied successfully in full-scale applications at both conventional vat and heap leaching operations (Smith and Mudder, 1991, Mudder and Whitlock, 1984, and Thompson, 1990). Although biological treatment of cyanide is generally less expensive than chemical treatment, it requires a longer period to initiate and complete. As a result, the benefits of reduced treatment costs are offset by the costs associated with leaving the operation open for a longer period. However, at Copperstone, time was less of a problem because of the need to allow the tailings pond surface to dry enough to permit access for covering with waste rock.

The climatic conditions at Copperstone are optimal with respect to initiating biological degradation of cyanide, using indigenous or augmented bacterial populations. A review of the chemical analyses of the reclaim and pregnant solutions suggested that biological degradation was already occurring, as indicated by the observed decrease in copper and cyanide levels and the corresponding increase in ammonia, nitrite, and nitrate concentrations. The resultant pH decrease is probably due to copper hydroxide precipitation and the destruction of carbonate alkalinity through nitrification.

Rinsing of the west half of the leach pad with fresh water was initiated in November 1992. Figure 2 illustrates the total cyanide degradation in the heap after the first fresh water rinse. A significant decrease, on the scale of two orders of magnitude, was observed. This suggested a strong, well-adapted population of bacteria was present and able to oxidize the available total cyanide very quickly. Total cyanide concentrations decreased from approximately 148.0 mg/*l* to 4.4 mg/*l* in 3 months.

As a result, biological treatment was used at Copperstone to reduce the cyanide level in the heap to the regulatory level of 0.2 mg/*l* total cyanide. The process designed for enhanced biological treatment consists of: production of bacteria proven to oxidize cyanide in spent ore and the pore solution in the heap; application of dilute solutions of the treatment culture; and, analysis of draindown solution and spent ore to verify biological treatment efficiency.

The rinsing process was operated as a closed system with no discharge to the environment. The bacteria populations and nutrients are natural and nontoxic.

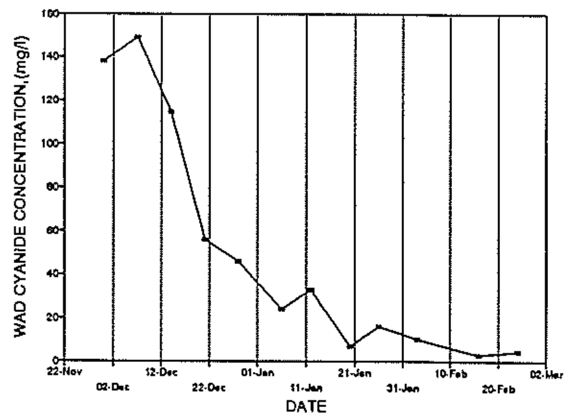

Figure 2. Decomposition of cyanide during rinse, west pad.

The heap leach ore has been rinsed to the regulatory limit of 0.2 mg/*l* total cyanide for leachate, the next step is that rinsed ore will be collected for testing. Eight boreholes will be drilled and sampled and analyzed for Synthetic Precipitation Leaching Procedure (EPA method 1312). Only if the solids criteria identified above are exceeded will the heap leach material have to be graded and capped with 2 ft of waste rock.

After verification of rinsing and detoxification of the spent ore, the pregnant solution pond liner will be punctured to prevent the development of perched water in the heap. The center of the heap where the pond is located will be filled with spent ore, forming a low spot to the southwest corner. Rinsed spent ore from the east side of the heap leach area will be dozed and graded to cover the western part of the tailings impoundment.

No materials will be removed from the overall lined area as part of the heap leach closure. The chemical, physical, and biological characteristics of the heap leach facility will pose no potential environmental liabilities after the biological treatment is complete. Cyanide concentrations will be at an environmentally acceptable level, and the bacteria and nutrients are nontoxic. Active treatment will not be necessary after closure of the heap leach facility. No discharge control will be required after closure because of low precipitation and high evaporative losses. No limitations on future land or water uses will be created as a result of heap leach closure activities.

This closure plan presented for the heap leach pad is consistent with the State water quality and air quality permit requirements. This closure plan also meets the objectives established by the BLM including--

- All process fluids will be detoxified and evaporated from the site eliminating a potential for ground water contamination.
- The spent ore will be stabilized against wind or water erosion.
- The cover will be graded and compacted to minimize infiltration.
- The area will be returned to premining land use.

Plant Closure

The processing plant and facilities will be closed and reclaimed by removing buildings and equipment. Two buildings will remain as the claim holder will purchase and secure bonding. Should cyanide contaminated soils be identified, the material will be excavated and buried in the tailings impoundment. The only materials which will remain consist of broken concrete building foundations. These materials will be covered with waste rock and top soil. Natural vegetation will establish through invasion. No treatment or control of discharge will be required as a result of the closure of these facilities. No limitations on future land or water uses will be created as a result of mining or closure activities in these areas.

Tailings Impoundment Closure

The tailings impoundment facility was constructed with two cells to contain the tailings. A 40-mil PVC liner underlies both cells of the impoundment facility. Cell A was constructed with liner extending underneath the embankments. Cell B was constructed as a fully contained impoundment with liner extending up the embankment sideslopes on three sides. The west embankment of Cell B served as a center drainage core between cells A and B.

The tailings have been deposited as a slurry using thin-layer deposition techniques. The tailings were deposited in thin layers in a managed cyclic rotation to maximize consolidation and drying of the tails. Deposition in cell A started in the third quarter of 1987. In 1988 a downstream raise to cell A was constructed and cell B earthworks were also completed. The average production rate throughout the operating life was 2,900 st/d. Figure 3 graphically shows the tailings deposition history of cell B.

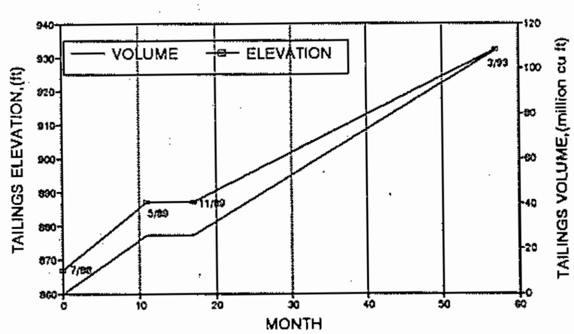

Figure 3. Tailings deposition, cell B.

The tailings facilities were constructed with internal drainage systems overlying the liner. Seepage collected in the underdrain system flows to the reclaim solution pond located outside the southeast corner of cell B. The tailings consolidate through self-weight and desiccation as water is decanted from an overlying pond, and by dewatering through the drainage system. The tailings deposition was managed to promote rapid drying of tailings, thus minimizing subsequent consolidation, and to allow placement of cover materials as soon as possible after project cessation.

In 1989 a net was placed over cell B to prevent avian mortality. This floating net consists of a polypropylene net suspended by cables. To allow permanent suspension of the net above the tailings, vertical risers were constructed. These were attached to polypropylene drums with a steel frame. These drums acted as "floats", raising the net as the tailings level rose. Maintenance activities were conducted on the net throughout the project life.

Closure and reclamation of the tailings impoundment started after milling ended. The polypropylene drums were punctured in March 1993 to allow them to be covered with tailings. After mill closure in June of 1993 evaporation of the excess tailings liquid evaporation began. It is expected that it will take at least six months to evaporate the remaining tailings and process solutions. The net will then be dropped on the tailings surface. Concrete scrap from the plant demolition and any cyanide contaminated soils will be placed on the net prior to covering it with about three feet of waste rock and spent heap leach material. The net will act as reinforcing while placing the cover thereby improving access.

The waste rock and spent ore will be spread and compacted with earthmoving equipment. Experience on site shows that these material break down readily under trafficking thereby forming a surface which will enhance runoff during the high intensity rainfall in the area.

Because of the expected settlement of the tailings surface over the first few years after cover placement it may be necessary to perform maintenance operations on the cap. Such maintenance may consist of regrading and reworking the cover surface to eliminate cracks and maintain positive drainage.

The reclaim solution pond liner system consists of a 30-mil XR-5 geomembrane liner and a 30-mil PVC geomembrane secondary liner. A leakage collection system between the primary and secondary liners includes a sand layer at the bottom of the pond and a drainage net in the pond sideslopes. Monitoring of the leak detection system located at the northwest corner of the reclaim pond is performed by sampling through a 4-in-diameter pipe.

The tailings impoundment closure requirements established in the State permit are as follows: the operator must assure that all solids will be properly capped with at least 3 ft of nontoxic native rock and solids; and, the area surrounding the tailing pond should be graded to preclude the migration of tailings off the impoundment during a 100-yr, 24-hr storm event.

In addition, any sludge or residue from the reclaim solution pond will be analyzed using U.S. Environmental Protection Agency approved methods for submittal to the agencies prior to burial or disposal.

Analyses of representative water quality samples from water collected from the tailings impoundment and water draining from the impoundment underdrain during operations indicated that free and weak acid dissociable cyanide are detected in significant quantities. These results indicate that the tailings water which ponds on the top of impoundment is of similar quality to the tailings pore water from the underdrain.

To determine the quantity and duration of water expected to drain from the tailings impoundment underdrain, a consolidation analysis was performed. During operations piezometers were installed at different depths and monitored in both cells A and B. A review of the piezometer data indicated that pore pressures during tailings deposition were less than the expected hydrostatic pressures at the piezometer locations. This indicates a downward gradient in the tailings deposit, and that the tailings are normally consolidated. Because the tailings are normally consolidated, classical consolidation theory was used for the postoperational consolidation analysis.

This analysis evaluated settlement likely to be caused by the surcharge load provided by the cover material to be placed on the impoundment. These results suggest that the surcharge load would result in approximately 0.6 ft of settlement. Seepage from the tailings impoundment underdrain system is estimated to increase in response to the surcharge load. The initial seepage flow is estimated at 41 gpm during the first several months, decreasing to approximately 3 gpm within 1 yr of cover placement. It is recognized that classical consolidation theory is not appropriate for large strains and may over-predict the consolidation period. However, it is usually conservative and was deemed adequate for this project.

The performance of the engineered tailings cover was evaluated to estimate stormwater runoff and infiltration from the reclaimed surface. This evaluation was performed using the HELP model version 2.05. Site-specific evaporation and precipitation were used in this evaluation. Three cases were evaluated with the HELP model in which the hydraulic conductivities for a 3-ft-thick cover layer of $1x10^{-3}$, $1x10^{-4}$, and $1x10^{-5}$ cm/s were evaluated.

The results from the HELP model suggest that zero runoff is expected from the reclaimed tailings surface, and that 94% of the precipitation falling on this surface will be lost to evaporation for a $1x10^{-4}$cm/s cover layer. The remaining 6% will infiltrate the tailing deposit, where it would be collected in the tailings underdrain system. The average annual seepage rate for a $1x10^{-4}$cm/s cover is estimated as 0.16 gpm. When the hydraulic conductivity of the cover layer is reduced to $1x10^{-5}$cm/s, the surface evaporation is reduced to 77% of precipitation. For this case, surface runoff is estimated to be 23% of precipitation. A third case was evaluated in which the hydraulic conductivity of the cover layer is $1x10^{-3}$cm/s, resulting in 87% evaporation with zero runoff.

The results from the HELP model indicate that zero surface runoff is expected from the cover layer with a hydraulic conductivity of $1x10^{-4}$cm/s or less. The HELP model predicts that a peak daily precipitation for the site is 1.45 in. Zero runoff is also estimated for this peak precipitation event when the hydraulic conductivity of the cover is $1x10^{-4}$cm/s or less. Based on the texture of the cover material, it is unlikely that the hydraulic conductivity would be much lower than $1x10^{-4}$cm/s. Therefore, it can be concluded that very little runoff can be expected from the reclaimed tailings surface under average precipitation conditions.

A simplified water balance for the reclaim pond was evaluated to determine the volume of solution present in the pond during the postoperational and reclamation period.

Seepage resulting from consolidation will drain into the existing reclaim pond for evaporation during the first 2 yr. Based on on-site evaporation data (83 in lake evaporation per year) the evaporative capacity of the reclaim pond is 10.7 gpm. The initial seepage rate from the tailings impoundment is estimated to exceed the evaporative capacity of the reclaim pond for the first 6 months. During this period some buildup in solution may occur in the pond until a negative water balance is established. The pond has ample capacity to store this volume without overflowing. The netting covering the reclaim pond will be left in place until the reclaim pond is backfilled.

The reclaim solution pond closure will be conducted once the flow from the tailing impoundment drains drops below 10.7 gpm. As discussed above, this is the balance point between inflow and evaporation.

The pond will be reclaimed by covering the lined area with alluvium and waste rock. A standpipe will be installed in the infilled pond for water level monitoring. The seepage will infiltrate the cover materials and be retained as soil moisture content, or be lost to evapotranspiration.

The quantity of inflow into the reclaim solution pond is currently about 40 gpm. This inflow quantity is expected to diminish to approximately 3 gpm within 1 yr. Because of the potentially low quality of this water flowing into the reclaim solution pond, the liner will be left intact. The quantity of flow within 1 yr will be insignificant. As such, filling in the pond with alluvium and waste rock will prevent the potential for wildlife exposure to the cyanide-bearing water.

In summary, no materials will be removed from the tailings pond during closure. The net will be dropped on the surface of the tailings after evaporation of excess tailings liquid is completed. Finally the tailings impoundment will be covered with 3 ft of waste rock and spent ore.

This closure plan also meets the objectives established by the agencies including--

- All process fluids will be detoxified and evaporated from the site, eliminating a potential for ground water contamination.
- The tailings will be stabilized against wind or water erosion.
- The cover will be graded and compacted to minimize infiltration.
- The area will be returned to premining land use.

Postclosnre Monitoring

Postclosure monitoring by Copperstone will be performed to evaluate the success of the closure activities. The following monitoring activities will be performed:

- Water-level measurements will be recorded in the backfilled reclaim solution pond.
- A new groundwater monitoring well be installed downgradient of the tailings/heap leach area and sampled quarterly for total cyanide and metals for several years.
- Visual inspection of tailings impoundment cover.
- Visual inspection of stabilization and resistance of waste materials against wind and storm water.

Conclusions

The Copperstone Mine closure plan, as discussed above, is predicted to be successful for the following reasons: the mine closure activities result in a low-maintenance return to preexisting land uses; the mine closure activities comply with all State and Federal regulations; the site water management plan allows for detoxification and evaporation of all process solutions; and, the mine pit, waste rock disposal areas, heap leach facility, and tailings impoundment will all be stabilized physically and geochemically upon final closure.

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