MINE CLOSURE PLANNING IN PERU[1]

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Abstract. Recent legislation provides comprehensive closure regulations in Peru. The conceptual closure plan for the Antamina Cu/Zn mine, developed initially as part of the EIA, was updated to meet the new requirements. This included predicting future water quality, based on site operational monitoring data and large scale field kinetic tests, as the basis for design of a water treatment system. Cost estimates for water treatment, facility demolition and waste dump reclamation, etc., were prepared. This case study outlines the key components of the new legislation and illustrates the importance of designing and developing a mine with the ultimate closure in mind.

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Introduction

New mining legislation in Peru requires that mining projects will soon have to post adequate surety to meet their closure and reclamation obligations. This legislation is not only applicable to future mine development, but also to existing facilities such as the Antamina Mine. This paper summarizes the framework for the proposed legislation and presents the proposed Closure Plan for the facilities for Compañía Minera Antamina (Antamina). The Antamina mine is located in north central Peru, approximately 100 km east of Huaraz, at elevation 4,100 m (see Fig. 1). The main facilities consist of an open pit Cu-Zn mine with rock waste dumps, a processing concentrator, and a tailings impoundment (see Fig. 2). Associated facilities include a 302 km concentrate pipeline and a concentrate dewatering and ship loading facility located at Puerto Punta Lobitos near Huarmey. Mining operations commenced in 2001. The mine will cease primary production in 2019 and the long-term stockpiles will be depleted in 2022. This closure plan is based on the Life of Mine Plan, December 2002.

Legislation Framework

The Republic of Peru has, since the mid 1990's, adopted a policy of upgrading the environmental legislation for mining to be comparable to International Standards. The program started with International funding and technical support which led to the production, by the Ministry of Energy and Mines, of a series of Guidelines for design and management of technical and environmental aspects of mining facilities. In 1997 legislation was introduced requiring all mines to prepare a "Program for Environmental Management and Monitoring" (PAMA – Programa Ambiental Manejo y Monitorio) for all mining operations in Peru. In the early 2000's the Ministry of Mines began looking at the introduction of closure guidelines and closure legislation. Closure legislation is a challenging undertaking due to the complexity of closure and the complexity of providing adequate financial surety. As a result, there have been a number of drafts and proposals for wording of the legislation and the final wording and enactment of the regulations is in progress. In 2004, draft regulations were issued (Proposed Regulations V1-05-04), which included the following key provisions:

- Filing and Approval: Describes the requirements for submission of plans and review periods for Regulatory Agencies and overall acceptance/rejection of the plan, which is generally set as 180 days from date of submission. There is a requirement for public notification (15 days) and public response, which is 30 days from date of publication of the Closure Plan summary.

- Cost Estimate: The cost estimate and schedule for the works will be prepared by a specialized registered firm. The cost estimate will include all costs of reclamation and all indirect and complimentary costs, including legal, auditing, and administration.

- Changes and Performance: The requirements for notification of changes and for monitoring of the commencement and completion of closure activities are noted, along with requirements for recognition of third party rights during the closure period.

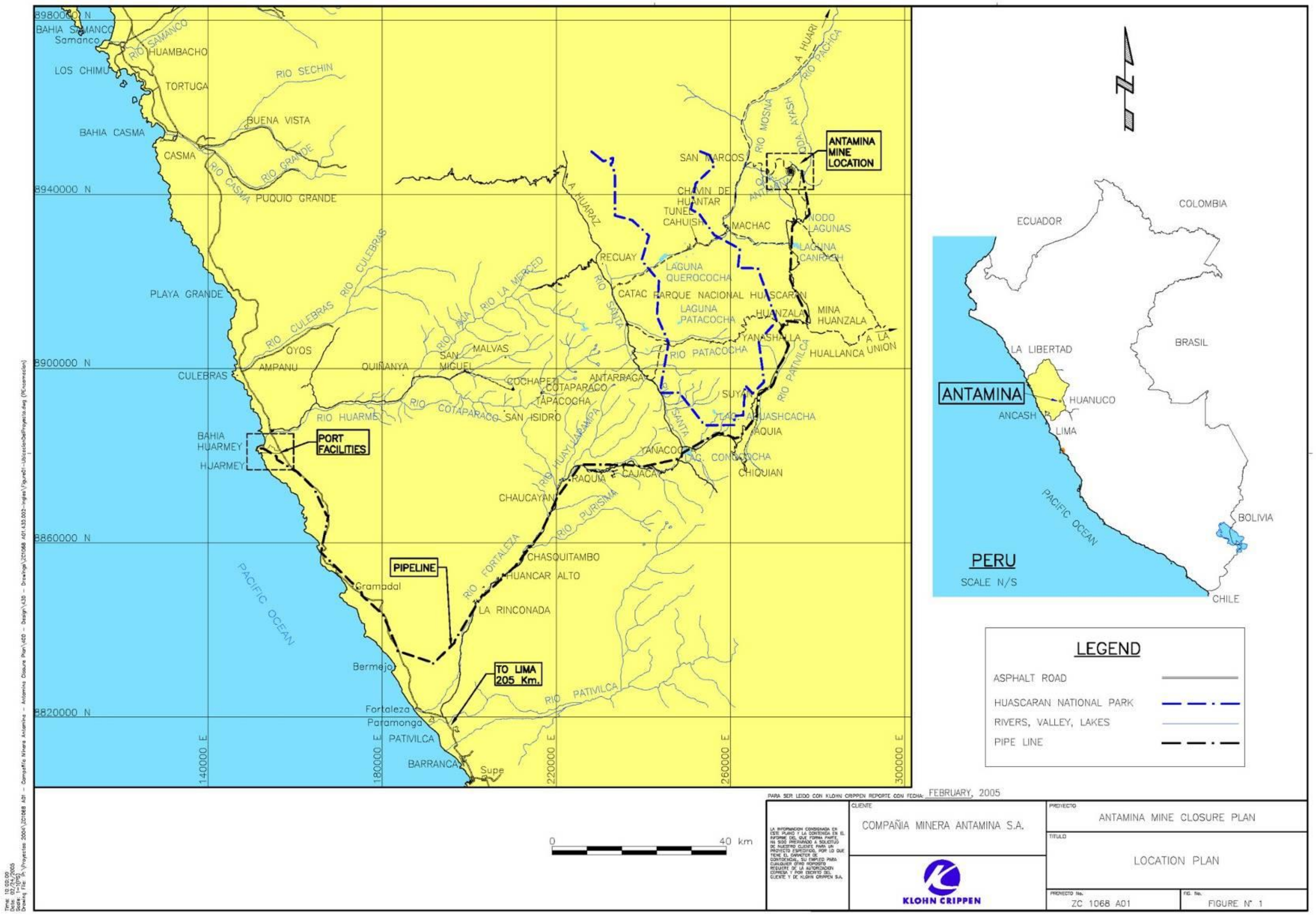

Figure 1. Location Plan.

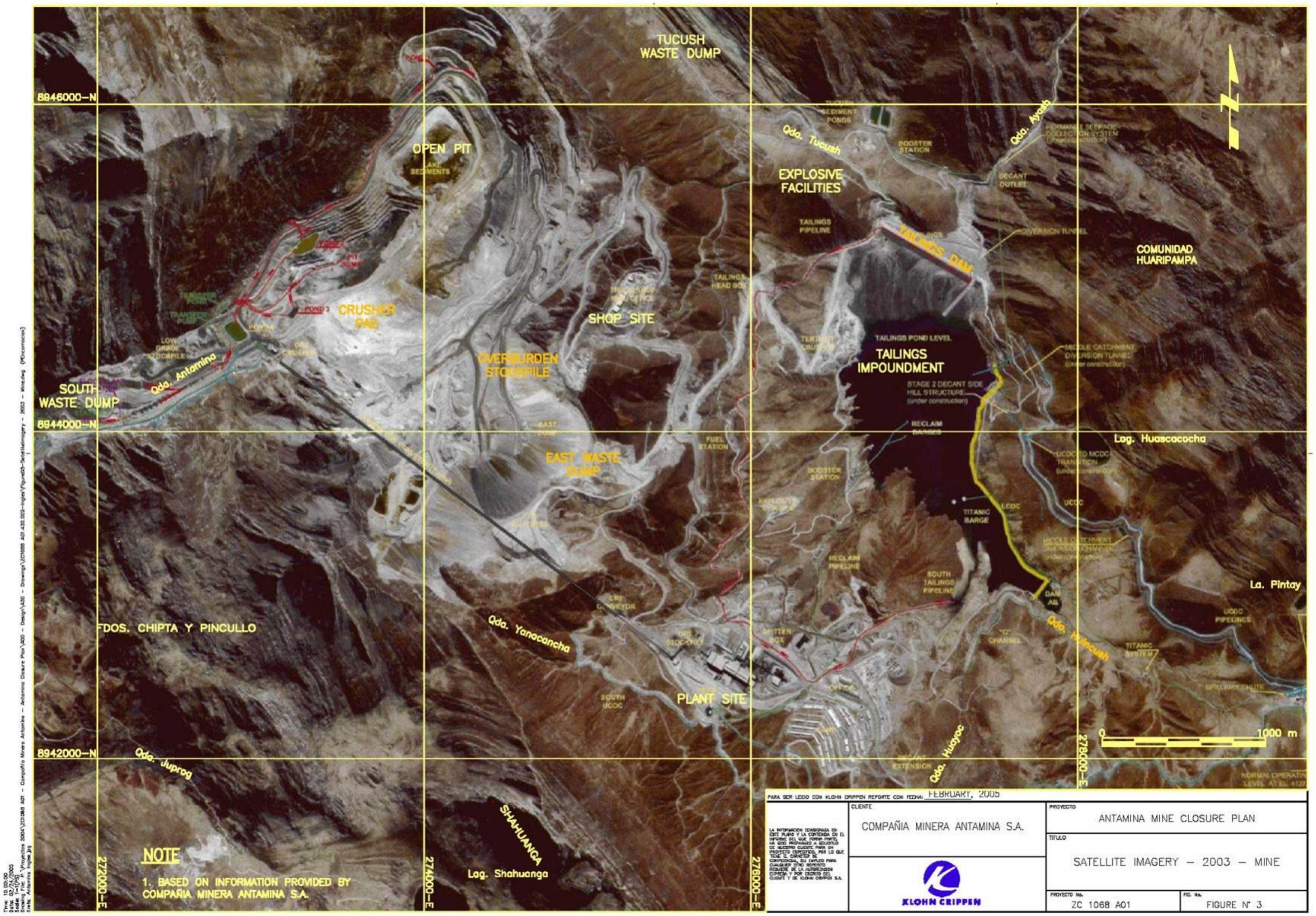

Figure 2. Satellite Imagery – 2003 - Mine.

- Guaranties and Audits: This continues to be a difficult issue to resolve and issues include the financing guaranties for closure costs. A framework for classifying mines according to their complexity and potential for environmental liabilities is integrated with various financing vehicles. Procedures for independent audits and sanctions, if the audit recommendations are not carried out, are provided.

- Information Required for a Closure Plan: This section outlines the table of contents and information requirements for the closure plan, which is similar in scope to closure plans prepared in North America.

Antamina Closure Plan

The development of the closure and reclamation plan for the Antamina site was based on the following primary objectives:

- Safety to the public accessing the site;
- Geotechnical stability of mining structures;
- Geomorphic stability of reclaimed landscape (i.e., minimize erosion and sediment transport);
- Water quality protection for streams receiving effluents from the site; and,
- Provision of a post-mining land use equal to, or better than, it's pre-mine use.

Closure of the Antamina facilities will occur over a period of approximately ten years. This includes at least four years of major progressive reclamation work, during operations, on the mine waste dumps. The main conceptual works are summarized below. These concepts will be revised throughout the mine life and optimized to suit actual conditions and best available technologies on closure.

Mine Area – Progressive Reclamation

- Progressive reclamation of the East, Tucush and South waste rock dumps will begin approximately 4 years before completion of mining operations. The closure works include regrading of the waste dump slopes from the current angle of repose to slopes of 2H:1V to 3H:1V using mine equipment.

- The Tucush and South dump surfaces will be covered with topsoil and revegetated. Associated works include surface water diversion and erosion control channels. The waste rock in the Tucush and South dumps contain low levels of mineralization and treatment of seepage water on closure is not anticipated. See Figure 3.

- An engineered wetland has been constructed (see Fig. 4) downstream of the Tucush waste dump to treat 70 L/s of water to reduce nitrates and metal levels in the waste dump runoff.

Figure 3. Tucush Dump in development.

Figure 4. Tucush Dump Engineered Wetland.

- The East Dump contains reactive waste rock that is expected to release Cu, Zn and Mo. A seepage collection system and a water treatment plant will be constructed to treat contaminated seepage. The waste dump cover will include an additional layer of limestone rockfill/glacial till to provide a buffer zone for vegetation root penetration. Topsoil will be placed over the rockfill cover and the surfaces will be revegetated. See Fig. 5. Surface water and erosion control channels will be constructed.

Figure 5. East Dump Revegetation Test Plots.

- During the last stage of the tailings dam raise, a permanent spillway will be constructed for the tailings facility. The spillway will consist of a major rock excavation in the right (east) abutment of the dam.

<u>Mine Area – Closure Works</u>

- The open pit (see Fig. 6) will infill with water over a period of approximately 50 years and then discharge into Quebrada Antamina. Water quality at that time is anticipated to be similar to pre-mining conditions and water treatment will not be required. Safety berms will be constructed around the open pit and a security berm will be constructed near the outlet to Quebrada Antamina. The 10 m high security berm is provided to attenuate a potential flood wave in the event of a slope failure of the open pit.

- All contaminated waste rock and soils beneath the low grade and marginal grade ore stockpiles in the Quebrada Antamina valley will be removed and placed in the open pit. The area under the former low grade and marginal grade ore stockpiles will be regraded, topsoil will be placed on it, and vegetation suited to the growing conditions will be planted. The historic Quebrada Antamina creek channel will be re-established.

- The decant tunnel for the tailings dam will be plugged with a concrete/soil plug and all exposed pipelines and associated works will be removed and placed in the open pit. Buried pipelines will be flushed and abandoned. A 400 m to 500 m wide tailings beach will be left adjacent to the dam (see Fig. 7), and the beach will be covered with limestone rockfill, topsoil and will be revegetated. The diversion channels will be regraded and the areas revegetated.

- Provisions will be made to operate the seepage pumpback system during the dry season for a period of at least 5 years after the cessation of mining. This will be combined with monitoring of the water quality. When seepage pumpback is not required to maintain water quality, the system will be decommissioned.

- Water treatment of the tailings pond seepage is not expected to be required. However, if water treatment is required, the East Dump water treatment plant capacity would be expanded to treat some or all of the tailings pond seepage.

- The water supply Dam D and the Polishing Pond Dam will be breached and the areas regraded. The spillways will be buried. The impoundment areas will be amended with topsoil, as required, and revegetated.

- Industrial facilities (see Fig. 8 and Fig. 9) will be cleaned of contaminated soils and hazardous wastes prior to demolition. Demolition will be carried out with experienced personnel with specialized equipment and all material will be disposed of in the open pit or in a landfill area to be constructed within the tailings impoundment.

- The main powerline to the mine will be left in situ for the local communities. Sub-station facilities for the mine will be removed.

Figure 6. View south of open pit, along Qda Antamina valley. Note in-pit crusher.

Figure 7. View of Tailings Impoundment from diversion channel showing pond and beach with dam crest. Present Elevation: 4045 m.

Figure 8. Concentrator area.

Figure 9. Haul truck maintenance shop.

Pipeline and Port - Closure Works

- Above ground sections of the concentrate pipeline and all surface facilities, such as pump, valve, pressure monitoring, cathode protection and terminal stations, will be removed and disturbed areas will be regraded and revegetated. Buried sections of pipeline will be flushed and left in situ.
- All facilities at the Port (see Fig. 10) will be demolished, placed in a landfill and covered with soil. The reforestation project (see Fig. 11) will be decommissioned by harvesting the trees and mulching of all vegetation.

Water Quality Predictions for Closure

The East Waste Dump is located east of the pit and directly west and upslope of the tailings pond, see Fig. 2. The East Dump was the first waste dump created and by the end of 2003 it contained approximately 220 Mt of waste rock (see Fig. 12). Over the life of the mine, this dump is expected to hold 690 Mt of waste, of which 200 Mt will be clean rock and the remainder is expected to be potentially reactive waste. The "reactive" waste rock is that which will likely release heavy metals – primarily consisting of endoskarns, exoskarns, and intrusive as well as some hornfels/marble/limestone, any of which have concentrations greater than 700 ppm Zn, greater than 400 ppm As or greater than 2% sulfide sulfur.

Figure 10. Warehouse and storage area.

Figure 11. Irrigated Forest with diverse tree species.

Figure 12. View of East Dump from Engineering/Geology lot.

To evaluate the potential requirements for water treatment at closure, the existing waste dump and low grade ore stockpile seepage water quality data and the data from several on-site field bins were examined. For example, Zn concentrations from the East Dump drainage are typically in the order of 1 to 10 mg/L dissolved Zn. Table 1 summarizes the existing and expected long term water quality of the dump drainage. The paper "Waste Rock Geochemical Characterization and Water Quality Prediction at the Antamina Mine" (Brown, et al., 2006), also presented at this conference, provides details of the current water quality data. The projected values were arrived at by plotting the available data on a time series graph and extrapolating current trends, considering likely mineralogical constraints. The pH of the dump seepage is not expected to decrease below its current neutral pH range because of the abundance of reactive limestone in the dump. Similarly, Ca and SO_4^{-2} concentrations are expected to be limited by gypsum solubility and are derived primarily from dissolution of gypsum minerals in the waste rock (although limestone dissolution and SO_4^{-2} oxidation will contribute slightly to Ca and SO_4^{-2} oadings, respectively, as well). Note that several parameters, such as Cu, Mo, Ca and SO_4^{-2} are anticipated to reach or exceed their respective solubility limits at the expected neutral pH of the dump drainage, and thus, depending on reaction kinetics, may not achieve dissolved concentrations quite as high as indicated in the table. However, for treatment plant sizing and reagent costing purposes these theoretical constraints were not considered.

The future water quality of the influent as shown in Table 1 is estimated to reach metal contents that are best treated by the use of a high density sludge (HDS) process. A search of the literature and recent water treatment installation practice suggests that the most appropriate treatment is a co-precipitation circuit using $FeSO_4$ as an inexpensive source for Fe, and dry lime to provide a controlled rise in pH. A two-stage HDS process with pH maintained at pH 4 to pH 5 in the first reactor tank and raised to pH 8 to pH 8.5 in the second tank, has the capability of removing both molybdenum and Zn from neutral pH influent in the presence of the Fe^{+2} iron, O_2 and Ca. The proposed HDS process can lead to the formation of ferrimolybdates, anionic molybdate adsorbed on $Fe(OH)_3$ and calcium molybdate (powellite). Zinc is removed as the hydroxide along with the various other metal oxides and oxyhydroxides. The treatment system is sized to treat an average flow of 70 m^3/h of drainage from the East Dump. A flow equalization basin will be used to collect higher flows during the wet season and store the excess water for treatment during the early part of the dry season. Only campaigned operation of the treatment system is anticipated as seepage flows are expected to decrease during the latter part of the dry season. Approximately 125 tonnes per year of excess underflow sludge production is expected. The sludge will be stored in a portion of the tailings impoundment.

Continued monitoring of the East Dump drainage and the performance of the field bins will allow for regular updates to the predictions of post-closure water quality over the life of the mine, ensuring that the most appropriate treatment system design and capacity is selected for implementation at closure. Nevertheless, the current exercise provides a reasonable basis for advance definition of an appropriate system and cost estimate.

Table 1. Metals of Interest for Water Treatment from East Dump

Source	Waste Rock Type	- - - - - - - - - - Median Dissolved Concentrations (mg/L) - - - - - - - - - -						
		Calcium	Copper	Iron	Molyb-denum	Lead	Sulphate	Zinc
East dump seepage	Type A Intrusive and Exoskarns	450	0.03	0.01	0.02	0.03	1100	1.5
LGMG Seepage	Type A Intrusive & Exoskarns	200	0.4	0.05	0.14	0.02	370	4
Celda-04	Type A Intrusive	200	0.015	0.001	21	0.02	430	0.07
Celda -05	Type A Intrusive	380	0.016	0.001	9	0.02	850	1.0
Celda -07	Type A Endoskarn	240	0.03	0.03	45	0.02	500	0.22
Celda-16	Type A Exoskarn	600	0.019	0.009	0.12	0.02	1320	3.8
Projected*	Type A	500	5	0.01	100	0.1	1200	80

***** Projected values are current best estimates for potential drainage water quality at closure.

Land Use and Social Considerations

Land use after closure could include combinations of grazing land, forest, and lake habitat. Community involvement with the implementation of closure land use is important to ensure the sustainability of the ecological environment. For example, over-grazing could lead to erosion of the slopes, particularly on the East Waste Dump, which could lead to increased levels of water contamination. Sustainable land use of the area is a common objective for both Antamina and the community.

Social objectives of closure consider the transition of the economy of the area from a “cash” economy mixed with “subsistence” economy, with some people employed at the mine, back to a "sustainable" economy with people providing their own resources. The trained workforce at the mine will be able to move to other mining operations in Peru or worldwide.

Certain assets may have value to other parties after mine closure. For example, local communities may want to use warehouses at the mine site, mill equipment may be salvaged, or the port may be of interest to other industries. While Antamina will consider alternative uses of its facilities after operations cease, the closure cost estimate assumed that all facilities will be removed or decommissioned and the land reclaimed.

Summary

The closure of the Antamina mine will be a significant engineering and environmental program. A cost analysis of NOT designing for closure was never performed. However, the overall cost for the reclamation of the mine site, in the range of US$ 60 million (not including progressive reclamation and long term treatment costs), is low for an operation of this magnitude and reflects the benefit of designing for closure from the start. If, for example, the tailings impoundment had not been designed to provide a water cover for the potentially acid generating tailings or if a system for waste rock classification and segregation had not been developed and implemented, closure costs and long term liabilities would have been dramatically higher.

Antamina has taken a proactive approach in developing a comprehensive closure plan early on in the mine life. The plan will be regularly updated to respond to and meet the evolving legislation in Peru and to minimize the environmental liabilities to its shareholders and to the community.

Literature Cited

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