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# RUNOFF, EROSION AND SEDIMENT CONTROL IN THE PERUVIAN HIGH ANDES: THE ANTAMINA COPPER AND ZINC MINING PROJECT

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## ABSTRACT

One of the few mining mega-projects in the world today, the construction phase of the Antamina copper-zinc project was recently completed. The open pit mine and flotation concentrator produce copper, zinc and molybdenum ore concentrates from a remote site in the Peruvian Andes, some 200 km inland from the Pacific Ocean and at an elevation of 4,200 metres above sea level. The copper and zinc concentrates are delivered via a 302 km slurry pipeline to the Huarmey port site for shipment to customers worldwide. To provide access to the mine site, a 120 km road was constructed through the rugged terrain of the high Andes. This paper presents an overview of the Antamina project with emphasis given to the control of runoff, erosion and sedimentation. A case study of particular significance will be presented that describes the successful control of severe sedimentation associated with the instability of road cut and fill slopes that was affecting a pristine alpine lake and trout fishery.

## INTRODUCTION

One of the few mining mega-projects in the world today, the construction phase of the Antamina copper-zinc project was recently completed. The general location of the concentrator facility and mine site is shown in Figure 1. The open pit mine and flotation concentrator can produce up to 70,000 tonnes per day of copper, zinc and molybdenum ore concentrates from a remote site in the Peruvian Andes, some 200 km inland from the Pacific Ocean and at an elevation of 4,200 metres above sea level. The copper and zinc concentrates are delivered via a 302 km long, 350 mm diameter slurry pipeline to the port of Huarmey for dewatering, storage, handling and shipment to customers worldwide. To provide access to the mine site, a 120 km road was constructed through the rugged terrain of the high Andes.

The physical scale, geographic extent, diverse land use, climatic variability and extreme sensitivity of some ecosystems posed numerous environmental challenges and required a high standard of environmental control on the project. This paper presents an overview of the Antamina project with emphasis given to the control of runoff, erosion and sedimentation. Problems were frequently encountered in areas with limited or no heavy equipment access and required special techniques utilising hand labour and natural terrain features to achieve a satisfactory resolution with minimal impacts to the surrounding sensitive environment.

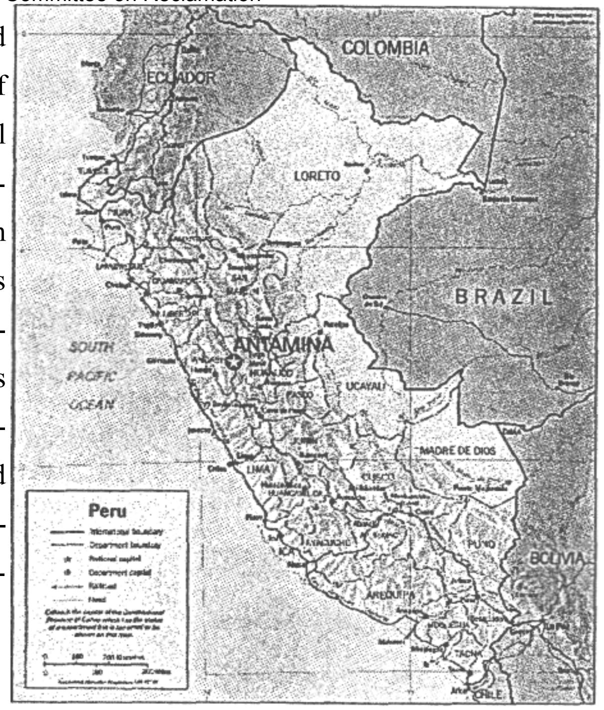



**Figure 1. Location map of the Antamina mine site.**

A case study of particular significance will be presented that describes the successful control of severe sedimentation associated with the instability of road cut and fill slopes. Laguna Canrash is a pristine alpine lake situated 4,250 metres above sea level. The surrounding land is used for livestock grazing and the lake has a significant non-indigenous trout fishery. Annual average rainfall exceeds 1,300 mm and the steep terrain generates significant volumes of runoff. In 1999, cut and fill slope stability problems on a 3 km section of road above the lake caused a plume of fine particles to enter the lake, reducing light penetration to levels that affected biomass production in the south end of the lake and threatened the trout fishery. Prompt response and implementation of an integrated and innovative system of control measures resulted in a clear bke by the following rainy season. The lake has since remained clear.

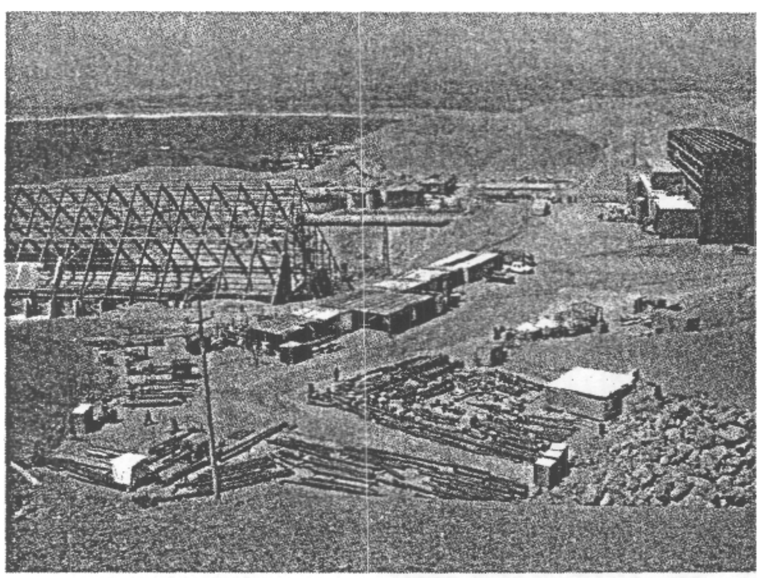
**PROJECT OVERVIEW**

Copper, zinc and molybdenum ores are extracted from the mine pit at an elevation of approximately 4,500 metres above sea level (masl). The ore goes from the pit to the primary crusher and is transported on a conveyor belt via a tunnel to the concentrator. The ore is granulated and mixed with water for transport via a 350 mm slurry pipeline for the approximately 300 km trip over the Andes to the port facility at Puerto Huarmey.

A single pumping station is needed to lift the slurry from the concentrator at elevation 4,200 masl over the 5,000 metre high point at Yanashalla in the first mountain range to the west. From there, the slurry flows under pressure due to the dropping elevation as the pipeline first traverses the Cordillera Blanco, crosses the high Sierra near Laguna Conococha, then drops 4000 metres from the Cordillera Negra down the Rio Forteleza valley towards the Pacific ocean. Four throttling stations are required to reduce the pressure in the pipeline to safe levels due to the rapidly decreasing elevation. The pipeline takes a final rise through a pass at Huaricanga before descending to the spectacular coastal sand dunes where it turns north for the final 80 km leg northwards to the port.

**Photograph 1. Overview of the mine pit area.**

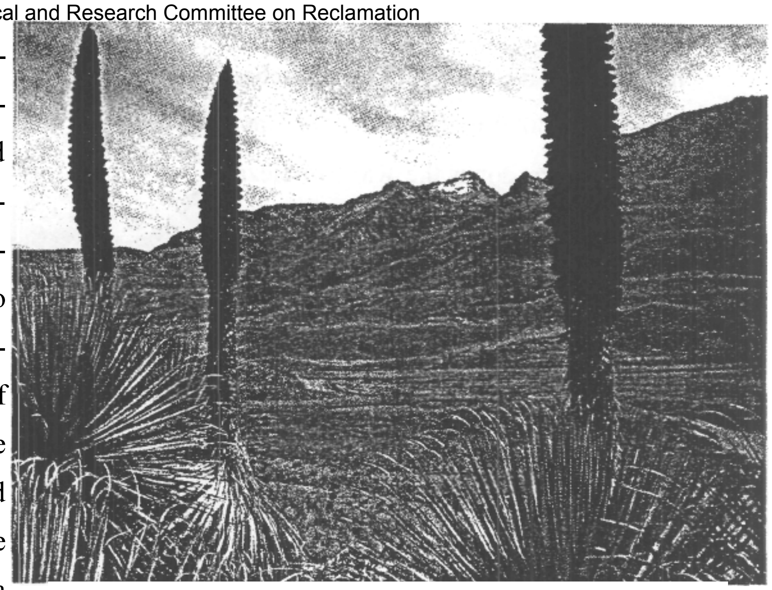
Along its route, the pipeline makes 42 iburied river and stream crossings and 5 aerial crossings. Aerial crossings were kept to a minimum for reasons of security and cost. A major constraint in the route selection and design of crossings was the 15% maximum slope criterion needed to mobilize the slurry following a pipeline shutdown. Along much of the route, the pipeline trench is earned in the public highway from Barranca to Conococha and the 120 km mine access road thereafter.



**Photograph 2. Port de-watering facility, transport conveyor and storage building.**

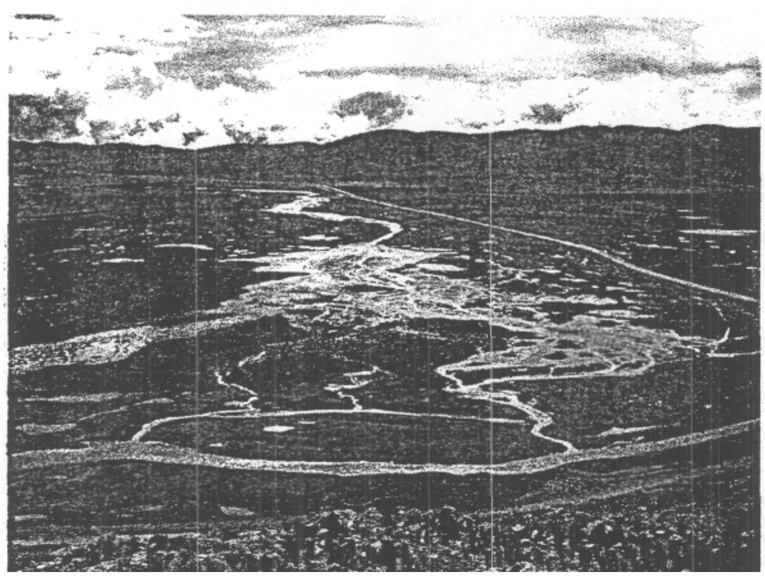
## RUNOFF, EROSION AND SEDIMENT CONTROL

Surface soils, vegetation and rainfall characteristics vary widely along the pipeline and access road route. Rainfall is infrequent in the coastal areas but has high erosion potential when it does occur. As one moves into the higher Andean regions east of the Cordillera Negra, between Laguna Conococha and the mine site, wet season precipitation increases to tropical levels, with high intensity and large volumes of daily rainfall in peak months.



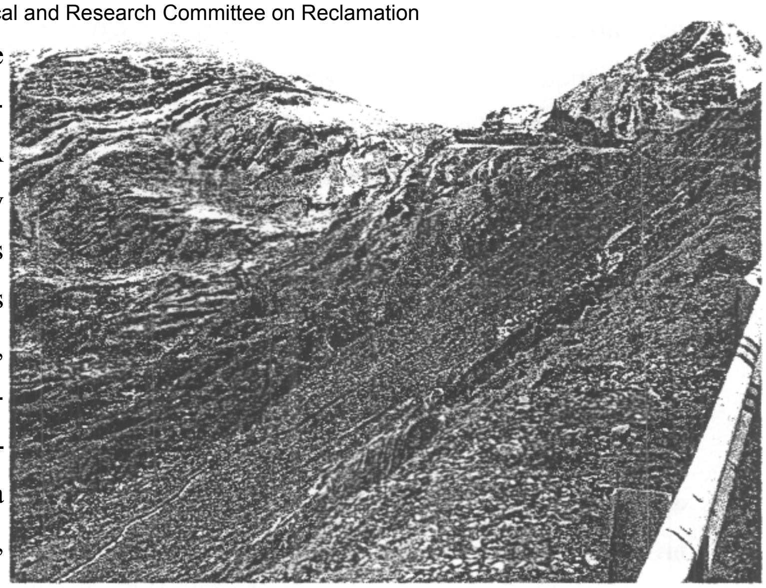
**Photograph 3. *Puya Raimonii,* a large alpine bromellidae, is abundant in southern Huascaran National Park.**

The tremendous variability in the distribution and magnitude of rainfall required careful assessment and monitoring of rainfall, runoff and erosion impacts on all aspects of the project The access; road and pipeline also traversed numerous ecologically sensitive areas, such as the southern edge of Huascaran National Park and the Conococha waterfowl and wetland area. Ensuring that the project met the required environmental standards vis a vis sedimentation from road and pipeline construction, river crossings and other activities, in both the short and long term, was achieved by designating a full-time Environmental Monitor for the project. The Monitor had responsibility for formulating a monitoring and review framework that applied to the activities of all contractors working on the project.



**Photograph 4. Sensitive wetland habitat surrounding the mine access road and pipeline corridor at Laguna Conococha.**

The Monitor identified all activities on the: project that were expected to have significant sedimentation impacts and provided a guideline for contractors to prepare Sediment Control Plans (SCPs) for these activities in advance of beginning construction work. Contractors were required to formulate and submit for review by the Monitor a complete SCP for those activities designated as potentially posing high or moderate sedimentation impacts on surface waters. The Monitor was also responsible for inspecting operations in the field to ensure that activities were being conducted in accordance with the SCP, and where variances with the approved plan were made, that these changes did not reduce the effectiveness of the Sediment Control Plan. A post-mortem review of each activity and the effectiveness of the SCP was conducted so that subsequent SCPs would be even more effective. SCPs, field inspection records and post-mortems were kept on file for project documentation. The strategy of using a dedicated Sediment Control Monitor, reporting directly to the top-level manager of the Projects group, proved to be very effective in achieving the environmental standards established for the construction phase of the project.



**Photograph 5. Steep road slopes above Laguna Canrash.**

Long-term controls for run-off, drainage, erosion and sediment control were required at numerous locations to solve a variety of problems. While many of these activities were straightforward, others required innovative approaches to meet the project sediment control criteria. A particular example involving the development of a variety of sediment control strategies, including two sets of large settling ponds, at Laguna Canrash is described next.

## SEDIMENT CONTROL FACILITIES AT LAGUNA CANRASH

Access to the mine site during the construction and production phases of the mine is along existing highways, including the Pan-American and Highway 2-14 from Pativilca to Huaraz. A new mine access road approximately 118 km in length has been constructed from Laguna Conococha through the rugged terrain of the high Andes to the mine site.

Several difficult sections of the road exist at various locations along the route and have been problematic with respect to construction and stability. One of these sections occurs between Km 87+500 and 89+700 (mine access road distances are measured from L. Conococha) and lies on a steep mountainside above Laguna Canrash as shown in Photograph 5. During construction of this road segment, excavated material was sidecast downslope of the extensive, steep cuts required along this portion of the road.

In addition, during the rainy season of 1999-2000, two slump failures occurred on the slopes above the road cut, contributing additional loose material to that already exposed on the cut and sidecast fill slopes and increasing further the availability of particulates that could be eroded by rainfall and surface water runoff, Slope and road drainage at the time was provisional at best and considerable eroded material was transported from the slope above the road cut into the outlet stream of the lake.

Moreover, some: cross drainage structures brought runoff and eroded material from upslope side of the road down into the drainage areas below the road where it entered the lake directly. Material on the sidecast slopes below the road was also severely eroded and considerable sediment was introduced to the lake, particularly at the south end where the proportion of silt and red clay fines in the exposed soil of the slope is highest. Soil samples were taken from this area and particle gradations obtained. The contractor acted quickly to implement a wide variety of sediment control measures, including lined crown and ditch drains, a roadside berm, rock fences and check structures, sediment traps, silt fencing and mulching. While the impact of the soil erosion was reduced by these measures, the sediment control provided by the various structures was generally not adequate to control the ongoing erosion and sedimentation of both the Laguna Canrash and its outlet stream. A significant plume of reddish fines developed in the south end of the lake and persisted throughout most of the following dry season.

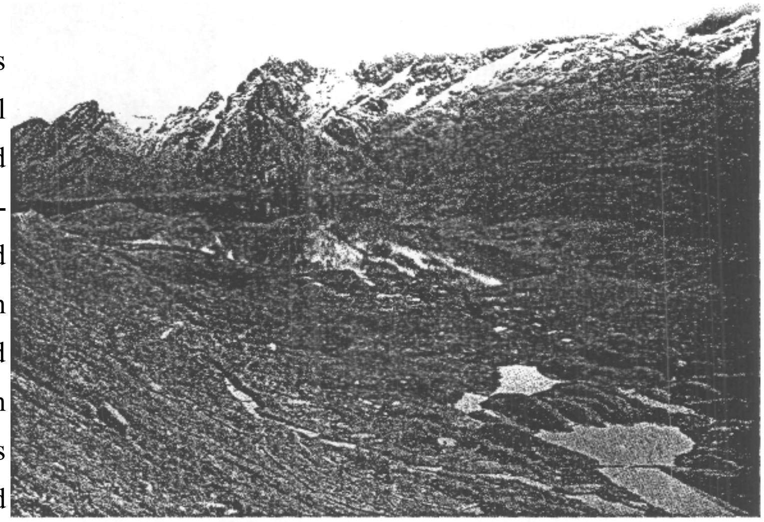
## SEDIMENT CONTROL CRITERIA

The sediment control criterion for the project was set at a maximum total suspended solids (TSS) concentration in effluent flows of 50 mg/L. Temporary sediment control facilities were designed to handle the 2-yr, 24-hr storm, while permanent facilities (i.e., those expected to be in service more than 5 years) would be designed to handle sediment inputs for the 10-yr, 24-hr storm and a maximum flow equal to the 100-yr runoff.

A thorough analysis of the regional hydrology and erosion characteristics was carried out to provide a basis for a rational design of sedimentation ponds at two locations; Km 87 and Km 89. The analysis included watershed hydrology, soil erosion, flow routing and sediment transport as well as sediment removal utilizing various control options. The performance of sediment control strategies considered the present condition of the mine access road and disturbed areas adjacent to Laguna Canrash, the short term changes in source erosion control, the long term condition of a stabilized road and reclamation of disturbed areas, and the use of engineered sedimentation ponds. In this way, proposed sediment control facilities were evaluated using the long-term design criteria, but their performance was also weighed against the short-term risks of violating the design criteria during the time needed to successfully revegetate, stabilise or provide other permanent cover to disturbed areas.

SEDIMENT PONDS AT KM 87

Control objectives at the Km 87 ponds included capture of all eroded material on the sidecast slopes below the road cut. A long interception trench was constructed parallel to the road and routed sediment laden runoff to the upstream end of a series of sediment traps and ponds. Clean water intercepted from natural slopes above the road cut was intercepted by lined crown ditches and brought downslope in a number of plastic pipes and staircase spillways. These "jump" the lower interception trench and convey water directly to the effluent channel of the lower ponds.



**Photograph 6. View of Laguna Canrash in March 2001 showing Km 87 sediment control facilities. Note covered and partially revegetated sidecast slope, interception trenches, rock walls, sediment traps and sediment ponds.**

Due to the soft foundation material, rocky topography and steep side slopes above the lower ponds, the sedimentation control facilities had to be constructed by hand, largely using materials at hand. Trenches and channels, sediment traps and contour "walls" were all constructed using rock readily available on site. The Peruvian workers were extremely skilled at constructing this type of facility as it is a traditional techniques used for clearing pastures and crop fields. Outcrops of conglomerate provided "natural" pools that needed only some sandbag berms to create sediment ponds. Large amounts of sand had already been collected in the numerous small sediment traps in the area and this provided ample material for filling the required sandbags. Decant weirs for the ponds were similarly formed used sandbagged material. A coagulant and flocculent system was also implemented to aid in precipitating fine sediment particles in the largest pond.

An interesting phenomenon occurred towards the end of the dry season of 2001. Warm and sunny days led to the development of two algal blooms in the lake. The residual sediment particles in the water column appear to have "precipitated" along with the dying algal cells. By the end of the dry season, the lake had virtually returned to its former levels of very low turbidity. It may be that the algal cells were "electrostatically" charged and clay particles could have adhered to these in much the same way as they would to a flocculent/coagulant treatment.

In the wet season of 2001, no sediment plume was visible in the lake and turbidity measurements showed only slightly elevated levels of TSS in the south end of the lake, indicating that the ponds were effectively removing sediment from the runoff to the lake. This is evident from the difference in water colour between the ponds and the lake seen in Photograph 6 (previous page).

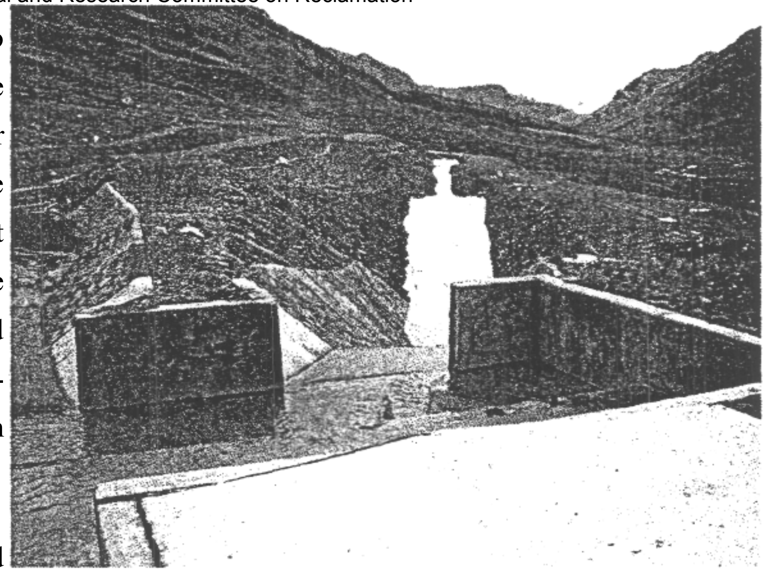
**Photograph 7. Inlet channel, mixing and distribution chamber, and parallel terraced ponds at Km 89.**

SEDIMENT PONDS AT KM 89

Rainfall runoff and eroded sediment from the cutslope above the road alignment is collected in a large road side ditch. This sediment laden water is conveyed to the low point of the road adjacent to the lake outlet stream. Limited land availability, steep topography and high design flow rates were significant constraints in designing the sediment control facilities at this location. Time factors also played a role in adopting a staged implementation of sedimentation ponds at his location. The negotiations with local land owners for land acquisition were protracted with the result that little time was available for design and construction of permanent sedimentation ponds.

Based on an anticipated agreement for a small, elongated parcel of land, the contractor prepared drawings for a set of long parallel temporary ponds. Due to the sloping nature of the site, terraced ponds in series were used to minimise excavation for the temporary ponds, allowing rapid construction of the facilities. Although undersized for the 10-yr, 24-hr storm loadings, these temporary ponds were suitable for the 2-yr, 24-hr loading. Hence, the probability of exceeding the effluent TSS criterion was 50% over the course of the 2001 rainy season. However, even if this occurred, it would constitute a violation of the discharge criterion with a temporary diminution in stream water quality but would not likely create an an environmental disaster.

Use of the temporary ponds and acceptance: of a known and limited short-term risk of sediment criterion violation allowed adequate time for the development of an efficient and cost-effective design for the permanent sediment control facility. It also allowed the opportunity to collect data for one rainy season that could be used to refine the design basis for the permanent structures.



Photograph 8. Km 89 sedimentation ponds in operation during rainy season.

A coagulant/flocculent system was also employed at these ponds to remove the fine sediment particles. Performance for the 2001 rainy season was adequate with effluent criteria being met except for one short period in mid-March. The violation occurred as a result of rapid filling of the ponds with sediment following a small mass wasting episode on the road cutslope.

Review of the design parameters based on rainfall and pond performance data is being carried out. Re-design and upgrading of the pond capacity will soon be completed for construction of the permanent sedimentation pond facility this dry season.

**LESSONS LEARNED**

1. Rainfall runoff, soil erosion, drainage and sediment control are essential components of most mine development projects. These factors can significantly influence slope stability and surface water quality. Hazards and environmental impacts associated with erosion and mass wasting and the resultant sedimentation problems can be largely avoided or mitigated through integrated planning of drainage and sedimentation control at the conceptual stage of a project.

2. During the construction phase, monitoring of contractors work by the owners is essential to meeting the project environmental standards. This is best accomplished through the use of independent review or by establishing a dedicated Monitor position for runoff, erosion and sediment control reporting to the highest management level of the owners' Projects group.

3. Local skill sets and materials available often dictate the most effective strategy and facilities for runoff, erosion and sediment control.