DEVELOPMENT OF REHABILITATION PLANS FOR ACID ROCK DRAINAGE CONTROL AT TWO CLOSED UNDERGROUND MINES

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ABSTRACT

Underground mines have long been recognized as sources of acid rock drainage (ARD). Point discharge of low pH and metal laden solutions occurs at portals and shafts. Rehabilitation is often required to mitigate the chronic long-term effects of ARD from underground mines. This paper presents the methodology used in the development of rehabilitation plans for ARD control for two closed underground mines in B.C., namely the Tulsequah Chief Mine and the Baker Mine. Factors that influence the rehabilitation options for a given site are discussed. A brief summary of the conditions observed at the two mine sites and the proposed rehabilitation plans are presented. Control of ARD from underground mines may be achieved by flooding the mine through the construction of concrete bulkheads.

Key Words: acid drainage, site assessment, decommissioning, underground mine

INTRODUCTION

Underground mines have long been recognized as sources of acid rock drainage (ARD). Point discharge of low pH and metal laden solutions occurs at portals and shafts. Where such ARD has developed it can continue for an extended period of time, such as at the Britannia Mine in B. C. where ARD has occurred since the start of mining about 90 years ago (SRK et al., 1991a). Acid generating materials at these mines can include: waste rock, in situ and broken ore, and backfill material such as waste rock or tailings. Generally, for underground mines most of these materials are within the workings and only a little is on surface.

One might classify underground mines simply as either shaft mines or adit mines. Shaft mines are located entirely below the regional topographic low points. These mines nearly always flood naturally upon closure and, except for flushing of stored oxidation products, do not pose a long-term environmental liability. Adit mines, on the other hand, are located, at least in part, above the topographic low points and do not flood naturally upon closure. Any surface or groundwater that enters the mine will flush some of the oxidation products out of the lower adits. Only adit type mines are addressed here.

This paper presents the methodology used in development of rehabilitation plans for ARD control for two closed underground mines in B.C., namely the Tulsequah Chief Mine and the Baker Mine. Examination of the tailings at these mines was not required. Factors that influence the rehabilitation options will be discussed. Six steps for rehabilitation plans are detailed. Conditions observed at the two mine sites and the proposed rehabilitation plans are summarized.

Underground mines are often amenable to relatively inexpensive control of ARD when compared with tailings or waste rock piles. This is achieved by flooding the mine workings to reduce further oxidation to the extent practicable. The flooding is facilitated through the construction of bulkheads or plugs in the adits and other openings to surface. This approach is proposed for the Tulsequah Chief and Baker mines. It has been employed at the Skorovas Mine in Norway (Liseth, 1991), the Beth Energy Mine 105W in West Virginia (Hause 1986).

FACTORS INFLUENCING REHABILITATION OPTIONS

Ten factors influence the rehabilitation options for control of ARD from underground mines.

1 Geology and Geochemistry

The potential for acid generation and neutralization is a function of the geology and geochemistry of the mine materials. Methods for characterizing the acid generation and neutralization potential of mined materials are described in detail in SRK 1992a.

2 Mine Geometry and Mining Method

The mine geometry and mining method influence the quantity and distribution of exposed acid generating and neutralizing materials. Mine geometry includes orientation, position and interconnections of the mine workings. Any raises to surface, drill holes or areas of subsidence will influence the water flow through the mine and may limit the effectiveness of flooding as a control option. The mining method is a key factor because of the amount of acid generating material which may be distributed throughout the mine. Mines where open sloping or caving methods were used or where backfilling with waste rock or tailings was practiced may have a significant storage of oxidation products which could be mobilized upon flooding. In addition, pathways for the flow of water into and out of the mine are controlled by the mine geometry and geology.

3 Regional Hydrology

The regional hydrology and climatic conditions influence the seasonal variations in the volume of water flowing into the mine, as well as any seasonal fluctuation in the flooding level. Most importantly, the hydrology controls the volume of water in the receiving environment and the amount of dilution which is available to mitigate the ARD.

4 Background Water Quality

Background water quality is the upstream or pre-mining water quality in the water courses at the mine site. Where the situation involves a closed mine to be rehabilitated the pre-mining water quality is likely to consist of one or two samples, at best. Therefore, upstream water quality is usually used to evaluate the incremental impact of the mine ARD on the receiving environment water quality. Upstream water quality may also be used as a scale against which the effectiveness of the rehabilitation measures are evaluated.

5 Site Hydrogeology

The site hydrogeology influences the volume and routing of groundwater flowing into the mine. It will have a similar effect on the balance of inflows and outflows if the mine is flooded. Even in a mine environment where the rocks are potentially acid generating it is common to find that the groundwater is somewhat alkaline and is providing some mitigation to the ARD.

6 Environmental Impact

The level of environmental impact is usually evaluated relative to the water quality guidelines published by the Canadian Council of Ministers of the Environment (CCREM), Metal Mining Liquid Effluent Regulations and Guidelines and applicable provincial standards. The impact may also be evaluated in terms of loss of fisheries resources, wetland area or other criteria.

7 Rehabilitation Objectives

The main objective is the reduction of environmental impact, which may be defined as a water quality criteria, a reduction in metals release from the site, or return to biological productivity of a section of the receiving environment. Additional rehabilitation objectives which may need to be considered are the public health and safety aspects of the site and land use considerations. The level of ongoing maintenance or activity at the site can range from walk-away rehabilitation to ongoing intervention or active care, such as water treatment. These aspects of rehabilitation objectives are discussed in Brodie et al, 1992. Corporate considerations such as long-term liability, corporate policy, and public image may influence the development of rehabilitation plans. Legal action by a government agency may dictate the extent of rehabilitation.

8 Timing

Timing for the implementation of rehabilitation measures may also influence the development of the plan. Arresting a worsening condition may take priority over conducting detailed environmental impact studies. Timing of the rehabilitation work must also consider the practical working season at the mine site.

9 Location

Remoteness of a site and its accessibility is a factor.

10 Cost

The cost of any rehabilitation plan must be seen in the context of benefit for the expenses incurred. At most sites, increasing rehabilitation effort, and hence cost, will generally result in further reduction of environmental impact. Generally, walk-away or passive care control systems are the primary objectives in the development of rehabilitation plans. As such these plans tend to evolve around source control measures, generally exclusion of oxygen, and migration control, such as infiltration barriers. The third option, collect and treat, may be the most costly and is generally applied only as a last resort. The high cost arises from the funding required to provide perpetual treatment.

DEVELOPMENT OF REHABILITATION PLANS - GENERAL APPROACH

The six main steps in the development of rehabilitation plans for ARD control are: data collection, contaminant release characterization and quantification (i.e. inventory of sources), identification of practicable rehabilitation options, selection of the best rehabilitation option, development of a monitoring program, and, cost estimating and scheduling. Each of these steps is described in more detail below.

Data Collection

The ultimate success of the rehabilitation measures depends greatly on the quality of the data used in the development of the rehabilitation plan. It is essential to address the compromise between developing a highly dependable data base and the number of years of ongoing environmental impact it will take to develop such a data base. A judgmental decision of the required data collection effort considering the potential rehabilitation options, based on a cursory overview and the level of environmental impact, may be required.

There are generally two phases to data collection: compilation of existing data and a site investigation. Existing data may be obtained from a number of sources including: mine exploration, permitting and operating records, monitoring data from mine or government files, government permits and orders, government files for topographic and hydrologic data, and consultation with personnel from the operating period of the mine, if they are available.

A site investigation may range from a one or two day inspection and sampling to a long term monitoring program. In the case of an underground mine, the former is more likely because the situation is less complex than a site with significant and diffuse ARD sources such as tailings or numerous waste rock piles. If a one or two day site investigation is conducted then, ideally, it should be timed to coincide with a period of peak flushing of stored ARD products. Typically this is the spring freshet. This type of site investigation and sampling will yield only an instantaneous picture of the site conditions with respect to water quality. Modelling will be required to develop an understanding of the annual cumulative metal release and the seasonal variations there of.

Data to be collected during the site investigation should include, at least: water and rock sampling, examination of the site topography, hydrology and mine geometry; and most importantly, a preliminary assessment of the practicality of implementing rehabilitation alternatives. Water quality samples should be collected from upstream of the site, all discharging portals, downstream of the site, and, if safe and practicable, within the mine at the intersections of the main flows. Water quality sampling protocol is described in SRK 1992a. A measurement of the volume of flowing water should be made at each water quality sampling location and any accumulation of precipitates should be noted.

Contaminant Release Characterization

The second step in developing a rehabilitation plan is characterization of the contaminant release. This consists of two parts; i) instantaneous site load assessment, and, ii) cumulative annual load assessment.

i) *Instantaneous Site Load Assessment*

The objective of the instantaneous load assessment is to provide a mechanism to rank the various sources according to their contribution to the overall site load. Ranking of the sources provides direction in the rehabilitation plan as to which sources should be addressed.

ii) *Cumulative Annual Load Assessment*

The cumulative annual load assessment is completed on the basis of historical data. These data are often sketchy at best, and modelling based on the instantaneous load data may be required. The objective of the cumulative annual load assessment is threefold; it aids the ranking of sources, provides an indication of seasonal impact, and is used in assessing the effectiveness of rehabilitation options.

Identification of Practicable Rehabilitation Options

The identification of practicable rehabilitation options needs to consider both the underground mine itself and any waste rock on surface.

i) *Underground Mine*

As described above, the main rehabilitation option, aside from "do nothing", to control ARD in an underground mine is source control by flooding to prevent further oxidation. This option is favored because preventing further oxidation with a water cover is a proven approach and can provide a walk-away solution. Three factors to be addressed in flooding an underground mine are: water balance; rate of flushing of stored oxidation products; and rock mass integrity at the proposed bulkhead locations and elsewhere in the mine. The water balance is key to the long term effectiveness of the plan because in virtually all cases there will be a seasonal fluctuation in the water level in the mine. At some sites where the seasonal fluctuations are extreme or loss of mine water by groundwater pathways is excessive, it may be beneficial to direct surface runoff into the mine so as to maintain the highest possible water level at all times.

Flooding an underground mine will result in dissolution of oxidation products which have not been flushed out. An estimate of the water quality in a flooded mine can be made by leach extraction testing of samples of broken ore or backfill. It is likely that the quality of the water in the mine immediately after flooding will be as poor as, or worse than, the existing portal discharge.

It is important to recognize that flooding an underground mine will not create a stagnant water body. Water will flow out of the mine as groundwater, and at times when there is a surplus by either overtopping flow via openings to surface or flow-through discharge via a pressure regulating value at a bulkhead. Overtopping flow occurs where any surplus water leaves by overflowing near the top of flood level in the mine. The main advantage of this condition is that the poorest quality water will sink to the bottom of the mine, due to its density, and better quality water will discharge from the top. The poorer quality water will discharge relatively slowly into groundwater thus allowing greater dilution in receiving waters. If there is oxidation above the flood level then diffuse and un-regulated discharge of poor quality water will result. Overtopping flow may be applied where seasonal variation in the flooding level is minimal, the overall integrity of the mine is high and the relative exposure of rock above the flooding level is minimal.

In the case of flow-through water control, essentially all of the oxidation products in the mine will be flushed out as soon as the mine has flooded. The main advantage of this method is that the discharge is regulated for easy routing to a water treatment facility. This would be desirable in cases where it is not possible to flood all of the mine. Flow-through control may be beneficial at sites where infiltrating alkaline groundwater provides neutralization to counteract continued oxidation of rock above the flood level or as a result of high seasonal fluctuation in the level.

Other options for ARD control in underground mines include: limiting airflow (for oxygen depletion) and passive or active treatment of the discharge. Limiting air flow as an ARD control measure requires that there is essentially no air movement and replenishment of oxygen. In tailings and waste rock applications this has been found to be difficult to achieve. We believe that a similar level of difficulty exists for most underground mines because of the effects of subsidence, openings to surface, and numerous exploration drill holes.

Passive treatment options include in situ sulphate reducing bacteria, wetlands, alkaline trenches, or a combination. Active treatment options may require a collection and treatment system or batch addition of an alkaline material to the mine. These methods for control of ARD are discussed further in SRK et al. 1989.

In cases where it is expected that very poor quality water could be released upon flooding of the mine some type of concurrent or pre-treatment may be warranted. Addition of limestone prior to flooding, or alkaline addition during flooding are options. Addition of milk of lime is likely to yield low effectiveness of the lime because the slurried (particulate) lime would be armored through the formation of iron hydroxides, thus preventing further chemical reaction. Soda ash may yield better efficiency due to its high solubility, but is significantly more costly.

ii) *Surface Rock*

The options for ARD control from surface rock have been discussed in SRK et al. 1989 and are only identified here. Aside from the do nothing option, the rehabilitation options for waste rock are: underwater disposal, consolidate and cover, addition and blending of alkaline material, passive treatment using wetlands or an alkaline trench, or collection and treatment.

SELECTION OF BEST REHABILITATION OPTION

In a rigorous evaluation this step consist of five phases: impact assessment of the practicable options, rough cost/benefit analysis, risk assessment, ranking of options, and selection of the best option. Site conditions may limit the practicable rehabilitation options to only one or two, such that the identification of the best option may become straight-forward.

As described previously, the cumulative annual load assessment is typically used to assess the incremental source-load contribution to the receiving water quality. Decreases in the source-load contribution are assessed on the basis of the source control option. For example, for an underground mine the efficiency would be assessed on the level of flooding that may be achieved, the portion of broken rock and exposure to flushing that remains above the flood level, and the level control option applied, (i.e. flowthrough vs. overtopping)

A rough cost/benefit analysis is conducted to eliminate those options which are either too costly or for which there is a less costly alternative which yields comparable benefits.

Some risk evaluation of the potential plan should be conducted because, unlike the design of a new facility where information is collected to answer most questions, the development of a rehabilitation plan for a closed underground mine will probably be based on an incomplete data base. Consequently, there will be an element of uncertainty regarding the proposed plan and it should be evaluated in light of the consequences of not meeting the rehabilitation objectives.

Once the various rehabilitation options have been assessed for environmental impact, cost/benefit, and risk, then they should be ranked in terms of these factors. The option with the most favorable ranking is then selected for detailed cost estimating and scheduling.

MONITORING PROGRAM

A monitoring program should be developed so that the effectiveness of the rehabilitation measures can be assessed. Components of the monitoring program may include: water level monitoring in the flooded mine, water quality sampling upstream and downstream of the mine plus any mine discharge. Flow measurements should be made with all water quality samples.

COST ESTIMATING AND SCHEDULING

A detailed cost estimate should be prepared for the selected option. Items which should be included in the cost estimate are: bulkhead construction, grouting, waste rock rehabilitation, mine water discharge system, surface water control measures such as ditches, mobilization, engineering and quality control/quality assurance, and monitoring. There may be little or no infrastructure to support the mine rehabilitation effort at a closed mine. Consequently, mobilization costs may be high. We suggest that costs from similar operations be used or a contractor consulted to develop the cost estimate. In cases where the regulatory agencies are seeking financial assurance that the proposed work will be carried out it may be necessary to develop all of the cost estimate using third party or contractor costs. Finally, considering that the rehabilitation plan may have been developed from a less than ideal data base and that some uncertainty will exist regarding the site conditions, we suggest that a contingency of 30% be added to the cost estimate.

A schedule should be developed for implementation of the rehabilitation work. Ideally, the work should be conducted in one or two sessions to keep mobilization costs down. The timing of the monitoring program should be included in the schedule.

CASE HISTORIES

A summary of the work is conducted for two underground mines in B.C., namely the Tulsequah Chief Mine and the Baker Mine, is presented here. This information is extracted from SRK 1992b and SRK 1992c.

Tulsequah Chief Mine

The Tulsequah Chief Mine is a former underground base and precious metals operation. It is located on the east bank of the Tulsequah River approximately 97 km southwest of Atlin, B.C. The site is remote and access is generally by helicopter. There are no roads to the site.

The mine was operated by Cominco Ltd. between 1951 and 1957. Approximately 600,000 tonnes of massive sulphide ore, containing copper, lead, zinc, gold and silver, was mined by shrinkage and open sloping. An interpretive cross section of the underground mine is shown on Figure 1.

Water from the rock piles and underground mine is contaminated by ARD and drains into the Tulsequah River. Copper is the primary metal of concern at the site. The summary of estimated annual dissolved metal loads released from the site is presented in Table 1. An estimated 83 % of the copper released from the site is generated by the underground mine workings and discharged via the 5200 and 5400 Portals. The mine rock piles produce 17 % of the total annual load.

The selected rehabilitation measure for the underground mine is flooding. This will be achieved by constructing concrete bulkheads in the 5200, 5400, and 5900 portals. It is expected to yield an 80% reduction in copper discharge from the mine. Because of groundwater pathways and drill hole intersections, the mine cannot be flooded to the top. At this time it has not been decided whether the mine will be flooded for flow-through or overtopping flow.

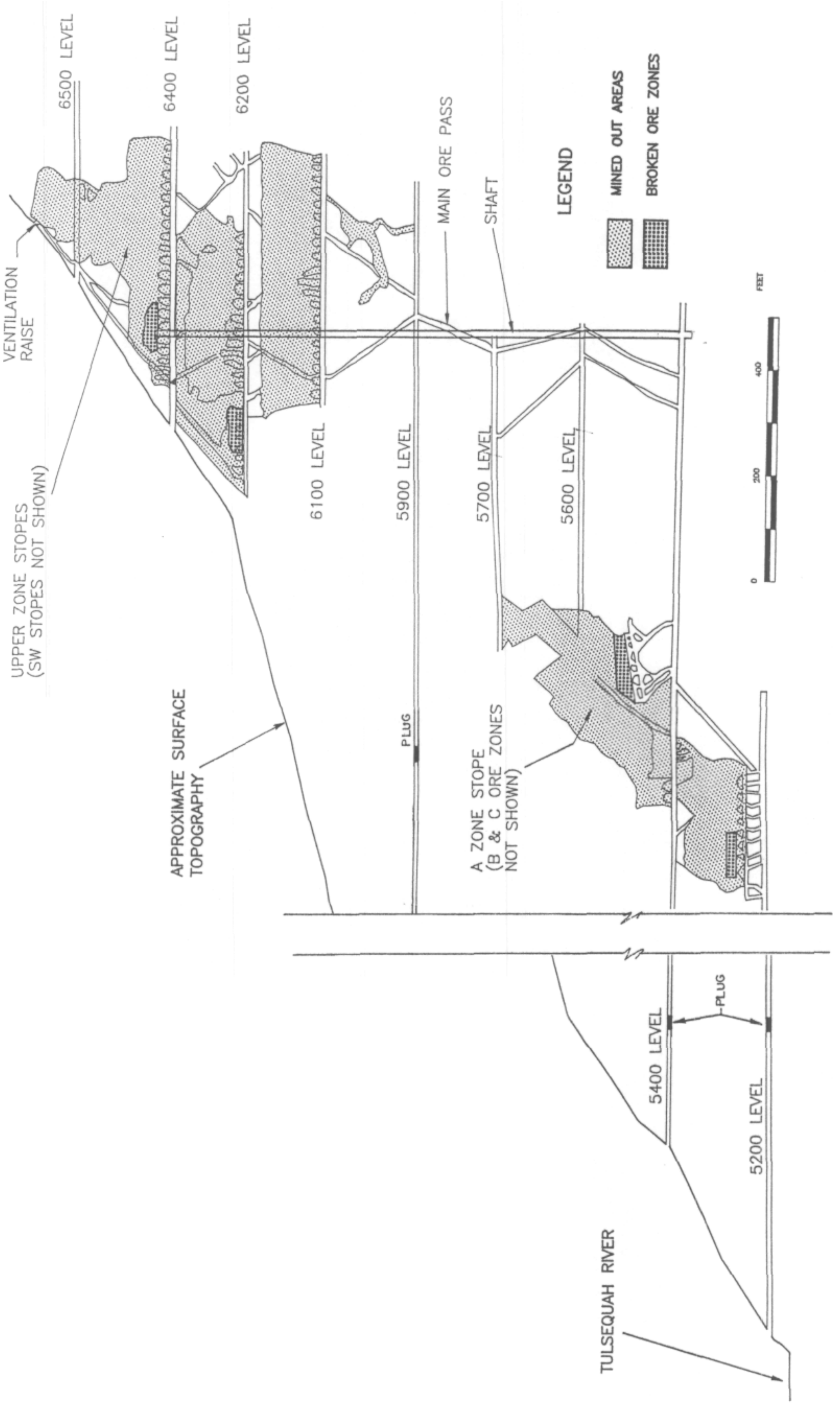
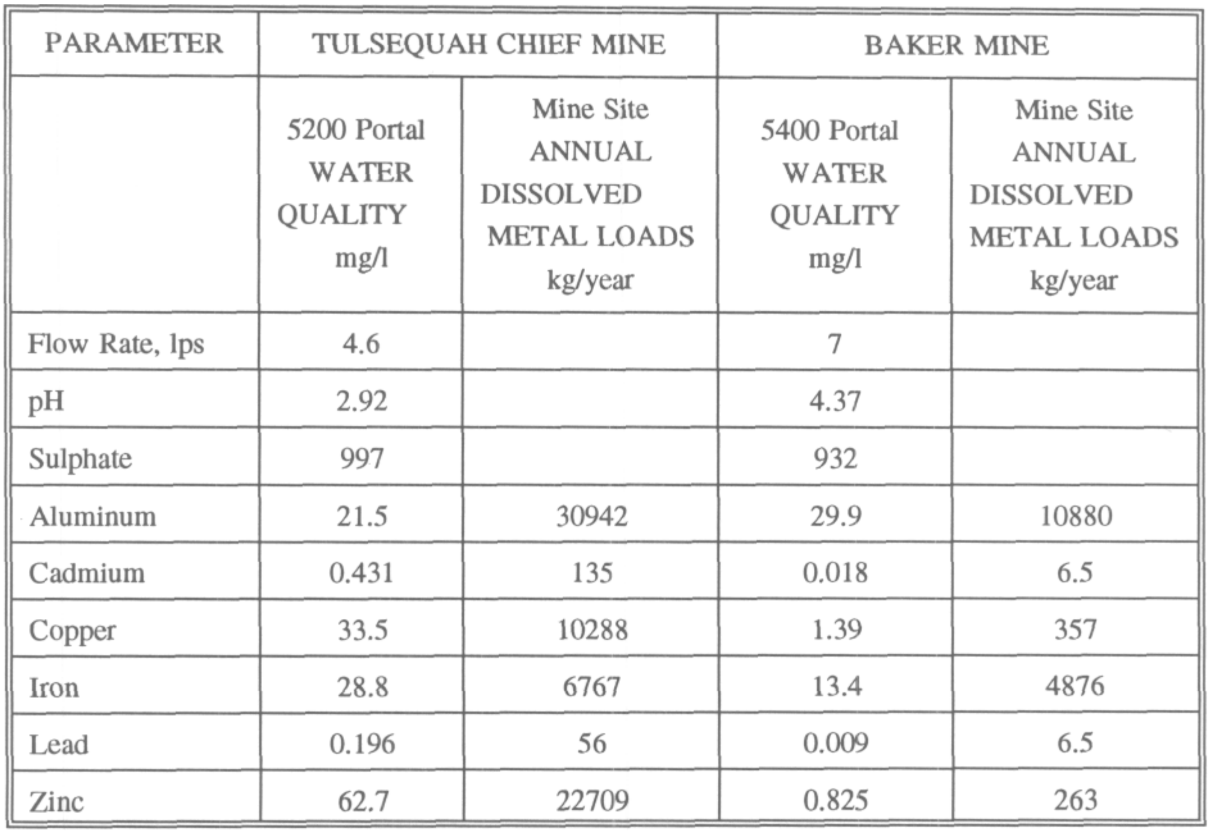


FIGURE 1 SECTION OF TULSEQUAH CHIEF MINE

About 1.5% of the copper load from the site to the environment is produced from the mine rock located at the upper portals. Rehabilitation measures for the ARD load from these sources are not considered to be cost effective because these rock piles are difficult to access.

Table 1 Summary of Estimated Annual Dissolved Metals Loads



PARAMETER	TULSEQUAH CHIEF MINE		BAKER MINE	
	5200 Portal WATER QUALITY mg/l	Mine Site ANNUAL DISSOLVED METAL LOADS kg/year	5400 Portal WATER QUALITY mg/l	Mine Site ANNUAL DISSOLVED METAL LOADS kg/year
Flow Rate, lps	4.6		7	
pH	2.92		4.37	
Sulphate	997		932	
Aluminum	21.5	30942	29.9	10880
Cadmium	0.431	135	0.018	6.5
Copper	33.5	10288	1.39	357
Iron	28.8	6767	13.4	4876
Lead	0.196	56	0.009	6.5
Zinc	62.7	22709	0.825	263

The selected rehabilitation measure for the waste rock at the lower portals is consolidation and covering with a 60 mil HDPE liner. This arrangement will be similar to that used at the Kj01i mine rock pile remediation in Norway (SRK, 1991b). These measures are expected to yield up to a 90 - 95% reduction in copper load from the covered mine rock, which combined with the flooding of the underground mine is expected to reduce the total site release of copper by 70 - 80%.

Ongoing monitoring has been conducted at this site since the site visit. This data compares reasonably well with the predicted seasonal variations in water quality which were developed from the instantaneous load calculation.

Baker Mine

The Baker Mine is a former underground and open pit gold mine. It was operated by Du Pont Explorations Ltd. for 31 months in the early 1980's and produced about 66,000 tonnes of ore. The mine is located about 270 kilometers north of Smithers B.C. in a remote sub-alpine setting. Drainage water from the underground mine is contaminated by ARD, and drains into Galen Creek via Adit Creek.

Upon commencement of operations in 1980, mining activity was by open pit. Subsequently, underground mining by cut and fill sloping was carried out, and waste rock from the open pit was used for fill. The underground development was accessed by two portals. A long section of the mine showing mined out areas is shown in Figure 2.

It is estimated that about 34,000 tonnes of waste rock are located on surface and 48,000 tonnes of waste rock are in the mine backfill. All of the rock types on sites are potentially acid generating. The neutralization potential of the mine rock is comparatively small and has been consumed for the more oxidized materials.

Water enters the underground mine in two ways: surface runoff which enters the pit and drains through the collapsed crown pillar in the pit bottom, and groundwater flow which enters through fractures in the rock and exploration drill holes.

The mine discharge water quality and flow data are summarized in Table 1. At the time of the site visit, no surface runoff was observed from the rock piles or within the pit. The analysis for the copper load distribution indicates that the majority of the copper present in Galen Creek from October to April is generated by the underground mine. Approximately 80% of the annual copper load in Galen Creek is produced from the mine, 15% is produced by the surface rock and 5% is from Adit Creek upstream of the mine.

Based on the site assessment, it was concluded that: the primary objective for remediation should be a reduction in the load generated by the underground mine. This is to be achieved by flooding the mine with the construction of a concrete bulkhead in each of the adits. In addition, about 3000 tonnes of low grade ore will be placed back in the mine before the bulkheads are constructed.

In the long term, assuming that water will flow into the mine from the pit as well as from groundwater recharge, and discharge via groundwater flow and/or leakage to surface water, all loads generated within the pit catchment should pass through the underground mine. Thus, while the contaminant loads originating within the underground mine will essentially be eliminated, some ongoing acid generation would occur. Based on our assessment of the underground mine, it is anticipated that in the long-term a reduction of between 60 and 70% in the acid generation and metal load presently discharged from the underground mine may be achieved through implementation of the rehabilitation plan.

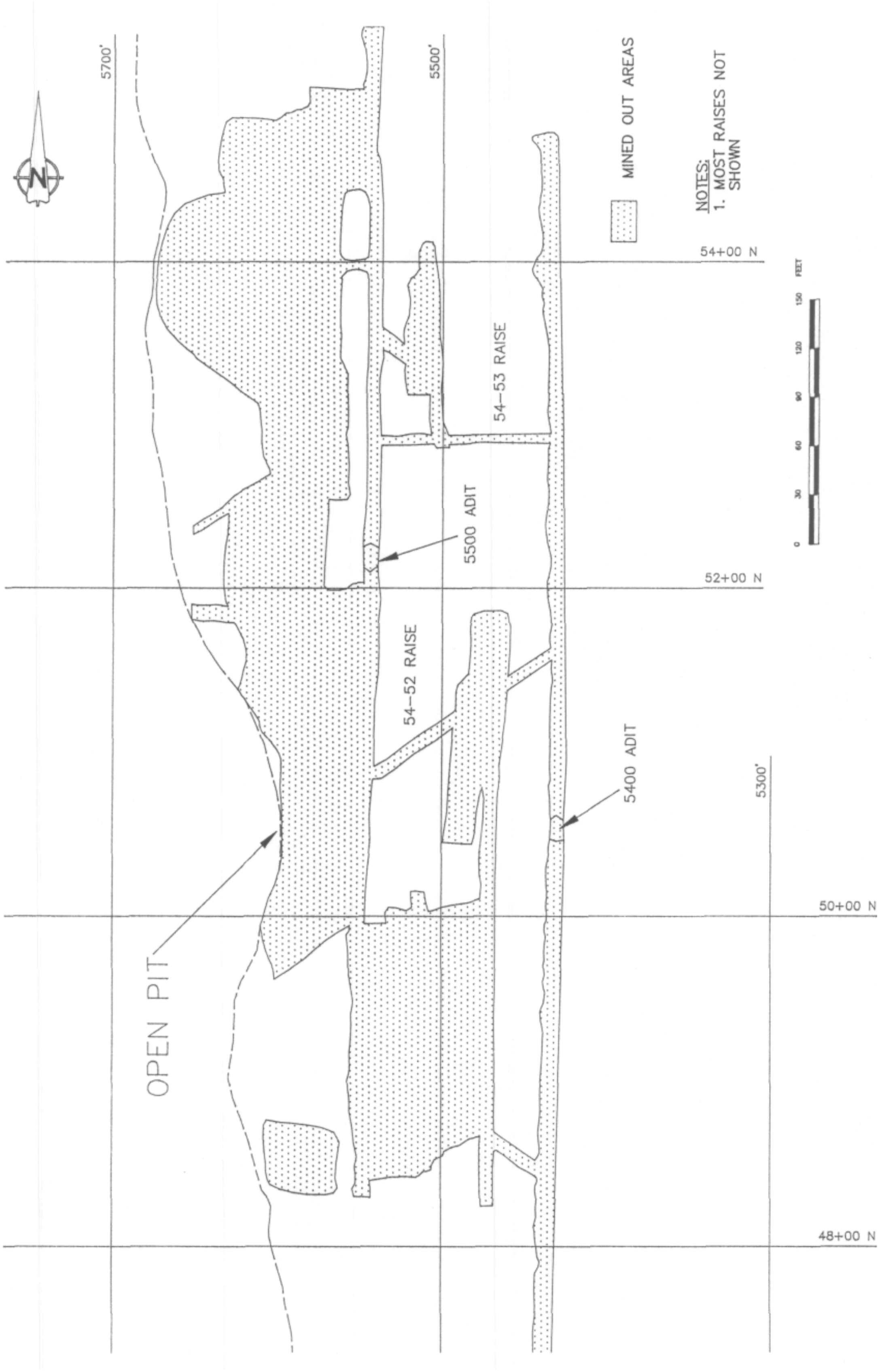


FIGURE 2 LONG SECTION OF BAKER MINE

CONCLUSIONS

In conducting these projects, the following conclusions were reached:

- Of the ten factors which influence rehabilitation options for control of ARD at an underground mine the most important are: i) geology and geochemistry, ii) mine geometry and mining method, iii) regional hydrology, and, iv) cost.
- Site characterization based on a brief site visit to yield an instantaneous water quality model with subsequent scaling to predict seasonal variations and annual metals release is sufficiently accurate to develop rehabilitation plans.
- Control of ARD in and underground mine can be effectively achieved by flooding. A reduction of the annual copper release of 60 to 75% is predicted to be achieved by this method for the Tulsequah and Baker mines.

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