The Mitigation of Acid Rock Drainage: Four Case Studies from British Columbia

William A. Price
CANMET, Natural Resources Canada
Smithers, British Columbia

Abstract

A large number of mines throughout the world are faced with the high cost and technical challenges associated with ARD mitigation. The objective of this paper is to use four different British Columbia mines to describe the challenges mines face, generic components of cost effective mitigation, and site-specific approaches to reduce environmental risk and the post-mining liability. Potential mitigation strategies for individual mine components should be evaluated in terms of how well they must perform, how long they must last, what they will cost, compatibility with site conditions and their contribution to the cumulative risk and liability of the site. A key part of cost effective mitigation is gaining the necessary understanding of both the site and mitigation measures. A mine can dramatically reduce mitigation costs by using supportive site attributes and by making mitigation an integral part of the mine plan. Recognition of closure issues early in the mine life enables a mine to use operating facilities and personnel to address closure issues and run long-term, large scale tests under actual field conditions.

Introduction

After mineral extraction, some mine sites can be completely reclaimed and the mining company has no further responsibilities. However this is not usually the case where there is a need to mitigate[1] metal leaching[2] (ML) or acid rock drainage (ARD). A large number of mines throughout the world, including more than 40 mines in British Columbia, are doing work to mitigate ARD or elevated metal levels in neutral pH drainage (Price and Bellefontaine, 2002). Estimates of the projected costs for all forms of ARD cleanup in Canada are between \$2 billion and \$5 billion (Feasby and Tremblay. 1995). Cost effective mitigation is also an important issue for neighboring communities. Community concerns include the adequacy of the understanding, long-term performance of mitigation structures, accuracy of projected mitigation costs, and that mines have sufficient financing for post-closure remediation and are committed to preventing impacts to community resources.

There are many technical challenges associated with ARD mitigation. These include long-term performance requirements, large information requirements, our limited operating experience, ongoing changes in important processes, a need for proactive detection and resolution of concerns, difficulties in predicting the potential for significant ML/ARD, high costs, and the multi-disciplinary and highly specialized nature of ML/ARD work (Price, 2002). With most mitigation measures, the ML/ARD potential of the original materials does not dissipate over time, and mitigation must last forever (Price and Errington, 1998). The requirement for long-term performance means that structures, such as dams and ditches, must be capable of withstanding extreme climate and seismic events. This creates onerous design, monitoring, maintenance and repair requirements, and is responsible for a large part of the cost.

[1] Mitigation measures are required when there is a need to prevent metal leaching or acid rock drainage impacts to other resources. The definition of acceptable and unacceptable drainage quality will depend on a number of factors, including the type of resource being protected.

[2] Although ARD often receives most of the attention, the primary source of toxicity are trace metals. Elevated metal leaching is associated with acidic drainage due to high metal solubility and sulphide weathering rates under acidic conditions. For many rock types/environmental conditions, metal leaching will only be significant if drainage pH drops below 5.5 or 6. However, neutral pH drainage does not necessarily prevent metal leaching from occurring in sufficient quantities to cause negative impacts. While the solubility of aluminum, iron and copper is greatly reduced in neutral pH drainage, elements such as antimony, arsenic, cadmium, molybdenum, selenium and zinc remain relatively soluble and can occur in significantly high concentrations. The term metal is broadened to include metalloid elements, such as arsenic, which are also products of rock weathering and potential problematic drainage contaminants.

There are a great variety of mitigation strategies available to prevent the impacts of ARD. These include underwater storage, blending materials, covers, segregation, and drainage collection and treatment. There are also a wide variety of mines, including historic mines where ML/ARD was never a consideration, mines where ML/ARD mitigation was an after-thought and mines where the closure requirements for ML/ARD have been an integral part of the mine plan at every stage of the operation. The objective of this paper is to use four different British Columbia mines to describe the challenges mines face, generic components of cost effective mitigation, and site-specific approaches to reduce environmental risk and the post-mining liability.

Duthie Mine (1920s and 1950s)

Duthie, a Ag-Pb-Zn underground mine which operated in the 1920's and 1950's, is an example of a historic mine where mining was conducted with no consideration of ML/ARD. The limited waste rock is not a metal leaching concern, but the site has 50,000 tonnes of oxidized, acid generating tailings; 20,000 t in the pile and 30,000 t in the forest between the pile and the mill, and below the pile. The primary environmental concern is high dissolved Zn, which is > 100 mg/L in seepage from tailings. The seepage also contains high As.

In addition to the small mass of tailings, the site also has significant dilution and attenuation prior to the sensitive fresh water aquatic life to be protected in the receiving environment. Presently the Zn concentration at the first receiving environment location is 5 mg/L. A further 200 times reduction in loading is required to reach the BC water quality guideline value of 0.03 mg/L for the protection of fresh water aquatic life. Based on the site conditions, a loading reduction of a 200 times is potentially feasible with measures to limit leaching and maximize dilution and attenuation, avoiding the costs and sludge disposal problems associated with lime treatment.

The first step in mitigation was to remove the tailings from the forest, move them onto the pile and ensure the pile is properly constrained. Re-handling materials is expensive, which was one reason for not moving the pile itself. Costs depend on such factors as the ease of pick-up, length of the haul, amount of material and the size and amount of equipment. At Duthie, the tailings allowed to flow into the forest covered a wide area. Retrieval required removal of trees, working on steep or swampy terrain, and unavoidably collecting a large amount of the under and over lying soil. 100,000 t of mixed tailings-soil material were picked up at a cost of $471,000 or $15.7/t of tailings in order to collect the 30,000 t of tailings.

The second step was to construct deep upstream ditches to cut-off groundwater inputs. The Duthie tailings pile is in an area of groundwater discharge, with groundwater considered to be responsible for at least 98 % of the drainage from the tailings pile. Therefore success of the mitigation plan will depend in large part on the groundwater interception. The objectives of the ditch design are to maximize groundwater interception and minimize long-term maintenance costs. The ditch system consists of an outer ditch to intercept clean groundwater and an inner ditch to collect drainage from the tailings. The capital cost of ditch construction, including a gravel cover, is estimated to be $75,000.

The third step will be to construct a surface cover to limit leaching of the pile by incident precipitation. The cost of a surface cover is estimated to be $200,000, based on 10,000 m^2 surface area and $4/ m^2 for an HDPE cover. Use of clayey till material uncovered during the tailings removal for the cover will likely reduce this cost.

The fourth step will be to increase downstream attenuation of the remaining seepage from the tailings pile by draining it through a constructed wetland.

Monitoring, primarily of water quality, presently costs $25,000 per year. Monitoring will be important in determining how components of the mitigation system are functioning and whether maintenance, repairs or refinements are required.

Observations regarding mitigation costs at Duthie are as follows.

- Small size relative to surrounding drainage sources makes measures to minimize leaching a feasible long-term remediation strategy.
- Obviously proper containment when the tailings were first produced would have greatly reduced the reclamation costs.
- The relatively high rate of present groundwater leaching results from the original placement of the tailings in an area of groundwater discharge. For a number of reasons including initial costs, waste disposal commonly occurs in low-lying areas, the portion of the landscape with the highest rates and greatest potential for overland flow. While this may save money in the short-term, there are potentially large long-term costs if metal leaching is a concern. At Duthie, it is the cost of constructing and maintaining a sophisticated clean water diversion system for the foreseeable future.

Equity Silver Mine (1980 - 1994)

Over the last forty years, British Columbia mines have placed their wastes in a secure location and monitored site drainage. As a result of the latter, they have been able to identify ARD or elevated metals in neutral pH drainage, and where required take remedial action. However, only in the last 10 to 15 years did mines address future ML/ARD concerns. The lack of pre-mining prediction and subsequent measures for ARD prevention, coupled with the large size of the mines, has resulted or will result in long-term, drainage treatment for at least fifteen mines. Fortunately most of these mines are owned by responsible, well-financed mining companies, which are able and committed to preventing impacts to other resources

One of the sites requiring ARD collection and treatment is the Equity Silver Mine, owned by Placer Dome. Equity operated from 1980 to 1994, producing Ag, Au and Cu, primarily from open pit mining, with a limited program of underground mining. Features remaining from the original mine development include:

- two open pits and one backfilled pit,
- a contiguous series of waste rock dumps,
- the plant site and
- a flooded tailings impoundment.

Flooding the tailings has minimized oxidation, preventing ARD. ARD comes from the 77 million tonnes of sulphidic waste rock, which cover 110 ha, and was not flooded. The ARD from the dumps has a pH of 2 to 3, approximately 10,000 mg/L acidity, 100 mg/L Cu and 200 mg/L Zn. At least a 10,000 times reduction in contaminant loading and concentration is required to prevent adverse impacts to off-site resources. To date, large-scale drainage collection and lime treatment has been the only feasible mitigation strategy.

The infrastructure required for collection and treatment of ARD and discharge of the resulting effluent includes fresh water diversions, ditches and sumps to collect ARD, pumps and pipes to transport the ARD up the treatment plant, storage ponds to hold ARD, a lime treatment plant, storage ponds for treated water, pumps and pipes to transport sludge to the pit, an office and a maintenance shop. Use of the Main Zone Pit to store treatment sludge avoided the need for a more expensive, high-density sludge treatment plant. The sludge contains residual alkalinity, which neutralizes ARD from mine walls above the pit lake, and aerates the water column, which maintains the stability of the trace metals, which are co-precipitated in the sludge with iron hydroxides.

When the mine closed in 1994, four full time staff were required to operate the collection and treatment system and the annual operating costs were more than $1.5 million/yr[3]. While drainage collection and treatment was unavoidable for the foreseeable future, there was obviously a desire to reduce costs. The largest cost at the site is the lime used to neutralize acidity. Since lime use is strongly correlated with the volume of ARD, the

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[3] All costs are in Canadian dollars. One $Cdn is worth approximately $US 0.65.

effort to cut costs focused on ways to reduce drainage inputs into the dumps. Drainage inputs to the dumps come from either groundwater or incident precipitation. Since the Southern Tail and Main Zone Pits form an almost complete barrier to upslope groundwater inputs, it was concluded that the majority of dump drainage came from incident precipitation and that the best means for reducing the volume of ARD would be with a low permeability cover.

The first phase of cover construction was to re-contour the dumps, removing steep slopes. The cover was built from a fine textured glacial till[4] found on the mine site and consists of a 50 cm compacted layer overlain by a 30 cm un-compacted surface layer. The objectives in the design of the compacted layer were to limit conductivity and maintain saturation, minimizing the infiltration of water and oxygen. The more porous, un-compacted, upper-layer plays a number of roles, including erosion protection, water storage to replace any losses from the compacted layer, a surface for revegetation and evapotranspiration, and an initial flow path for water unable to infiltrate the underlying layer.

The cover on the waste rock dumps (130 ha) was constructed from 1990 to 1994. The plant site cover (35.3 ha) was constructed from 1994 to 1997. The waste dump and plant site cover costs averaged $35,000/ha or approximately $5.5 million.

The volume of ARD at Equity fluctuates depending on annual precipitation. However, a comparison of data normalized for annual precipitation from before and after the dump cover was completed (1989-1994 versus 1994-2000) shows that the cover decreased lime use from approximately 6,000 to 4,000 t/yr and the volume of ARD from approximately 900,000 to 600,000 m^3/yr, in each case a decrease of approximately a third.

In the spring 1997, a large snow pack and high temperatures resulted in a 1:30 year flood event. The mine had insufficient pumping capacity and had to release untreated ARD. Subsequent investigations found that the collection system had been sized using a precipitation rather than a snow melt event. Improvements made in 1998, including substantial increases in clean water diversion and a large increase in the pumping capacity, were thought to provide 1:200 year protection. At the time of the 2001 security review, the mine had three full time staff, an operating budget of $1.2 million, the net present value of the liability was $23.55 million and the mine was spending over $400,000 per year in site upgrades, studies and monitoring aimed at reducing risks and cost.

A major focus of the studies was on the hydrology of the dumps. While the cover has caused a significant reduction in the volume of ARD, the decrease was considerably less than expected based on the predicted interception of groundwater flow by the pits and monitoring results from cover lysimeters[5], which indicate that infiltration through the cover is less than 5% of incident precipitation (Ferguson and Aziz, 2000). There are a number of possible reasons for the less than expected reduction in flow, including higher than expected groundwater inputs, a loss of residual drainage, and that the lysimeters may not provide an accurate measurement of infiltration through the cover. Discrepancies between the lysimeters measurements and actual infiltration may be because the lysimeters are in upper, relatively well-drained areas of the cover, the scale of lysimeters is too small to measure infiltration through local cracks and the cover as a whole, infiltration flows around lysimeters, and significant infiltration occurs from dump runoff ditches.

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4 Glacial till is a non-lithified material deposited directly by glacial ice without modification by any other agent of transportation. Till can be transported beneath, beside, on, within and in front of a glacier. The mineralogical, textural, structural and topographic characteristics of till deposits are highly variable and depend upon the original source and the mode of deposition. In general, till consists of well-compacted to non-compacted material that is non-stratified and contains a heterogeneous mixture of coarse fragments in a matrix of sand, silt and clay.

[5] A device for collecting drainage passing through overlying material. The term lysimeter is primarily used for field test apparatus. Lysimeters are installed in real mine components or under field test pads to measure the quality and/or quantity of drainage.

One valuable conclusion from groundwater studies done on the dumps was that water in the Main Zone Pit would drain into the dump through fractured bedrock at an elevation well below the spillway and a number of years before discharge was predicted. Based on this information, pumping down of the water level in the pit in 2001 prevented a possible doubling of the volume of dump drainage.

Another major focus of studies is weathering within the dump. This includes oxygen and temperature probes and seep monitoring. Prior to installation of the cover, sulphate and acid loadings were increasing. Seep monitoring was started in 1997, and increased in 2001, to track trends in drainage chemistry.

In the spring 2002, again prolonged freezing temperatures resulted in a large snow pack. This time rain and relatively cool temperatures caused a 1:60 year flood. The mine had insufficient pumping capacity to handle the flow and insufficient treatment capacity to handle high acidity, and as a result had to release untreated ARD. Subsequently, the mine has redone the water balance assuming much higher infiltration through the cover, doubled the pumping and ARD storage capacity, added extra lime slaking, and is in the process of adding more staff and constructing a high-density sludge plant. The additional slaking and the HDS plant will double the treatment capacity.

The experience at Equity illustrates a number of important points regarding ARD mitigation, collection and treatment, and covers.

- Any theories regarding groundwater should be confirmed through monitoring. In order to improve the understanding of future leaching, new mines are advised to map hydrological features, such as drainage sources, zones of groundwater discharge and concentrated seepage, prior to dump construction.
- There is significant uncertainty about present and future cover performance, dump hydrology, waste rock weathering and the chemistry of the ARD. This makes it difficult to predict future mitigation costs and resource requirements.
- Reliable procedures are needed for measuring cover performance and identifying what, when and where cover repair is required. This information is required to ensure repairs or improvements occur in a timely and cost effective manner. Issues to consider include infiltration from areas of ponding, on slopes and beneath runoff channels, the accuracy of the lysimeters, and the need to monitor runoff from different sections of the cover.
- Runoff collection and removal is an important, yet often insufficiently addressed aspect of cover design. In the absence of accurate information on groundwater inputs, an accurate large-scale measure of runoff is required to determine cover performance.
- While a decline in lime use will eventually occur, it is presently impossible to predict the timing and form of the decrease, and whether this might be preceded by increased acidity. This information is needed for treatment plant design and determining operating costs. Future research priorities for the industry as a whole should include monitoring of the evolution in dump geochemistry and hydrogeology.
- Milling should occur prior to significant weathering of low-grade stockpiles. Equity milled the low-grade ore at the end of mining. Due to weathering only half the high sulphide, low-grade ore could be processed. The rest remains in the dump complex and given the high sulphide content, it is likely a source of significant acidity.
- Use caution when using alkalinity in other drainage to neutralize acid rock drainage (ARD). While it was operating, Equity used alkalinity in the impoundment to neutralize ARD from one of the dams, whose base was built with waste rock. About 5 years after milling stopped, the pH of the water cover declined from

above 7.5 to the pH of rainwater (less than pH 6), releasing Cu from the precipitated ARD.

Snip Mine (1991 - 1999)

One of the most difficult challenges in mitigation is what to do when there is significant uncertainty about whether materials will produce significant ARD or metal loadings, or whether predicted discharge will have a significant environmental impact. This is a common problem. Mitigation requirements are uncertain for a significant mine components at over forty sites in British Columbia.

The Snip Mine consisted of an underground mine and a mill, and operated from 1991 to 1999, producing approximately 1.3 million tonnes of ore. At the time of construction, there was an understanding of the importance of an ARD assessment, but the assessment procedures were relatively crude and did not adequately consider issues such as variations in waste composition. From the perspective of ARD, the main features are:

- the tailings impoundment and
- the underground workings.

The tailings impoundment is flooded preventing ARD and significant metal leaching from approximately 850,000 tonnes of potentially ARD generating (PAG) tailings and 100,000 tonnes of PAG waste rock. Remediation measures at closure included addition of a soil cover, improving the dams to withstand a 1-in-a-1000 year flood and seismic events and construction of a spillway. The addition of toe berms to the dams created an effective slope of 6:1 at far less cost than other procedures. Geotextile fabric was used to place soil on the saturated tailings.

Post-closure, the primary task has been monitoring to check flows and water quality, ensure all PAG waste is flooded and determine whether the remaining exposed tailings should be covered. Placement of waste rock within the impoundment has had no significant impact on water quality. One important consideration regarding monitoring and maintenance is that no one lives in the area and the mine is only accessible by helicopter or boat, so access is expensive. To reduce the required frequency of inspection, boulders were placed in the spillway to prevent beavers from damming the flow.

The underground workings at Snip are in the mountain above the tailings impoundment. The main ARD concern with the underground is the backfill, which consisted of:

- 344,648 tonnes of waste rock,
- 466,959 tonnes of tailings sand and
- 1,306 tonnes of cement.

Operational monthly ABA analysis results indicate the composition of the waste rock and tailings sand are as follows.

Waste Rock:

- 5th and 95th percentile are 0.31 & 5.61% sulphur, 68 & 215kg/t Sobek-NP and an NPR (calculated using the Sobek-NP) of 1.2 & 15.0
- approximately 20% of the samples had NPR values less than 2
- median values of total As and the 95th percentile values of total Ag, Cd, Cu, Mo, Pb and Zn were an order of magnitude higher than typical background

Tailings Sand:

- 5th and 95th percentile are 2.8-7.1% sulphur, 148-230 kg/t Sobek-NP and an NPR (calculated using the Sobek-NP) of 0.8-2.3
- most of the samples had NPR values between 1 and 2, approximately 20% had NPR values slightly less than 1
- median values of total Cd, Mo, Pb and Zn were five to ten times higher than typical background, Ag and Cu were twenty to thirty times higher, As was two hundred and fifty times higher, and Se and Sb, which are elevated in humidity cell drainage and potentially a concern, were not measured

The NPR data indicates that the tailings sand have the potential to generate ARD (PAG) and are also enriched in elements, such as As, which may be a concern in neutral pH drainage. Humidity cell measurements of sulphide oxidation, coupled with the high NP and calcite content (5-15%) indicate that ARD, if it does occur, will not occur for at least ten years. At the Island Copper Mine with 0-4% S and NP values of less than 80 kg/t (Morin & Hutt, 1996), it took 15 years for the waste rock dumps to produce ARD. At Snip, where the NP is much higher, if ARD does occur it may take far longer to develop.

Mineralogical work (XRD and SEM/EDS) done at closure showed that up to 40% of the carbonate is ankerite and siderite. The potential contribution of Fe and Mn carbonates to Sobek test results, raises a concern that the portion of PAG tailings could be much higher than indicated by NPR values calculated using the Sobek-NP. Conversely if low temperatures, a low rates of oxygen supply and low sulphide contents (remaining after all the calcite is exhausted) result in low oxidation rates, the 20% content of chlorite, biotite and other phyllosilicates in the tailings may provide more NP than that indicated by the Sobek measurement.

At closure, bulkheads constructed in the two lowest adits flooded the lower workings and approximately 15 to 25% of the backfill. Recovery of the ore rich crown pillar and subsequent subsidence made it impossible to flood the upper two thirds of the underground workings. In the upper workings, portal pugs will limit oxygen entry and may reduce the rate of, but are not expected to entirely stop, sulphide oxidation.

Dealing with uncertainty about the future level of metal leaching or acidity (e.g., Snip) or the long-term effectiveness of mitigation measures (e.g., the cover at Equity) is a major challenge at many mines and creates significant uncertainty about future resource needs. Presently, Snip has a contingency plan to treat ARD or elevated metal in neutral pH drainage and will continue to monitor drainage from the underground. One of the conclusions during the Snip closure was that recognition of closure issues earlier in the mine life would have enabled the mine to make better use of the facilities and expertise available when the mine was operating, and allowed them to run long-term, large scale tests under actual field conditions. This conclusion is being put into practice at the Eskay Creek Mine, Barrick's other operating mine in British Columbia, where ARD closure planning started when the mine opened.

Huckleberry (1997 - present)

British Columbia now has a number of mines where ML/ARD concerns were addressed right from the start and mitigation requirements were an integral part of every phase of the operation.

- QR Gold
- Mount Polley
- Kemess
- Huckleberry

Huckleberry is a porphyry Cu-Mo mine, opened in 1997 and operated by Imperial Metals Corp. It consists of two pits, a tailings impoundment and the plant site. Typically, it mines 10 million tonnes of waste and ore a year. The closure plan is to flood potentially ARD generating wastes, with the objective of limiting post-closure requirements to the relatively small costs of monitoring, maintenance and water management.

Mining started in the higher grade East Zone Pit to offset stripping and other mine development costs. East Zone tailings and waste rock, both of which are PAG (NPR < 1 and 2 to 5% sulphide-S) were deposited in the flooded tailings impoundment. The starter dam for the impoundment was constructed from the till stripped from the East Zone pit.

In part to reduce ARD mitigation costs, after two years (in 1999) mining switched to the Main Zone Pit. In contrast to the predominantly PAG East Zone, the Main Zone Pit contains both PAG and non-PAG waste rock. This is important because beyond the starter dam, till use in the impoundment dam is limited to the core, and buttressed on either side by waste rock. PAG waste rock is used on the upstream (flooded) side. Non-PAG waste rock is used to construct the aerated downstream side. The Main Zone has provided most of the non-PAG rock used to construct the downstream side of the tailings dam. In addition to being non-PAG, waste rock used for downstream construction must have no neutral pH drainage concerns. At Huckleberry, the only trace elements occurring in elevated concentrations are Cu and Mo. Due to site-specific conditions, neither element is considered a neutral pH discharge concern.

Operational separation of PAG and non-PAG waste rock in the Main Zone Pit required frequent sampling and analysis of blast-hole chips (whole rock) and regular checks on the composition of the fines in the post-blast material. The resulting material characterization is noted in operational dig plans and clearly marked on the muck piles and in the directions given to shovel operators and truck drivers.

In addition to the upstream side of dams, PAG waste rock is used for road construction and placed in dumps within the area of eventual flooding. As there may be up to 10 years delay before some roads and dumps are flooded, there is a concern that ARD would occur prior to flooding, creating a need for drainage treatment. The concern was primarily with the dumps. On the roads, crushing continually releases new NP and the material is mixed with calcareous till.

The concern about pre-flooding ARD generation is handled as follows:

- material characterization to identify waste rock with a low NP,
- monitoring pH and the carbonate content in areas of prolonged exposure,
- minimizing dump height so most flood within 24 months, and
- provision of a financial security that would pay to move all the exposed waste rock to a flooded location if ARD starts.

Minimizing PAG exposure is an important part of the mine plan. Excluding 1.5 million tonnes used for surfacing roads and in ore stockpiles, presently less than 100,000 of the more than 10 million tonnes of PAG waste rock mined to date will be exposed (not flooded) in 24 months. During years 1 to 5, waste rock and tailings were flooded in the tailings impoundment. Mining has now switched back to the East Zone for the last 7 years of mine life, allowing the Main Zone Pit to be used as a flooded disposal site, reducing the waste haul distance and impoundment construction costs.

A common concern with flooded impoundments is the proximity of the water cover to the dam crest. Although closure at Huckleberry is years away, to address this concern, the mine has already completed test work showing how it can modify the mill process to produce non-PAG tailings that can be used to create a beach adjacent to the dam at the end of mining.

The main outstanding issue at Huckleberry and the subject of ongoing study is post-closure water quality in the East Zone Pit. The main concern is with ARD from talus produced from the PAG mine walls and accumulating on benches above the zone of flooding. Various remediation strategies are possible, including measures to minimize the number or size of the exposed benches, filling the exposed benches with non-PAG materials, biological treatment of the pit lake (Price and Bellefontaine, 2002), upslope drainage diversion, and dilution and neutralization by the alkaline drainage discharge from the backfilled Main Zone Pit and the tailings impoundment. Due to the limited recharge area, post-closure mitigation requirements should be relatively inexpensive.

Conclusions

A large number of mines throughout the world are faced with the high cost and technical challenges associated with ARD mitigation. The best management practices for ML/ARD mitigation is to address these issues as soon as possible. By addressing the closure issues so far in advance, Huckleberry is able to incorporate the mitigation requirements into the mine plan creating a cost effective solution rather than one forced on it in a hurry. Integration of mitigation work with other aspects of the operation can dramatically reduce costs. Recognition of closure issues early in the mine life would also enables a mine to use site personnel and facilities to run long-term, large scale tests under actual field conditions.

A key part of cost effective mitigation is gaining the necessary understanding of both the site and mitigation measures. Every mine should conduct a site-specific assessment that provides the necessary understanding, including adequate consideration of risk, for sound environmental and fiscal management (Price, 2002). Developing the required understanding may be expensive, costing thousands of $ and take a year of more. However a lack of understanding could cost millions of $ and the repercussions to the environment, the company and the industry as a whole may last forever (Price, 1999a).

A mine can dramatically reduce mitigation costs by using supportive site attributes and by making mitigation an integral part of the mine plan. While the previous examples focused on traditional mitigation procedures, site conditions may permit the use of innovative or location specific mitigation methods. At the Sulphurets and Eskay Creek Mine, harsh weather, huge snow falls and a limited snow free period creates a number of difficulties. However, these conditions also result in abundant, relatively un-productive fish-free lakes and large dilution downstream of the lakes prior to fish habitat, permitting lake disposal rather than the normal practice of deposition in a constructed impoundment (Price, 1999b).

No matter what the procedure, there are a number of generic questions that must be answered when assessing potential mitigation strategies (Price and Errington, 1998).

- How well must it perform?
- How long must it last?
- What will it cost?
- What is the contribution to the cumulative risk and liability of the mine?
- Is it compatible with the mine plan and conditions on the site?

As a result of our limited operating experience, ongoing changes in important processes, a difficulties in predicting the potential for significant ML/ARD and the need for proactive detection and resolution of concerns, no matter what mitigation measures are selected, monitoring is an essential component of successful long-term mitigation (Price, 2002). Monitoring programs should be set up to detect significant geochemical and hydrological changes, provide early warning of potential problems (e.g., detect a reduction in design capacity), inform corrective measures (e.g., direct maintenance) and allow timely implementation of contingency plans.

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