POLICY FOR METAL LEACHING AND ACID ROCK DRAINAGE AT MINESITES IN BRITISH COLUMBIA

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1. INTRODUCTION

There are numerous examples throughout the world where elevated concentrations of metals in mine drainage have had adverse effects on aquatic resources and created severe impediments to the reclamation of mined land. Metal leaching (ML) problems can occur over the entire range of pH conditions, but are most commonly associated with acid rock drainage (ARD). Once initiated, metal leaching may persist for hundreds of years. In North America, metal leaching and ARD (ML/ARD) have led to significant ecological damage, contaminated rivers, loss of aquatic life and multi-million dollar clean-up costs for industry and government. The ARD liability associated with existing Canadian tailings and waste rock is estimated to be between 2 and 5 billion dollars.

Preventing impacts from ML/ARD is the most costly and time consuming environmental issue facing the British Columbia mining industry. It is also one of the most technically challenging. Due to poor historical practices, large remediation costs, technical uncertainty and the potential for negative environmental impacts, ML/ARD is a major issue of public and regulatory concern.

Most metal, and some coal mines, have a potential for toxic ML/ARD release and environmental impact. The challenge faced by the Provincial Government in regulating ML/ARD is to ensure that all mines are planned and operated in a manner that allows for effective problem detection and mitigation, and emphasizes problem prevention at the outset. In most scientific work, practitioners would be satisfied with a 90 to 95 percent success rate. However in ML/ARD prediction and prevention, any failure that results in significant environmental impact[1] is unacceptable.

Every minesite has unique geological and environmental conditions and these conditions vary widely, which is an important consideration in ML/ARD regulation. Universal rules for ML/ARD impact prevention are not appropriate or practical since they would be unnecessarily restrictive for most minesites, but would not be sufficiently stringent to detect all anomalous conditions that could threaten the environment. The British Columbia Government has chosen to evaluate ML/ARD on a site-specific basis and to focus on the process of information gathering. To detect anomalies without precluding acceptable mining practices, the Province requires that mines have a detailed understanding of their site-specific ML/ARD prediction and prevention requirements and constraints. The Province's objective is to reduce risk by requiring comprehensive reviews of all mine components and by being cautious in the absence of the required understanding. This process should ensure the detection of the small proportion of mines where anomalous conditions invalidate standard practices without unnecessarily restricting the development of the Province's mineral and coal resources.

Although our understanding of ML/ARD is far from complete, the available prediction and mitigation tools combined with a well informed, cautious approach should allow mines with a potential for ML/ARD to meet receiving environment objectives and minimize the liability and risk.

[1] Metal Leaching and ARD are considered to have a significant impact if they cause an exceedance of receiving environment objectives established by the Ministry of Environment, Lands and Parks or preclude attainment of reclamation objectives established by the Ministry of Energy and Mines under the *Mines Act*.

1.1 Legislated Requirements

The Mines Branch of the Ministry of Energy and Mines (MEM) and the Pollution Prevention Program of the Ministry of Environment, Lands and Parks (MELP) share the Province's responsibility for regulating ML/ARD from proposed, new and existing mines. Minesites are regularly inspected by staff of MEM and MELP to ensure compliance with ML/ARD permit requirements.

Mining is regulated by MEM under the *Mines Act* and the Health, Safety and Reclamation Code. A mine must apply for, and obtain, a permit from the Chief Inspector of Mines under Section 10 of the *Mines Act* prior to mining, or significant ground disturbance. This permit approves the mine plan, the program for the protection of land and watercourses and the reclamation program. ML/ARD prediction and prevention plans must be submitted as part of this application. Plans must be updated every five years or whenever significant changes occur. Permits issued under Section 10 contain conditions for ML/ARD prediction and prevention including conditions for excavation, waste deposition, waste characterization, reclamation, and the provision of financial security for outstanding reclamation liability.

MELP sets discharge quality requirements, through the *Waste Management Act,* that prohibits the introduction of waste which may substantially alter or impair the usefulness of the environment. As a consequence of requirements of the *Waste Management Act,* specific water quality objectives for the receiving environment based on the BC Water Quality Criteria are established, as well as discharge and receiving environment monitoring programs. In addition, the *Water Act* regulates the use, storage and diversion of water associated with the minesite.

While both MELP and MEM have legislation that provides for the establishment of financial security, a protocol agreement allows for the posting of the security under the *Mines Act* provided the conditions meet the requirements of MELP.

1.2 Metal Leaching and Acid Rock Drainage

Metal[2] leaching and acid generation are naturally occurring processes which may have negative impacts on the receiving environment if they occur in the absence of adequate neutralization, dilution and/or attenuation. Acid generation occurs when sulphide minerals and elemental sulphur are exposed to the weathering effects of oxygen and water. Acidity is generated from the oxidation of sulphur and the precipitation of ferric iron. ARD occurs when the resulting acidity is entrained by water. Although ARD has received most of the attention, the primary source of toxicity are metals. For many rock types, 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. Neutral pH metal leaching is generally only a concern if discharge is into a sensitive resource and/or with little dilution. High concentrations of metals in neutral pH drainage often result from localized, relatively small zones of acidic weathering.

[2] The definition of metal is broadened to include metalloid elements such as arsenic which are also products of rock weathering and potential drainage contaminants.

ML/ARD are major concerns for mining because most precious metal, base metal, and some coal deposits in British Columbia are relatively rich in sulphide minerals and because mining greatly increases the amount of rock surfaces exposed to oxygen and water. An additional contributing factor is that metal mine deposits usually contain high concentrations of one or more potentially deleterious trace metals.

2. GUIDING PRINCIPLES

Mining and exploration activities in British Columbia will be regulated in a manner which supports the Province's goals of sustainable resource development, reclamation, environmental protection and minimization of economic risks. To this end, the Provincial Government supports productive mineral extraction while recognizing that the mining industry can only be sustained through environmentally sound, economically viable management practices.

Guiding principles for the regulation of ML/ARD in the Province of British Columbia include:

Ability and Intent - A mine proponent must demonstrate the necessary understanding, site capacity, technical capability and intent to operate a mine in a manner which protects the environment. Mitigation[3] plans must meet the environmental and reclamation objectives for the site and be compatible with the mine plan and site conditions.

Site Specific - The current regulatory philosophy appreciates that every mine has a unique set of geological and environmental conditions and therefore ML/ARD will be evaluated on a site-specific basis.

ML/ARD Program - Whenever significant[4] bedrock or unconsolidated earth will be excavated or exposed, the proponent is responsible for the development and implementation of an effective ML/ARD program. The program must include prediction, and, if necessary, mitigation and monitoring strategies.

Prediction and Prevention - The primary objective of a ML/ARD program is prevention. This will be achieved through prediction, design and effective implementation of appropriate mitigation strategies.

Contingency - Additional mitigation work or contingency plans will be required when existing plans create unacceptable risks to the environment as a result of uncertainty in either the prediction or primary mitigation measures. The timing and degree of preparation required will depend on the risk, when the potential event of concern may occur and the resources required for implementation.

Minimize Impacts - Where ARD or significant metal leaching cannot be prevented, mines are required to reduce discharge to levels that assure long-term protection of the receiving environment. An important secondary objective is to minimize the alienation of on-site land and water resources from future productive use. Impacts and risks must be clearly identified by the proponent and will be considered during the project

[3] The term mitigation refers to all measures taken to avoid a negative impact on the receiving environment, including ML/ARD prevention, reduction and treatment.

[4] Significance is ideally determined by the potential for ML/ARD to have a negative impact on the receiving environment or preclude reclamation objectives. Since this definition cannot be applied prior to prediction, the minimum disturbance for which prediction is required is set at 1000 tonnes. While this arbitrary minimum disturbance criteria will be conservative in most cases, the minimum tonnage should be reduced if a highly reactive material is to be placed next to a sensitive receiving environment.

review process, in conjunction with other environmental, economic, community and aboriginal impacts and benefits. Mitigation is usually more effective if problem prediction and prevention occur prior to the occurrence of significant metal leaching or ARD.

Cautious Approach - Cautious regulatory conditions based on conservative assumptions will be applied where either the ML/ARD assessment or the current level of understanding is deficient.

Reasonable Assurance - The regulation of ML/ARD will be carried out in a manner which minimizes environmental risk and with reasonable assurance that government will not have to pay the costs of mitigation.

Financial Security - As a permitting condition, financial assurance will be required to ensure sufficient funds are available to cover all outstanding ML/ARD obligations, including long-term costs associated with monitoring, maintenance, outstanding mitigation requirements, and collection and treatment of contaminated drainage.

3. PREDICTION

3.1 Prediction Principles

Whenever significant bedrock or unconsolidated earth will be excavated or exposed, the proponent must prepare a ML/ARD prediction program. The objective of a prediction program is to reduce uncertainty to a level at which potential risk and liability can be identified and effective extraction, waste handling and, where necessary, mitigation and monitoring strategies can be selected. This requires a prediction of the most probable performance of mine materials and components and of the potential for unacceptable conditions. Informed, site-specific decision making is crucial to problem identification, issue resolution and avoidance of unnecessarily conservative rules for waste handling and storage.

Every prediction program must include the following three steps:

1. Identify and describe all geological materials excavated, exposed or otherwise disturbed by mining.

2. Predict the ML/ARD potential and, where applicable, the timing, for each geological material in the forms (i.e. particle size) and environmental conditions in which it will be exposed.

3. Develop a mitigation and monitoring program based on the predicted ML/ARD potential and environmental protection needs.

Commonly, the most efficient and cost effective way to characterize geological materials, determine the ML/ARD potential and create management units will be an iterative process of testwork and review, similar to that used to determine other geological characteristics such as ore reserves. The proponent must determine if the proposed sampling, analysis and test procedures will answer the prediction questions critical to their particular site, materials and waste handling, and remediation plans. Each phase in the prediction program should be guided by the preceding work. Data analysis and interpretation is required following each phase of testing.

All test procedures, rules and analyses, including those provided here, should be verified for their applicability to the specific project, site conditions and prediction questions. Common errors in prediction include testing unrepresentative samples, incomplete analysis of test materials and erroneous assumptions regarding the parameter measured by the test. Many ML/ARD tests provide very specific information. To ensure results are not misused or misinterpreted, practitioners should use accurate and precise terminology and specify the analytical procedures utilized to determine broadly defined parameters such as acid generation potential (AP) and neutralization potential (NP).

Practitioners must allow sufficient time for the completion of testwork, data analysis and interpretation. The requirement for phased testing and the long duration of kinetic tests can make prediction a lengthy process. Due to the significant analytical costs, potential for delays, site-specific requirements and uncertainty regarding proper test protocols, a mine proponent is advised to discuss each phase of the prediction program with the appropriate regulatory agencies prior to implementation and as testwork progresses.

3.2 Step 1 - Identify and Describe Geological Materials

Much of the variability in ML/ARD potential results from differences in geological properties. Thus, the first step of a prediction program is the identification, description and mapping of all bedrock and surficial materials that will be (for new mine proposals) or have been (for existing or historical mines) affected by mining. While Step 1 is often overlooked in the rush to do more ML/ARD-specific testing, an understanding of the geology is necessary to ensure that all possible sources of ML/ARD are evaluated, that the entire range in geological variability is addressed and that subsequent testwork is representative and comprehensive.

3.3 Step 2 - Predict the Metal Leaching and ARD Potential

The objective of this, the main phase of the prediction program, is to determine the ML/ARD potential and, if applicable, the timing for each different geological material, in the forms (waste rock, tailings and mine walls) and conditions (deposited aerially or underwater) in which it will be exposed. The assessment must also consider the effects of post depositional processes such as weathering, erosion and sedimentation.

The selection of appropriate test procedures, sample materials and data interpretation should be based on project needs and site-specific requirements, such as each mine component's probable weathering environment and geological make-up. The following analytical procedures are generally recommended for ML/ARD prediction, however they may not all be required at all sites:

<u>Static Tests</u>:

a) Trace element content

- total concentration
- soluble concentration (for weathered and oxidized materials)

b) Acid-base accounting

- total-, sulphate- and sulphide-sulphur
- bulk neutralization potential
- carbonate content
- pH

c) Mineralogy and other geological properties

- Petrographic and sub-microscopic examination

<u>Kinetic Tests</u>:

Reaction rates and drainage chemistry

- humidity cell
- site drainage monitoring
- in-situ field tests

Comprehensive pre-mining material characterization and weathering studies are required to determine the potential for contaminant release, the mechanisms involved and the potential for environmental impact. Where the potential for ML/ARD exists, post-excavation monitoring of materials and drainage, and on-site kinetic testwork are required to verify and refine pre-mining predictions of material composition, AP and NP availability and performance.

3.4 Step 3 - Develop a Mitigation and Monitoring Program

Materials handling and mitigation play a major role in determining the physical and geochemical conditions that control weathering and contaminant transport, and therefore, must be considered in the design of a prediction program. Separate mitigation and monitoring prescriptions should be developed for geological units and exposure types that perform alike and can be deposited, or will occur, together. Each project will have unique site-specific needs for ML/ARD prediction, materials management and environmental protection. Mitigation requirements will become more clearly defined as prediction testing proceeds.

Materials handling and mitigation requirements will also be important in the decision of how much testwork is required. The significance of contaminant release and inaccuracies in prediction will depend on loadings, available dilution/attenuation and the sensitivity of the receiving environment. Significant changes in mitigation plans may necessitate changes or additions to prediction testwork. To ensure additional testwork is cost effective, the proponent should consider the purpose and likely impact of the results. In some cases, the provision of contingency mitigation measures coupled with operational testing during mining will be more effective than additional pre-mining prediction testwork which is likely to be inconclusive, or of limited significance, to the overall mine plan.

4. MEASURES TO PREVENT OR REDUCE ML/ARD

4.1 Mitigation Principles

Guiding principles for mitigation include:

Mitigation Plans - Mines with the potential to create significant impacts to land and water courses from ML/ARD, must provide detailed mitigation plans demonstrating how contaminant loadings will be reduced and receiving environment objectives will be achieved. Mitigation plans are required for the entire minesite and for individual mine components with a potential for ML/ARD. Potential mitigation strategies for individual mine components should be evaluated in terms of their contribution to the cumulative risk, liability and land use impact of the entire mine.

Compatibility with the Mine and Environment - For a mitigation strategy to be successful, it must be compatible with the mine plan, the biogeoclimatic conditions of the site and the surrounding land uses. Waste handling and mitigation plans must be based on detailed site-specific studies of the minesite, the surrounding environment and the excavated and exposed material. Important biogeoclimatic conditions in addition to the geochemical and hydrogeological conditions, include soil resources for covers, water balance for underwater storage, waste proportions for blending and ground conditions for drainage collection, bulkheads and flooded impoundments.

While successful mitigation requires a compatible mine plan, the converse is also true. Mitigation requirements can play a determining role in the economic feasibility and environmental impact of all, or parts of, a project.

Selection of the Best Mitigation Strategy - Selection of the best mitigation strategy for a potentially problematic material or mine component should be done in two phases:

1. Identify strategies that will prevent negative impacts to the receiving environment.
2. Evaluate the relative abilities of potentially effective strategies to satisfy the general environmental protection and reclamation objectives of minimizing liability, risk and post-mining alienation of land and water resources.

Long-term Mitigation Requirements - Most ML/ARD mitigation facilities or structures must be designed, constructed and operated in a manner that allows them to perform indefinitely. Successful long-term operation requires sustained operator vigilance and regular monitoring to identify possible upset conditions. Conservative design criteria are typically required to achieve operational objectives during and after extreme climate events. Plans and resources must be available to enable timely maintenance.

4.2 Avoidance

From the perspective of environmental protection and minimizing liability and risk, the most effective mitigation strategy and the first that should be considered is avoidance through prediction and mine planning. Total or partial reduction in excavation or exposure of problematic materials can limit or prevent sulphide oxidation and metal release. If avoidance is not practical, other mitigation strategies may be necessary to ensure environmental protection. Where avoidance is the only practical mitigation strategy, the need for ML/ARD protection may preclude all or part of the mine.

4.3 Underwater Storage

If problematic materials are to be excavated, exposed or created during mining, underwater storage is generally the most effective means of preventing ARD and reducing metal leaching. Due to the low solubility of oxygen in water, underwater disposal can essentially prevent sulphide oxidation, thereby reducing acid generation and metal leaching to levels that generally no longer pose an environmental concern. An important consideration in underwater storage is that flooding usually does nothing to reduce the potential for sulphide oxidation should the materials be exposed at some point in the future. Therefore, the storage location must remain permanently flooded and geotechnically stable.

4.3.1 Information and Design Requirements

Material Characterization - Material characterization is required to determine the suitability of waste materials for underwater disposal, identify materials which do not require flooded storage, determine the required storage capacity and predict the resulting drainage chemistry. Since flooding reduces a major dissolution constraint, a determination of the concentration of highly soluble contaminant species and the impact on metal discharge will be required.

Delay in Flooding - Where there is a significant period of aerial exposure prior to flooding, the proponent must predict the time to ARD onset and build-up of significant soluble acidity and metals. Where an unavoidable delay prior to flooding creates the potential for a significant deterioration in water quality, additional mitigation plans will be required.

Incomplete Flooding - Where only partial flooding will occur, the proponent must predict the composition of potentially exposed mine walls and waste materials and determine the impact of aerial weathering on drainage chemistry. Mining can have a significant impact on groundwater hydrology, drawing down the water table and decreasing recharge rates. A lower water table may result if mining exposes or creates fractures that connect mine workings to porous strata. Pre-mining predictions of the rate and extent of flooding, based on the existing water table and undisturbed flow rates, must be verified.

Maintenance of Flooding - The extent of flooding must be sufficient to prevent significant oxidation and metal release even during extreme climatic conditions. The maintenance of flooded conditions will depend on the water holding capacity and drainage input and output rates of the storage location; factors which are determined by climatic and hydrological[5] conditions.

Oxidation - The underwater storage plan must evaluate the possible mechanisms for oxidation and demonstrate that their impact will be insignificant or provide adequate mitigation. Important information includes the duration and extent of pre- and post-flooding aerial exposure, the rate of oxygen input through groundwater and the potential for waste material remobilization into an overlying oxygenated water column.

[5] In this document the broad definition of the term hydrology has been used; it incorporates the studies of both surface and groundwater (i.e. includes hydrogeology).

Long-term Performance of Impoundment Structures - Structures built to create flooded storage conditions must be designed, constructed and maintained in a manner which ensures long-term geotechnical stability and effective performance throughout the entire range of possible site conditions. Monitoring is required to detect situations for which maintenance or repairs are required. Constructed water-retaining dams or bulkheads are not considered walk-away technologies because of the indefinite maintenance and monitoring requirements.

Management For and After Closure - Flooded storage systems must be designed, constructed and operated in a manner that ensures receiving environment and reclamation objectives can be met after the mine closes and natural physical and biological processes resume. As nature reasserts itself, there are a number of possible mechanisms that may cause contaminant release. The current expectation is that the impact of processes like sedimentation and biological uptake on contaminant migration will be relatively small and that any potential problems can be prevented through additional mitigation. During the life of the mine, the operator must conduct testwork to assess the potential for post-closure contaminant release and determine if additional mitigation is required.

4.3.2 Constructed Surface Impoundments

The practice of building water-retaining dams has been successful in British Columbia and as a result, underwater storage of tailings or waste rock in permanent engineered impoundments is an accepted method for ML/ARD prevention. However, since water retention creates additional geotechnical risks and construction, monitoring and maintenance requirements, permanent water retaining dams should be kept as small as possible and only utilized if required. Poor geochemical prediction and waste management planning is an unacceptable rationale for assuming a waste is potentially ARD generating (PAG) and creating an unnecessary geotechnical hazard and ML/ARD concern.

4.3.3 Pits and Underground Workings

Underwater storage in flooded pits and declined underground workings can be an effective method of preventing sulphide oxidation from mine walls, talus debris and backfilled mine wastes. Concerns to be addressed include the potential delay in flooding, the extent to which flooding will occur, water level fluctuations and the eventual loadings and discharge locations.

4.3.4 Underground Bulkheads

Bulkheads used to flood underground workings have often been unsuccessful. Fractured bedrock and bedrock collapse have resulted in failures to flood and uncontrolled discharge. A major concern in bulkhead design is the question of where the impeded underground drainage will eventually emerge. Other concerns include the difficulties of grouting, locating surface drill holes, detecting geotechnical problems and carrying out repairs. Because of the potential problems, contingency measures are likely to be required whenever an underground bulkhead is proposed as the primary means of environmental protection. Declined underground workings are preferable to bulkheads in PAG ground or in areas used for the backfilling of problematic wastes.

4.3.5 Natural Water Bodies

Underwater disposal in natural water bodies, including marine environments, will only be considered if it can be demonstrated that the disposal site is environmentally preferable and there will be no significant impact on the environment or downstream water uses, both during and following disposal.

4.4 Covers

Engineered covers can be used to reduce the supply of oxygen to sulphide oxidation. They can also be used to reduce metal leaching and contaminant loads resulting from the infiltration of incident rainfall and snow melt. Cover use for ML/ARD mitigation has been limited. Most cover use in Canada has been to reduce drainage infiltration into already acidic wastes with the objectives of decreasing leaching, the volume of discharge and water treatment costs.

The ability of a cover to decrease drainage infiltration and/or air ingress will depend on the cover design, the characteristics of available construction materials, the geotechnical stability (i.e. little or no cover erosion or dump settling) and site-specific climatic conditions. At several sites around the world, covers have been shown to prevent convective air movement and reduce oxygen diffusion. Under humid British Columbian conditions, some drainage infiltration is expected through most covers; thus with regards to infiltration, covers are generally considered to be a reducing mechanism rather than a preventing mechanism. While it is possible to prevent infiltration with a multi-layer geotextile cover, for large waste volumes this is only feasible under very favourable economic conditions.

Cover use as the primary mitigation strategy will depend on the degree of reduction in infiltration and/or air ingress versus that needed to meet discharge quality requirements.

Two important areas of uncertainty in cover design and drawbacks to their use are long-term performance and the measures required to ensure the necessary degree of effectiveness. Long-term performance is required for most covers. Since few existing covers are more than ten years old, further operational testing is required to determine the long-term design criteria and complementary monitoring, maintenance and replacement requirements. Further operational testing is also required to determine the relationship between cover performance and design constraints. In general, covers are expected to be most easy to construct and maintain on fine textured, level or gently sloping wastes.

In addition to the properties of the cover, the ability of a cover system to delay ARD onset or enable receiving environment objectives to be met will depend on the presence of other air and drainage sources and the amount of weathering that occurs prior to cover installation. Important contributing factors include the characteristics of the waste, mine scheduling and design, the timing of cover placement and the hydrology of the disposal site.

Covers proposed for ML/ARD mitigation must be designed to be compatible with site-specific conditions and constructed according to the clearly defined specifications required to meet performance objectives. Cover design and construction supervision must be carried out by qualified and experienced professional engineers.

4.4.1 Information and Design Requirements

A cover proposal requires a detailed design and supporting testwork that demonstrates adequate performance for the intended period of use. The proposed design must include the cover type, the mechanism for reducing water and/or oxygen ingress, cover material characteristics, construction requirements, measures for cover protection, procedures for verification of predicted performance, instructions for maintenance and/or replacement, descriptions of proposed surface reclamation and the identification of air or drainage sources which may circumvent the cover or otherwise compromise the mitigation objectives.

The design of an engineered cover must ensure future performance over the required period of time and the expected range in climatic conditions and biological parameters. Factors to consider include the effects of potential settling, chemical weathering, desiccation, freeze/thaw cycles, erosion, root penetration and burrowing by animals.

4.5 Blending of PAG and NPAG Wastes

Blending refers to the co-deposition of potentially acid generating (PAG) wastes with materials with excess neutralization potential (NP), or non-potentially acid generating (NPAG) wastes. The objective in blending is to create a composite in which the acid produced by PAG wastes is neutralized by excess NP and drainage alkalinity from NPAG materials, with a consequent reduction in metal solubility.

The degree of mixing and the spatial relationship between PAG and NPAG materials plays a major role in determining both the performance and the effectiveness of the blend. Performance is generally maximized when complete, grain-by-grain mixing of PAG and NPAG produces a composite that is entirely NPAG. Where there is some degree of physical segregation between the blended materials, acidic pH conditions are expected to develop to some degree in the PAG material.

Blending has some potential strengths as a mitigation tool, including limited maintenance requirements, compatibility with a wide variety of terrestrial end land uses and in some cases fewer long-term geotechnical concerns (i.e. compared to a water retaining dam) and lower costs. However, blending also has a number of potential disadvantages which currently restrict its use. The type of constraints will, to some degree, depend on the degree of mixing and the spatial relationship between PAG and NPAG materials.

Major constraints include:

Costs - The major constraint for a completely mixed blend of PAG and NPAG wastes are the potentially prohibitive materials handling or amendment costs.

Performance Limitations - Elevated neutral pH concentrations of some metals are possible even if ARD from the segregated PAG material is neutralized. For a well mixed composite, there is the possibility of elevated neutral pH metal leaching from metal-rich sulphides even under neutral pH weathering conditions.

Technical Uncertainty - For a segregated blend, the composite waste performance will depend on the interactions of complex geochemical and hydrological processes, factors which are difficult to study and for which the current understanding is limited. This makes the prediction of water movement and geochemical performance difficult.

Demanding Information Requirements - Blending requires comprehensive material characterization and, in the case of a segregated blend, waste design and construction plans, both of which must be supported by detailed prediction information.

Extensive Material and Construction Requirements - PAG and NPAG materials must have suitable characteristics. NPAG wastes must occur in sufficient proportions and their composition and timing of excavation must be compatible with that of PAG waste. The requirement for detailed operational material characterization may delay excavation, materials handling and deposition. Also, blending often has demanding materials rehandling and deposition requirements.

The acceptability of a blending proposal will depend on the mitigation objectives, site-specific conditions, evidence provided and the proposed design. Blending will only be accepted as an environmental protection tool if supported by detailed design criteria, strong evidence of feasibility and effectiveness, and in the case of a segregated blend, adequate back-up or contingency measures. With a large surplus of effective NP, small drainage inputs and/or low, neutral-pH metal loadings, a blended waste may produce acceptable drainage for discharge. Where site conditions are less favourable, the role of blending will likely be restricted to that of an accessory tool to other more feasible or reliably effective mitigation procedures.

4.5.1 Information and Design Requirements

A proposal to blend wastes must include detailed materials handling and placement plans, supported by comprehensive material- and site-specific testing. A knowledge of the geochemistry, hydrology and consequent long-term contaminant discharge rates are required to set design criteria and determine the potential need and timing of contingency mitigation measures. Since the performance of blended wastes depends on complex site-specific processes, it is not possible to set generic blending design constraints.

Effective Neutralization - Effective neutralization requires NPAG materials with suitable weathering characteristics to be available in sufficient proportions and properly placed relative to PAG materials.. Design objectives to improve NP effectiveness include measures to reduce the rate of acid generation, maximize ARD contact with NP and reduce the blinding of neutralizing minerals by iron and aluminum precipitation.

Drainage Reduction - Reductions in the volume and rate of flow of drainage, especially through PAG materials, will maximize NP effectiveness and reduce metal loadings. Placement of the blended waste, especially its PAG components, in a topographic position that limits drainage inputs will reduce drainage discharge. The physical properties and configuration of PAG and NPAG materials within the blended waste can also be used to minimize the leaching of PAG strata.

Material Characterization and Monitoring - The proponent will be required to undertake pre-operational and post-deposition material characterization, and monitor the quality and quantity of drainage and the progress of weathering within the waste. It is essential that the mine plan allows sufficient time to carry out the necessary material characterization prior to material placement or mixing.

Compatibility with the Mine Plan - The proponent must demonstrate that the proposed PAG/NPAG material segregation and blending is compatible with the mine geology and excavation plan. The blending plan must show the relative proportions of PAG and NPAG rock types excavated during different phases of mine development, demonstrate that the plan is compatible with the mining sequence and indicate that there are sufficient resources for any required materials rehandling. A favourable waste balance, compatible PAG and NPAG material excavation, and the timely availability of disposal sites all minimize the need for rehandling.

Interim and Contingency Prevention/Mitigation Measures - Where significant uncertainty exists, detailed contingency plans will be required and blended wastes must be placed in a location and manner that permits drainage collection. A contingency plan must include provision of the necessary resources and a monitoring program to ensure timely and effective implementation of the secondary mitigation measures. Sufficient resources must be available to conduct any outstanding materials handling and mitigation requirements for stockpiled PAG waste in the event that a shut down precludes part of the plan. Interim prevention/mitigation measures may be required to delay ML/ARD onset in materials exposed in temporary stockpiles prior to final disposal in a blended dump or impoundment.

4.6 Drainage Collection and Treatment

With effective drainage collection and the appropriate process or technology, the treatment of contaminated drainage can be a highly effective and reliable means of protecting the downstream environment. However, long-term treatment has a number of significant potential drawbacks and, therefore, should only be used if preventative mitigation methods are unfeasible, unreliable or ineffective. Drawbacks with long-term treatment include the associated risks, liabilities, land alienation and secondary waste production. Where feasible, additional mitigation measures should be implemented to reduce these factors.

4.6.1 Information and Design Requirements

While various ML/ARD sources and treatment methods have different management needs and constraints, there are a number of generic factors which must be considered. The following discussion focuses on long-term drainage collection and chemical treatment using lime due to its importance and frequent use.

Quality and Quantity of Contaminated Water Sources - The design of an effective collection and treatment system requires a determination of the discharge locations, flows, acidity and metal loadings for all potentially contaminated drainage sources. Detailed studies of site hydrology are required to predict the rates of ML/ARD from different site components.

Effectiveness of Drainage Collection Systems - The drainage collection system must be capable of collecting and storing all significant sources of contaminated drainage. It must also be able to perform over the potential range of hydrologic and climatic conditions. Detailed climatic, geotechnical and hydrological studies are required to demonstrate that the collection of contaminated drainage is feasible. Comprehensive operational monitoring and timely maintenance are required to ensure drainage collection systems work as planned. Additional pre- and post-treatment storage capacity will likely be required as a contingency to handle extremely high flows.

Effectiveness of the Treatment Process - The treatment process must allow the mine to meet discharge limits and avoid negative impacts to the receiving environment over the entire range of drainage contaminant concentrations and flow rates.

Treated Effluent Discharge - Discharge requirements will depend on effluent quality, quantity, discharge locations and receiving environment objectives.

__Disposal of Secondary Waste Products__ - The proponent must predict the quality and quantity of any secondary wastes produced in the treatment process and provide an acceptable disposal plan which addresses the issues of physical security and geochemical stability. The proponent must monitor the composition and volume of the produced waste and carry out long-term monitoring of the drainage from the disposal site.

__Environmental Risk__ - Potential sources of environmental risk associated with collection and treatment include the continual presence of contaminated drainage, long-term operational requirements and the creation of secondary waste products. Constant vigilance, an effective monitoring program, the ability to perform under extreme climatic conditions, well prepared contingency measures, an on-going financial capability, a commitment from the proponent to carry out all operation and maintenance work and a comprehensive risk management plan are required to ensure the receiving environment will not be negatively impacted.

__Alienation of Land and Water Resources__ - The creation of contaminated watercourses, secondary waste disposal areas and the ongoing use of dams, treatment facilities and access roads prevent their reclamation and alienate them from future alternate uses. A mine plan which proposes long-term collection and treatment must identify potential impacts to other land uses and compare the costs and benefits of the mine against those of alternate land uses.

__Capital and Long-term Operating Costs__ - Existing and estimated future expenditures must be provided for each aspect of the collection and treatment system. This includes the capital costs for treatment and collection facilities and the operating costs for lime, power, personnel, pumps, maintenance, monitoring, treatment waste disposal and contingencies in the event of upset conditions. This information will be used to set the security bond and to ensure the proponent has the resources necessary to conduct the required work.

4.6.2 Long-term Chemical Treatment

While long-term drainage treatment with chemicals such as lime can be an effective means of protecting the off-site environment, it also results in significant long-term environmental risk, liability and land alienation. Therefore, long-term chemical treatment will only be acceptable under the following conditions:

1. if other preventative mitigation strategies such as underwater disposal, are not feasible or create more risk of environmental contamination, or

2. as a contingency measure where there is a small but significant uncertainty regarding ML/ARD prediction or performance of primary mitigation strategies, and

3. with satisfactory fulfillment of the information and design requirements.

The required supporting information includes detailed engineering, cost projections, consideration of relevant ecological factors and a comprehensive risk management plan to show that environmental values will not be jeopardized. Where collection and treatment is proposed for a new mine, this information will be used to determine if mining is an acceptable and viable land use for the site. The security bonding requirements are likely to make long-term collection and treatment a prohibitively expensive mitigation strategy for almost all new mines.

4.6.3 Commercial Acid Leaching

Existing operations in British Columbia have shown that commercial acid leaching can be a cost effective means of recovering metals from oxidized rock. Since acid leaching results in many of the same environmental protection concerns, the information and design requirements for collection and treatment of normal ML/ARD generating mine wastes also apply to commercially acid leached dumps. This includes provisions concerning the effectiveness of the drainage collection system and treatment process, commitments to implementing additional mitigation measures and submission of a security prior to creation of risk. The financial security for a commercial acid leach must be large enough to ensure acidic drainage/leach solutions can be collected and treated after the ore is exhausted or in the event the operation closes prematurely.

4.6.4 Passive Drainage Treatment

Experience to date in British Columbia has shown that most forms of passive drainage treatment are incapable of handling high metal loads or high flow rates and reliably meeting low discharge concentrations. Passive treatment is best suited as a drainage polishing measure or for treating small seeps. Passive treatment is generally only recommended as the primary means of environmental protection where the use of other more reliable, but invasive mitigation measures, increases the net impact.

5. CONSTRUCTION MATERIALS

Prior to the use or disturbance of materials for construction or mine development, the proponent must demonstrate that the rock and/or surficial materials have no potential for significant ML/ARD. This must be verified by geologically and spatially representative sampling and comprehensive laboratory analysis. The regulatory limitations set on the use of materials for construction purposes will depend on the deposition site, strength of the prediction testwork, environmental risk and mitigation measures.

6. BACKFILL

If properly managed, backfilling of mine wastes into exhausted mine workings can be a very effective disposal strategy. Backfilling should not occur until material characteristics, disposal site hydrology and future waste drainage are well understood, and there can be assurances of hydrological isolation or flooding within the required period of time. Potentially problematic wastes should never be placed in areas with fluctuating water tables or high rates of flow.

7. GEOTECHNICAL AND HYDROLOGICAL CONSIDERATIONS

Geotechnical conditions, site hydrology, receiving environment conditions and site water management play a large role in determining the impact of ML/ARD and the effectiveness of mitigation strategies. Therefore, in addition to ML/ARD-specific items, a mitigation proposal must be supported by detailed baseline information and comprehensive management plans for the relevant geotechnical and hydrological factors.

7.1 Drainage Management

Drainage management is an important requirement at all minesites and is especially significant for those with ML/ARD concerns. Effective drainage management requires a comprehensive understanding of site hydrology. Potential management measures include monitoring flow and water quality, the construction and maintenance of works for flood protection, the diversion of clean water around potential contaminant sources, a collection and disposal system for potentially contaminated drainage, and selection of the best disposal site for potential contaminant sources like dumps and impoundments.

Prior to mine development, the operational and post-mining hydrology of important mine components must be predicted through detailed site monitoring and hydrologic modeling. Pre-mining predictions based on the existing conditions must be verified by operational, and if necessary, post-mining monitoring.

7.2 Geotechnical Requirements

Minimum design criteria for ML/ARD mitigation features should be based on the consequences of failure and the availability of back-up and contingency protection measures. During mine operation, the design criteria for ML/ARD prevention and collection features, such as ditches, dikes, impoundments and pumping systems, should be a one-in-200-year flood. At closure, where the consequences of failure are high, the minimum design criteria should be the probable maximum flood and maximum credible earthquake.

7.3 Discharge and Receiving Environment Objectives

Water quality, loadings, flows and water use studies are required to predict and detect impacts and set regulatory conditions such as receiving environment objectives and discharge limits. To ensure the necessary data is collected during the pre-mining baseline environmental studies, the discharge requirements must be considered at the inception of mine planning.

Provincial water quality criteria, designed to protect the most sensitive water use, may be inappropriate as water quality objectives for water courses in the vicinity of mining projects. Many watercourses in the vicinity of economic mineralization have metal concentrations which exceed the Provincial criteria even before mining. In most cases, proponents are required to conduct the detailed studies of hydrology, water chemistry, aquatic life, and sediment needed to set site specific water quality objectives. Regional environmental impact assessment personnel within MELP should be consulted regarding specific information requirements.

8. FINANCIAL SECURITY

Financial security is required as a permitting condition. For mines with an existing requirement for chemical treatment or a significant potential for ML/ARD, full security is required to pay for all outstanding reclamation obligations, including long-term costs associated with monitoring, maintenance, drainage collection and treatment.

9. COMMITMENT TO IMPROVED PRACTICES AND REGULATION

British Columbia will continue to assist in the improved understanding and development of ML/ARD technology and revise policies accordingly.

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