GUIDELINES FOR METAL LEACHING

AND ACID ROCK DRAINAGE

AT MINESITES IN BRITISH COLUMBIA

William A. Price and John C. Errington

MINISTRY OF ENERGY AND MINES

August 1998

BRITISH COLUMBIA

TABLE OF CONTENTS

ACKNOWLEDGMENTS

These guidelines have been created with assistance from members of the Ministry of Energy and Mines' Metal Leaching/Acid Rock Drainage Expert Advisory Committee:

Garry Alexander	Ministry of Environment, Lands and Parks
Stephen Day	Norecol, Dames & Moore
Keith Ferguson	Placer Dome North America Ltd.
Glenda Ferris	Northern Ecology Action Committee
Walter Kuit	Cominco Ltd.
Kevin Morin	Minesite Drainage Assessment Group
Alan Young	Environmental Mining Council

At the request of the authors detailed reviews were also carried out by:

Peri Mehling	Mehling Environmental Management
Gilles Tremblay	MEND Secretariat

The authors gratefully acknowledge the extensive technical contributions and the time devoted to this project by the above individuals. However, their support should not be construed as an endorsement, in whole or in part, by them or by the organizations they represent.

Kim Bellefontaine, Ministry of Energy and Mines, is thanked for the extensive improvements she made to the clarity and to geological aspects of the document. Tim Eaton, Ministry of Energy and Mines, checked geotechnical aspects of the report. Bob Hart and Jim Hofwebber provided much of the detail regarding discharge and receiving environment objectives and the requirements of the Ministry of Environment, Lands and Parks. Valuable contributions were also made by Grace Harris, Carol Howell and Sylvia Van Zalingen of the Ministry of Energy and Mines; Laura Duncan of the Environmental Mining Council; and various regional reviewers of the Ministry of Environment, Lands and Parks.

The Ministry of Energy and Mines is committed to improving existing practices and regulation. Comments on this document and other aspects of metal leaching and acid rock drainage regulation should be submitted to:

William Price
Mines Branch, Ministry of Energy and Mines
Bag 5000, Smithers, BC
V0J 2N0

1. INTRODUCTION

1.1 PURPOSE OF GUIDELINES

There are numerous examples throughout the world where elevated concentrations of metals in mine drainage have adverse effects on aquatic resources and prevent 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 (Arnesen and Iversen, 1997). In North America, ML and ARD (ML/ARD) have led to significant ecological damage, contaminated rivers, loss of aquatic life and multimillion-dollar cleanup costs for industry and government. The ARD liability associated with existing Canadian tailings and waste rock is estimated to be between $2 billion and $5 billion (Feasby and Tremblay, 1995).

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.

Under existing British Columbia legislation and policies, mining companies are fully responsible for environmental protection and reclamation at their minesites and must demonstrate the effectiveness of their plans in the development, operation and closure phases of the mine (BCMEM and BCMELP, 1998). The responsibility of regulatory agencies is to indicate, as clearly as possible, what constitutes acceptable mine design and adequate technical evidence.

Although every rock, waste and minesite is somewhat unique, there are ML/ARD information needs, test procedures, design objectives and management requirements that apply under most circumstances. The primary objectives of this document and the complementary prediction manual (Price, 1997) are to describe generic requirements and outline common errors, omissions and constraints. This information will assist mines in developing comprehensive proposals that include the necessary documentation and consideration of risk for sound environmental management.

The guidelines have also been produced to assist regulators and members of the public who are interested in reviewing ML/ARD work. The Ministry of Energy and Mines (MEM) endeavors to be transparent in its regulation and to carry out comprehensive, well informed mine reviews. By documenting the technical basis for present practices, MEM hopes to promote greater understanding of ML/ARD issues and to enable the identification of gaps in the knowledge base.

The guidelines provide general direction on ML/ARD issues and management without limiting options and approaches. They were developed from previous experience, primarily in British Columbia, and do not apply to all minesites and conditions. Users of the guidelines, both in this Province and in other biogeoclimatic regimes or regulatory jurisdictions, must consider site-specific conditions and materials when deciding which principles and procedures apply, and how they should be implemented.

1.2 METAL LEACHING AND ACID ROCK DRAINAGE

Metal[1] leaching and acid generation are naturally occurring processes which may have negative impacts on the receiving environment. The environmental impact of ML/ARD will depend on their magnitude, the sensitivity of the receiving environment and the degree of neutralization, dilution and/or attenuation. Factors which enhance metal leaching include rapidly weathering metal-containing minerals, drainage conditions that increase solubility and high flow rates through contaminated materials.

Acid generation occurs when minerals containing sulphide 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. 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.

---

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

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. Unlike ARD, 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.

The characteristic low pH values and rust-coloured iron staining associated with ARD are often found in natural watercourses in the vicinity of undisturbed, naturally weathered outcrops of sulphide-bearing rock (i.e., gossans). The Provincial Regional Geochemical Survey, which has sampled and analyzed streams throughout British Columbia, has found numerous occurrences of natural acidic drainage (Lett et al., 1996). Rapid sulphide oxidation in undisturbed areas is usually restricted to the thin, unconsolidated surface layer or to a few outcrops.

Human activity can greatly enhance acid generation and metal leaching. Sulphide oxidation resulting in very acidic pH values is common worldwide in marine soils drained for activities such as farming (Pons et al., 1982). ARD also occurs where mineralized bedrock is excavated for use in construction. An example of this is some of the forestry road building on Northern Vancouver Island (Koyanagi and Panteleyev, 1994). 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 surface 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.

While sulphide mineral oxidation results in acid generation, mining operations that expose sulphide-bearing rock do not always create ML/ARD. In many cases, drainage alkalinity or other minerals neutralize the acid. Acid neutralization and the consequent reduction in metal solubility can occur immediately or at some downstream point. Acidity will only persist if acid generation is faster than the rate of neutralization or continues after the available neutralization is exhausted. Even if net acid conditions result, ML/ARD may not be a concern if there is adequate neutralization or dilution prior to discharge, or if insufficient water exists to transport acid weathering products.

The rates and timing of ML/ARD onset are dynamic processes which are determined by a large number of site-specific mining, geological and environmental factors. In some instances, the onset of acid weathering conditions and ARD are instantaneous. At other minesites it has taken 10 to 20 years to exhaust the available neutralization (Morin and Hutt, 1997). It may take many years before weathering or leaching conditions cross the biological, physical and chemical thresholds necessary for significant adverse impacts; therefore, the observation that ML/ARD has not yet occurred is, on its own, no assurance that they will not occur in the future.

1.3 DEVELOPMENT OF GUIDELINES

MEM first compiled its working policies and procedures for ML/ARD in 1991 (Errington, 1991). The first update was issued as an interim Provincial policy by the Reclamation Advisory Committee in July 1993 (BCMEMPR, 1993). In 1995, an expanded set of ARD guidelines (Price and Errington, 1995) was produced by MEM based on additional experience with earlier documents and comments received on the Provincial policy. This current document (Price and Errington) is more detailed than its predecessors and was developed from experiences in regulation, research carried out by MEM, Mine Environment Neutral Drainage Program (MEND) and others (Lapakko et al., 1995), and with significant input from MEM's ML/ARD Expert Advisory Committee. These new guidelines outline the information required to satisfy the general policy objectives of the new Provincial policy for ML/ARD (BCMEM and BCMELP, 1998). The Provincial policy was largely derived from these guidelines.

In response to frequent requests for advice and the need to improve existing practices, MEM has produced a separate prediction document entitled "Draft Manual of Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia" (Prediction Manual) (Price, 1997). The Prediction Manual recommends procedures and methods for providing required information; an updated version will be released later this year.

This document and the Prediction Manual are intended to be dynamic documents which will be periodically reviewed and revised when warranted by new developments.

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.

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[2] 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 impact prevention are not appropriate or practical for ML/ARD since they would be unnecessarily restrictive at most minesites but would not be sufficiently stringent to forestall all the anomalous conditions that could threaten the environment. The alternative and the approach taken by the British Columbia Government has been to evaluate ML/ARD on a site-specific basis and to focus on the process of information gathering. To ensure effective problem detection and mitigation 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

[2] 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 (MacDonald, 1997) or preclude attainment of reclamation objectives established by the Ministry of Energy and Mines (BCMEI, 1997).

process should ensure timely prediction and prevention at 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.

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

Ability and Intent **- A mine proponent must demonstrate that they have the necessary understanding, site capacity, technical capability, resources 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, prevention, 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.**

---

[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.

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 ML 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 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 ML 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 condition of a *Mines Act* permit, financial assurance will be required to ensure sufficient funds are available to cover all outstanding reclamation obligations, including long-term costs associated with monitoring, maintenance, outstanding mitigation requirements and collection and treatment of contaminated drainage.**

A well informed approach to ML/ARD issues is essential for successful site-specific management. Practitioners should recognize why past errors have occurred and have a good understanding of the technical limitations of prediction and prevention work. Many past errors were not caused by gaps in basic knowledge, but resulted from the failure of practitioners to use the appropriate test procedures, correctly interpret test results, test all mine components and consider the limitations and unique challenges faced in ML/ARD prediction and prevention testwork. Some of the technical challenges of ML/ARD assessment include:

- the potential for significant delays in ML/ARD onset,
- large differences in test materials and scale between testwork and actual operations,
- many important parameters are difficult to measure and may not be accurately measured by relatively inexpensive, standard test procedures,
- testwork can be expensive, time consuming and can sometimes conflict with development timelines and mining objectives,
- the need to construct mitigation facilities that last forever and function over widely ranging climatic conditions, and
- a ML/ARD plan has multi-disciplinary information requirements including aspects of geology, rock weathering, environmental geochemistry, hydrology, metallurgy, mining engineering and geotechnical engineering in addition to ML/ARD-specific technology.

For many sites prediction and prevention are relatively straightforward. A well informed approach to ML/ARD, including proper consideration of challenges involved, should ensure environmentally safe practices in situations where prediction and prevention are more complicated.

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 mine design, materials handling and waste 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 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.**

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, acid generation potential and neutralization potential availability and performance. Testing should determine both the range and variability.

The onset of ML/ARD is controlled by geochemical thresholds which may take many years to reach. An absence of acidic conditions, both on a minesite and in testwork, does not prove there will be no ML/ARD in the future. It is therefore imperative that ML/ARD prediction be conducted on all materials that will be disturbed or were previously impacted by mining. The type and amount of testwork required will depend on the prediction questions and site-specific conditions such as the stage of project development, rock/waste/exposure types, materials handling plans, the post-excavation environment and availability of test materials such as drill core. For example, if initial studies of tailings indicate a strong ARD potential but no metal dissolution concerns, the main prediction question for subaqueous deposition will be the effectiveness and long-term maintenance of an oxygen barrier.

Sensitivity analysis should be conducted to determine the sufficiency of available prediction information and the impact of possible inaccuracies. Factors to be evaluated include the accuracy of the ML/ARD assessment, predicted waste volumes, the capacity for waste segregation and storage, the availability of construction materials and the ability to meet discharge limits and receiving environment objectives. The results of sensitivity analysis can be used to determine if additional storage capacity is required, where more information could permit the use of lower risk mitigative methods and to identify where contingency protection measures may be necessary. They can also be used to set requirements for regulatory approvals and permitted waste handling.

3.2 PHASED APPROACH

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.

Due to the large number of factors to consider (i.e., geological, mining, environmental and ML/ARD information requirements), prediction testwork can be a significant undertaking in terms of the information required, resources necessary for data collection and expertise required for data interpretation. A phased approach to data collection and interpretation should ensure the proponent:

- focuses on the materials and areas of greatest concern,
- avoids unnecessary work on materials for which there is no significant ML/ARD uncertainty,
- uses the most appropriate test materials and procedures, and
- makes timely refinements in response to unforeseen conditions.

In a phased test program, the results from cheaper test procedures carried out on a large number of samples can be used to select representative samples for more expensive testing. This cuts down on the number of samples and ensures that the expensive, time consuming tests, are conducted on the proper materials. Examples of this approach include the use of geological mapping and static testing to select samples for kinetic test procedures and the use of static and kinetic testing to determine whether expensive sub-microscopic mineralogical determinations are necessary.

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.

A primary objective in ML/ARD prediction is often the identification of materials that will perform alike and can be managed with similar prevention/mitigation prescriptions. Based on the results of the preceding round of sampling and analysis, it may be necessary to further subdivide management units, refine prediction questions and modify test procedures. Conversely, it may be possible to reduce the number of management units by combining geological materials that have similar mitigation and waste handling requirements.

3.3 AVOIDING ERRORS

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.

Proper planning is an essential component of successful prediction. A well crafted prediction program can be both time and cost efficient.

3.4 PREDICTION MANUAL

To address the frequent requests for advice regarding laboratory testing and data interpretation, MEM has produced a separate prediction guidelines document entitled "Draft Manual of Guidelines and Recommended Methods for the Prediction of Metal Leaching and Acid Rock Drainage at Minesites in British Columbia" (Prediction Manual) (Price, 1997). The Prediction Manual is intended to be a companion to this document and should be consulted by practitioners looking for detailed guidance on prediction. Adherence to the generic prediction procedures recommended in the Prediction Manual should ensure that basic information needs are satisfied, while allowing the proponent to identify where shortcuts or site-specific refinements may be required. An overview of test procedures and information requirements are provided here.

3.5 STEP 1 - IDENTIFY AND CHARACTERIZE 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.

Information required in this initial reconnaissance can generally be derived from existing bedrock and surficial terrain mapping, drill logs and other relevant geological studies. Parameters to be reported for each material should include mass, dimensions, location, mode of genesis, lithology, bulk and vein mineralogy, sulphide mineralization, alteration features, alteration mineral assemblages, degree of oxidation, colour, results of the hydrochloric acid fizz test, grain size, particle size, structure, fracturing and strength. Usually one or more of the properties used to differentiate geological units are important contributors or controls in weathering processes.

An important factor in ML/ARD prediction is the spatial distribution of changes in geological properties such as structure, mineralization and alteration. In mineral exploration, the initial separation of rock types is usually based on differences in lithology. While there is often a strong correlation between the ML/ARD potential and lithology, significant variation may also occur within lithological units as a result of differences in structure, mineralization and alteration.

Ideally, geological materials can be separated into discrete, homogeneous geological units. However, where geological variability makes it impossible to separate surficial materials or bedrock into uniform units, the proponent should divide the geological materials into manageable units based on practical constraints such as size, location, access and future excavation. For example, bench or adit heights may be used to divide separately manageable units of waste rock.

Surficial and bedrock maps should show the location of the proposed mine workings (i.e., open pit and underground) and other mine components (i.e., waste dumps, tailings facilities, millsite). Structural features are also important items to include. Maps should detail the locations of faults, major fracture systems or fold structures. The accompanying text should describe the geological characteristics of each material and its ultimate forms of exposure (i.e., mine walls, tailings, waste rock, construction materials).

At existing operations, or where new mining projects will affect or be affected by historical mining, previously excavated mine workings and wastes must be mapped. In addition to the properties listed above, the information provided should include the mode of deposition and/or exposure and the quantity of materials (mass, volume and/or aerial extent). Existing mining-related disturbances should be mapped in sufficient detail to show the topography of the present surface, the original underlying terrain and the location of any permanent or intermittent watercourses. Mapping should also indicate the location of other minesites in the same watershed.

3.6 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.

Questions to be addressed at this stage include:

- What are the acid generation potential, neutralization potential and trace element contents?
- In what minerals do the metals, trace elements, acid sources and neutralization potential occur? What potential contaminants occur in reactive minerals? To what extent will the important minerals be exposed and available to react?
- What are the important weathering processes? Is dissolution a concern? Will acid generation and primary metal release occur entirely from sulphide oxidation?
- What physical changes will occur as a result of excavation and weathering and how will they alter other weathering reactions, drainage conditions and the amount of mineral exposure?
- Under what physical and geochemical conditions will weathering and contaminant transport occur?
- What differences exist between test conditions and materials and those present in the field?
- What criteria should be used to identify and possibly separate potentially ARD generating materials (PAG) from not-potentially ARD generating materials (NPAG)?
- How long will it take for ARD and other important hydrological or weathering events to occur?

Additional questions for existing mines with ML/ARD are:

- What portion and mass of the mine component in question is currently experiencing acidic weathering conditions and generating ML/ARD?

- What is the present hydrologic status of the site, how is it changing, what will be the final conditions and when will they occur?

Some weathering conditions, such as those related to reduction/oxidation potential, will largely be determined by the physical properties of waste, the depositional environment and mitigation procedures. Other conditions will result from concurrent weathering reactions. For example, geochemical conditions created by weathering will play a major role in determining trace element solubility and the potential for off-site transport. One of the most important factors controlling the rates and time to significant metal release and leaching will be whether or not ARD will occur and, if it will, the time to ARD onset.

Assessments of the potential for ML/ARD are typically done in three steps; first for individual samples, then for whole geological strata and finally for mine components.

3.6.1 Test Procedures

Prediction data may be obtained from a great variety of materials and methods, including detailed mineralogical studies, comparisons with other sites, drainage monitoring, static laboratory tests, kinetic laboratory tests and on-site field trials. There is usually no single piece of evidence or conclusive test; proponents must combine information from a variety of sources. For example, the drainage chemistry from historic wastes on the same site might be presented with detailed acid-base accounting and geological data to demonstrate that historic and future waste rock will have similar compositions and weathering conditions.

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 every site:

Static Tests:

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**

The following field test procedures provide very useful information and are commonly recommended:

- on-site test pads,
- wall washing stations, and
- monitoring of weathering in dumps, impoundments and mine workings.

Where field testing is not possible and the expected geochemical conditions can be duplicated, laboratory column studies may be used to predict drainage chemistry.

Factors to include in the interpretation of test and assay results include particle size, hydrology, the timing of ML/ARD events and differences between test materials and conditions and those in the field.

3.7 STEP 3 - DEVELOP MITIGATION AND MONITORING PROGRAMS

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.

Questions to be addressed at this stage include:

- What disposal/remediation methods are needed? This will depend on the prediction-related questions regarding important weathering reactions and potential drainage quality and quantity.
- What space or land base is required for the selected waste disposal strategies? This requires a determination of the mass or volume of each waste type. For lime treatment this requires an evaluation of the requirements for the collection system, the treatment plant, sludge disposal, the dilution zone for treated effluent discharge, and access for monitoring, maintenance and running the operation.
- What effect will differences in the schedule of materials production have on mitigation?

- What material characterization and drainage monitoring procedures are needed to guide the extraction, waste handling and disposal operations? Sampling requirements and laboratory and data analysis procedures will be determined from baseline studies, previous testwork and from the operational and environmental requirements.
- How long will it take for significant ML/ARD to develop in materials for which there will be a delay prior to the application of remedial measures? This is particularly important for PAG mine walls or PAG wastes which will be back-filled into presently active or slowly filling pits or underground workings. The kinetic testwork necessary to answer this question will usually include humidity cell tests. Wall washing stations can be used to estimate the leaching performance of mine walls.

The ML/ARD properties of individual wastes and mine walls are often highly variable, a factor which complicates both prediction and mitigation. A description of the recommended mitigation information requirements for materials with both benign and significant metal leaching components is provided in the section on Blending of PAG and NPAG Wastes (page 40).

4. MEASURES TO PREVENT OR REDUCE METAL LEACHING AND ARD

4.1 MITIGATION PRINCIPLES

Guiding principles for mitigation include:

Mitigation Plans **- Mines with the potential to create significant impacts to land and watercourses 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, operated and if possible decommissioned in a manner that allows them to perform indefinitely. Successful long-term operation requires sustained 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 PREVENTION AND REDUCTION OF ML/ARD

Effective mitigation requires a clear understanding of how mitigation methods work, the possible impacts and limitations, and the contributing chemical and physical processes. Mitigation actions may target specific chemical and physical inputs, mineral weathering reactions or aspects of the resulting ML/ARD and their environmental impacts. In order to demonstrate the effectiveness of their mitigation plans, practitioners must be able to communicate these points effectively.

Mitigation measures are commonly categorized as “prevention”, “reduction” or “control”. For example, a surface cover may be used to reduce the infiltration of precipitation, reducing metal leaching sufficiently that it prevents the impact on aquatic biota at a downstream location.

The term prevention refers to complete, or practically complete, avoidance or impedance. Complete prevention is possible for phenomena like ARD or sulphide oxidation which require the exceedance of defined thresholds (i.e., a minimum hydrogen ion activity or a minimum redox potential). While mitigation procedures may not completely prevent processes like oxidation or infiltration, they may reduce them sufficiently to prevent acid weathering and the associated high metal leaching. For example, in a flooded waste storage scenario, some sulphide oxidation may occur if surfaces are exposed to an oxygenated water column. However, the amount of oxidation is often too small to cause significant impact.

The term prevention may also be used with reference to environmental impacts, which are defined as exceedance of minimum thresholds at specified locations. The criteria will vary according to the parameter, the resource and its use (i.e., aquatic biota, drinking water and irrigation).

The term control refers to some form of modification in either magnitude or direction, an alteration of the process or impact without completely stopping it. Control is often used in relation to drainage management actions like diversion, collection, pumping and discharge. Where possible more precise terminology (i.e., reduction) should be used.

Reduction is often the best term to use when describing the mitigation of processes like oxygen movement and metal leaching or parameters like solubility, for which there are a large number of contributing factors and complete prevention is impossible. Factors contributing to metal leaching include the rates of metal release from sulphide minerals, drainage volume and rate of flow, and the solubility of metals in the leachate. Since metals are always soluble to some degree, the objective is to reduce metal concentrations to levels that prevent significant impacts.

When assessing the presence and effects of ML/ARD, scale and location are also important considerations. For example, although no ARD is observed in the existing monitoring, elevated metals in the dump drainage measured at a downstream monitoring point may be occurring due to small zones of acid weathering conditions either in the dump or at other undetected locations. Alternatively, the prevention of metal leaching impacts at the prescribed receiving environment location may be achieved, despite the occurrence of significant upstream weathering and dissolved metal concentrations, if the volume of contaminated drainage is relatively small.

4.3 AVAILABLE MITIGATION STRATEGIES

There are a great variety of mitigation strategies available to prevent the impacts of ML/ARD. These include avoidance, underwater storage, blending of PAG and NPAG materials, covers and collection and treatment. Each mitigation strategy targets different aspects of ML/ARD, uses different mechanisms or processes, and varies in its effectiveness.

The main objective of storing wastes underwater is to reduce the rate of oxidation to negligible levels which practically eliminates acid generation and metal leaching from sulphide minerals. Objectives in blending include the maintenance of neutral pH weathering conditions and the in-situ neutralization of acidic drainage. Covers are used to reduce the contribution of incident precipitation to the transport of acid and metal oxidation products and to reduce oxygen inputs to sulphide oxidation. The objective of collection and treatment is to contain, neutralize and precipitate leached weathering products at a downstream location.

Underwater storage and lime treatment have some clear advantages in terms of reliability and effectiveness and are the most common mitigation strategies implemented; the former for unweathered materials and the latter for large volumes of strongly weathered, ML/ARD-generating wastes. However, all mitigative methods have definite strengths and may be useful under certain circumstances. In many instances, a series of mitigative actions are required. For example, a possible mitigation strategy could be to segregate the PAG waste, blend it with limestone to delay ML/ARD onset, stockpile it, back-fill it into a pit and eventually flood it.

The following subsections in this chapter outline the main objectives of ML/ARD mitigation and briefly describe the relative performance of major mitigation strategies in meeting the general environmental protection and reclamation requirements. Readers are cautioned that this is a summary; there will be exceptions which deviate from general experience. Later sections of this document outline the capabilities, constraints, information requirements and best uses of each mitigation strategy in greater detail.

4.4 EFFECTIVENESS OF DIFFERENT MITIGATION STRATEGIES

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.**

Unfortunately, physical avoidance and ore extraction are often mutually exclusive. Avoidance is most easily practiced with access and ancillary components of the mine. The most common example of avoidance is the relocation of underground access from problematic rock types to more benign ground. **Where avoidance is the only practical mitigation strategy, the need for ML/ARD protection may preclude all or part of the mine.**

Underwater Storage - If problematic rock types are to be excavated or exposed, underwater storage is generally the most effective means of preventing ARD and reducing metal leaching. An important consideration is that saturation may also increase dissolution. Thus, materials must be flooded prior to significant acid weathering. Another important consideration 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.

Chemical Treatment - Where contaminated drainage can be collected, effective treatment can prevent further ARD migration, reduce downstream metal concentrations and prevent off-site impacts. Unlike underwater storage, treatment does not reduce sulphide oxidation or the in-situ leaching of weathering products; contaminated drainage will continue to exist upstream of the collection location. Where materials contain a high load of acidity or soluble metal salts, drainage collection and chemical treatment may be the only feasible[5] means of preventing off-site impacts, at least in the short-term. Due to high costs, on-site contamination, secondary waste production and high maintenance requirements, drainage treatment is generally considered to be the mitigation strategy of last resort to be used only if other prevention/mitigation methods are not feasible.

Blending and Covers - While blending and surface covers hold great promise as methods to reduce metal leaching, outstanding concerns regarding reliability and effectiveness presently restrict their use. Blending and surface covers are considered less reliable than underwater storage. Any proposal that utilizes blending or covers to enable receiving environment objectives to be met will only be accepted under clearly specified conditions, with a detailed design and strong evidence of long-term load reductions. While blending and covers may be useful mitigation tools, providing adequate technical evidence of the degree of effectiveness can be challenging and may require expensive, prolonged testwork.

Waste Segregation - The objectives in waste segregation, to reduce oxygen and/or drainage inputs and increase in-situ neutralization, are typically a hybrid of those for covers and segregated blending. Factors to consider and information and design requirements for waste segregation are discussed in the applicable sections for blending, covers, impoundments and backfill.

[5] Feasible is defined as capable of being done or carried out. The feasibility of a prevention/mitigation strategy is determined by long-term, site- and project-specific, technical and economic requirements.

4.5 SELECTION OF THE BEST MITIGATION STRATEGY

The process for determining the best prevention and mitigation strategy should be based on the ability to meet receiving environment objectives and minimize liability, risk and long-term land alienation.

Achieve Receiving Environment Objectives - The foremost goal of ML/ARD mitigation is environmental protection. The first step in choosing the best mitigation strategy is to identify which procedures or combination of methods will reduce ML/ARD to levels sufficient to meet discharge limits and achieve receiving environment objectives. This assessment should be conducted on each potentially problematic mine material or mine component.

Minimize Environmental Risk - Mines are required to minimize ML/ARD to levels that protect the off-site environment and reduce the alienation of on-site land and watercourses to the extent technically and economically feasible. Of the two objectives, reducing the risk of off-site contamination is considered the higher priority. Risk is defined as the probability and consequences of failure. Where significant risk is identified, additional mitigation and/or contingency prevention measures will be required.

Achieving the required level of understanding is an important part of risk reduction and a crucial task in mitigative planning and plan implementation. Plans must identify possible mitigation outcomes, mechanisms for failure, the likelihood of failure and the resulting impacts. This information can be used to determine the best mitigative approach, to refine the original strategy and to determine monitoring requirements. Monitoring is required during and after construction to guide management and verify the predicted performance.

While mitigation risks can be divided into geochemical, hydrological and geotechnical factors, it is often the combined effect which is important. For example, geotechnical and hydrological factors will affect the stability and effectiveness of dams and bulkheads, while geochemistry and hydrology are primary determinants of the consequences of failure.

In risk assessment, regulators rely heavily on previous experience. Procedures like underwater storage and lime treatment have an extensive track record that can be consulted to determine how materials or a minesite compare with others which are similar and whose performance is known. However, all materials are somewhat unique and proponents will be expected to consider how differences in important parameters will affect the planned mitigation.

Minimize Alienation of Land and Watercourses - Where it does not compromise the objectives of meeting receiving environment objectives and minimizing risk, mines are required to minimize the alienation of land and watercourses from future productive use. Future land use may be restricted by the operation and ongoing maintenance of mitigation works. Post-mining land productivity and land use options may also be restricted by the bare walls of an open pit, and by mitigation strategies which modify the surface such as underwater impoundments or soil cover. Typically, the largest mitigation-related alienation of land and watercourses occurs with active collection and treatment of contaminated drainage which requires collection systems, treatment and storage facilities, access roads and sludge disposal areas.

In addition to onsite impacts, mitigation may also require significant off-site land. This may include an airstrip, roads and quarries used for construction materials, rip-rap or limestone. For isolated minesites, significant post-mining land use may occur if mitigation prevents the decommissioning of access roads.

Minimize Reclamation Liability - Reclamation liability is defined as all outstanding environmental protection and rehabilitation work requirements including monitoring and maintenance costs. As a condition of a *Mines Act* permit, financial assurance is required to ensure sufficient funds are available to cover all outstanding reclamation obligations. In some cases additional funds may be required for the contingency of major repairs.

Mitigation costs vary significantly in their amount and timing. Logistical factors which may affect implementation costs include the proximity of imported amendments, the amount of waste rehandling and the timely availability of disposal sites. Materials handling and rehandling can be a substantial undertaking with prohibitive costs.

For constructed underwater impoundments, the greatest costs occur during the initial construction, with lesser resources required for ongoing maintenance and monitoring. Blending can have low operational costs, and limited maintenance requirements. If no major rehandling is required, the main costs for blending result from modifications in standard waste deposition and expenses and potential delays associated with detailed material characterization. In lime treatment, much of the cost is incurred from the purchase and transport of lime, plant operation, the pumping of drainage, maintenance of ditch and pond systems and sludge disposal. From the perspective of liability, the large future cost associated with ongoing operation of a treatment plant is a major disadvantage.

ML/ARD assessment programs and the development of cost effective ML/ARD prevention measures should be viewed as investments that will have substantial benefits in terms of reducing reclamation liability and assuring long-term environmental protection.

Consideration of Minesite as a Whole - 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. Considerable benefits may result from using existing facilities on a minesite. For example, where only a small amount of PAG waste rock must be flooded, little or no additional impact will occur if the rock can be stored in an existing flooded tailings impoundment. Additional liability, risk and land use impacts will result if no flooded facility exists and a new impoundment must be constructed. At many minesites, the best waste disposal strategy in terms of limiting liability, risk, and land use, is the backfilling of wastes into existing excavations.

4.6 CONTINGENCY PLANNING

When it cannot be determined with certainty that drainage released to the environment will be of acceptable quality, the proponent must provide contingency environmental protection plans. The objectives of contingency planning are to minimize impact, liability and risk, and to ensure that the necessary monitoring, plans, and resources are in place to allow timely implementation. Contingency plans are also required in the event that upset conditions or a premature shutdown preclude the planned mitigation. Common sources of uncertainty include post-mining water quality in a flooded pit and the potential for small ML/ARD seeps from waste rock dumps. Questions of uncertainty and the acceptability of proposed contingencies must be addressed in the mine plan and the project approval process.

4.7 INFORMATION REQUIREMENTS

Like all phases of a ML/ARD program, mitigation must be based on a thorough understanding of the natural environment, the minesite, the materials involved and the environmental protection requirements. Accurate terminology and complete descriptions are also required for effective communication. To enable timely review and avoid confusion, mitigation plans should clearly specify the mechanism, degree of effectiveness, location and duration of all mitigative procedures.

A mitigation plan submitted for review should include the following information for each mine component or management unit:

- composition and potential for ML/ARD,
- mass, volume, surface area and location,
- a comprehensive characterization of all potentially impacted surface and ground waters and the proportion by which potential ML/ARD must be reduced to ensure receiving environment objectives are met,
- relevant climatic, hydrogeology and geotechnical information,
- compatibility of mitigation measures with the mine plan,
- potential failure mechanisms, including their likelihood and consequences, and strategies for avoidance,
- information needs and proposed data collection,
- maintenance and monitoring requirements, including access needs and costs for annual work and major repairs, and
- provision of adequate contingency measures and plans for the disposal of secondary waste products like treatment sludge (if appropriate).

To guide mitigation, management and regulation, an operating mine should compile all ML/ARD information and continually update the database. Information compiled in this inventory should include:

- composition, mass, volume, surface area and storage locations of all materials excavated, exposed or disturbed,
- history of excavation, materials handling and mitigation,
- site maps showing the locations of materials, mine components, ML/ARD mitigation and site drainage features,
- monitoring data such as the progress of material weathering,
- hydrological conditions including water balance, height of the water table and the composition and rate of flow of all significant drainage input and output sources, and
- requirements and status of contingency plans.

In addition to ML/ARD properties, the database should also include the location and composition of potential construction materials like surficial materials and non-mineralized rock. At a number of sites, the shortage of construction materials for ML/ARD mitigation facilities is a major problem in mine design and a potential constraint to mine development. An accurate inventory of potential construction materials will enable efficient material use and prevent unnecessary damage or alienation prior to their use.

5. UNDERWATER STORAGE

5.1 GENERAL CONSIDERATIONS

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.

While saturation impedes sulphide oxidation, it may increase the dissolution of soluble components. Thus, two important considerations of underwater storage are the existing concentrations of soluble contaminants and the potential for aerial weathering prior to flooding. Excavated wastes are sometimes placed immediately underwater (i.e., underwater disposal). However, in many instances wastes are initially placed in an aerial environment and flooded at a later date. Aerial exposure is a concern because of the potential for soluble weathering products to accumulate and dissolve when flooding occurs at some later date.

Underwater storage also does nothing to reduce the potential for sulphide oxidation should the flooded materials be exposed at some point in the future. Therefore, proposals for underwater storage must provide:

- comprehensive geotechnical and hydrological data, and detailed construction and maintenance plans that demonstrate the storage location will remain permanently flooded and geotechnically stable, and
- financial security commensurate with the outstanding liability.

A commitment to an ongoing schedule of periodic inspections and as-needed repairs will be necessary if indefinite maintenance requirements exist, as is generally the case for spillways and ditches. Geotechnical security is optimized when underwater storage occurs in naturally flooded terrain (i.e., lakes), water retaining pits and declined underground workings.

Although every underwater storage scenario will have slightly different constraints, information requirements and management options, there are basic factors to consider and information/design requirements which apply to all of them. These are discussed below, followed by the specific requirements for different underwater storage options.

5.2 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.**

The concentration of readily soluble contaminants is primarily a concern when materials are oxidized as a result of historic supergene processes or post-excavation weathering. Many underwater storage plans include a period of exposure prior to flooding, creating an opportunity for weathering to occur. The question of how long a delay is possible before a potential problem exists will depend on the materials involved and their weathering rates. While neutral pH weathering may be important, the main concern is the rapid buildup of soluble acid or metal products which occurs after the onset of acid weathering conditions.

While flooded materials usually contribute the majority of the solute load, the chemistry and dilution volume of drainage inputs will also affect the final discharge water quality. For example the process water that accompanies tailings often contains alkalinity which may retard weathering and reduce contaminant solubility, at least in the short-term.

Delayed Flooding **- Where there is a significant period of aerial exposure prior to flooding, the proponent must predict the time to ARD onset and buildup 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.**

Commonly, the most attractive additional mitigation options are temporary measures which impede the progress of weathering or accelerate flooding. Short-term batch treatment of the initial drainage can be effective if dissolution products are limited.

The time to onset of ARD will largely depend on the magnitude of effective NP and its rate of decline. In materials containing little or no NP, or with very high oxidation rates, ARD can occur almost immediately and any delay in flooding may be of concern. Long delays prior to flooding may occur with low grade ore that has been stockpiled hoping for increased metal prices and waste that has been back-filled into active pits or underground workings. Where significant delays occur, operational monitoring is required to verify pre-mining predictions of aerial weathering rates.

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[6] conditions.**

Prior to mining, important hydrological parameters such as the height of the water table, the water balance, the timing and rate of flooding and fluctuations in these properties must be predicted from modeling and baseline hydrologic and climatic surveys. Many of these factors will be difficult to predict since the initial hydrology of an area is usually significantly altered by mining. A

---

[6] 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).

critical part of the hydrological assessment will be the identification of faults and large fracture systems, structures which may accelerate drainage and significantly lower the water table. Operational and post-mining monitoring will be required to determine the effects of mining on site hydrology and to verify modeling predictions. Contingency measures will be required where there is significant uncertainty regarding important hydrologic properties or events.

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.**

The magnitude and effect of oxygen inputs from an overlying water cover will depend on the depth of the water cover, the physical and geochemical composition of the waste at the waste-water interface, wave action, ice, biological activity, earthquakes, thermal overturn, surface and groundwater movement, and other relevant natural factors. The magnitude of oxygenated groundwater inputs will depend on oxygen concentrations, flow rates and possible oxygen sinks. While it is theoretically possible that dissolved ferric iron may oxidize materials in the absence of oxygen, this reaction is only expected to be significant in wastes that are already strongly acidic.

Active mitigative measures which may prevent surficial oxidation at the waste-water interface include the addition of a diffusion barrier or an oxygen consuming cover. A cover may also be used to prevent tailings remobilization. Over time the natural formation of an organic layer is expected to inhibit surficial oxidation.

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.**

The geotechnical design and maintenance protocols for water-retaining structures must enable them to withstand extreme meteorological conditions, seismic events and biological activities such as the blocking of overflow spillways and diversion channels by beaver. The location and design of the facility must also consider the impact of potentially deleterious off-site events like avalanches or the release of upstream drainage impounded by a landslide.

<u>Management for and after Closure</u> **- 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 hydrological and ecological 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.**

Operational management measures which may have an effect on ML/ARD and closure options for a flooded impoundment include the mode and location of waste deposition, the timing of flooding, alkalinity amendments, the types of drainage added and water levels. Possible mitigation measures include the addition of a cap of non-mineralized waste or removing additional sulphide in an amended mill process (i.e., desulphidized tailings). In cases where impoundment drainage is used as process water, reducing the need for drainage discharge, lime additions in the mill may reduce contaminant solubility. While underwater storage is used to prevent long-term treatment, short-term water treatment may be required at the end of mining to remove contaminants present in recirculating process water or added to the overlying water column from the dissolution of highly soluble contaminants that occurs after flooding.

Prior to closure, the mine must produce a comprehensive maintenance and monitoring manual. For constructed impoundments the manual should include instructions for the maintenance of flooded conditions, geotechnical security, reclamation and achievement of drainage discharge requirements. Discharge monitoring may include the measurement of seepage losses to groundwater.

The closure plan must also include consideration of future hydrological and ecological changes. When mining ceases and deposition into the impoundment stops, natural hydrological, biological and geochemical processes will take over. Where no geochemical constraints exist, a flooded surface impoundment will become an integral component of the site ecology, contributing habitat, food and drainage.

Post-closure hydrological and ecological development will affect many of the processes that control the rate of contaminant migration into the overlying water and vegetation. One process of possible concern is natural sedimentation and its effect on the migration of trace elements co-precipitated with oxidized iron species. Iron dissolution is likely to occur if the oxidized surface layer is smothered by oxygen consuming, organic-rich sediments. The magnitude of subsequent trace element release to the overlying water column will depend on the rates of contaminant flux, contaminant adsorption by the sediment and co-precipitation with iron sulphides.

Other potentially significant mechanisms which may alter contaminant migration include:

- changes that occur when geochemical and physical inputs (i.e., lime additions to tailings) cease at the end of mining,
- oxidation resulting from the aeration of resuspended particles, and
- biological uptake through plant absorption and ingestion by fauna.

All stages of research and planning should include consideration of the long-term performance of the underwater storage facility and the limitations, opportunities and cost effectiveness provided by different forms of pond management and post-closure mitigation. Modifications in operational pond management may be an effective means of avoiding uncertainty, additional research and security costs. From the perspective of cost, one of the most important factors to be addressed is whether an oxygen-consuming or geochemically-relatively-inert, physical barrier should be placed on top of the mineralized waste at the end of mining.

5.3 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 PAG and creating an unnecessary geotechnical hazard and ML/ARD concern.

A significant advantage of constructed surface impoundments is that they can be placed in locations that avoid or minimize the disturbance to sensitive resources. Their use can also ensure that flooding will not be delayed by, or interfere with, the operation of the mine. Potential disadvantages include geotechnical risks, onerous design and maintenance requirements and high construction costs, especially if there is a lack of suitable construction materials or terrain.

Historically, dam failures have primarily occurred where there has been inadequate maintenance, water management, seepage control, characterization of construction and foundation materials or safety factors in the design. In Matachewan, Ontario, a tailings dam failed due to the increased water level resulting from beaver dam construction (Baker et al, 1996). This demonstrates the need to consider potential natural hazards such as beaver or upstream landslides and avalanches and their impact on design capacity and the probable maximum flood event. Constructed water-retaining impoundments have been prohibited in some jurisdictions due to the past failure of poorly designed, constructed and/or maintained structures.

5.4 FLOODED 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, fractures, 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.

Open pits and declined underground workings which flood unassisted by bulkheads or impoundments have greatly reduced geotechnical stability concerns and maintenance requirements compared to constructed surface impoundments. Backfilling into already constructed flooded pits and underground workings may also reduce the loss of productive land. Disadvantages include the potential for long periods of aerial exposure prior to flooding, potential conflicts with the mining requirements and the high costs of materials rehandling if backfill storage space is unavailable at the time of waste excavation. Demands for backfill space and the desire to avoid waste rehandling is most likely to occur in open pit mines, especially if there is only one pit. This is less likely in underground mines where the additional ground support provided by backfill may actually increase the efficiency of ore extraction.

Information required in the evaluation of this mitigation option include:

- drainage input sources, volumes, rates and chemical loadings,
- rate, final height and fluctuations in the final height of flooding,
- duration of exposure and consequent buildup of soluble weathering products,
- composition of materials above the final height of flooding and the expected metal and acidity discharge, and
- resulting drainage chemistry and locations and rates of discharge.

Abandonment may be possible for flooded mine workings that do not utilize constructed impounding structures. Where dams and bulkheads are used to increase the height of the water table, proponents must provide the additional requirements outlined in the sections on Constructed Surface Impoundments and Underground Bulkheads.

The time to flooding may be delayed by the prolonged use of mine workings for ore extraction. Changes in metal prices or the discovery of new ore can extend mining and delay flooding beyond the period required for water quality protection. Even if flooding can start immediately, it may take a long time for large workings to fill. In many cases, it can take decades for precipitation, surface water and groundwater to naturally flood a pit. If this creates potential problems, additional water sources may be required to accelerate flooding.

Post-closure management of flooded mine workings will depend on the form, locations, quality and quantity of drainage losses. If there is significant uncertainty regarding future hydrological conditions and their impact on ML/ARD, post-mining monitoring will be required. Concerns about the degree of flooding are common for mine workings in hilly or mountainous terrain.

5.5 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.

In addition to flooding, bulkheads may also be used to regulate the discharge from underground workings, reducing peaks in the discharge of contaminated drainage and thereby reducing the capacity required for drainage storage and/or treatment.

It is hoped that future research and experience will allow bulkheads to become a more reliable form of ML/ARD prevention.

5.6 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.

Potential negative impacts from underwater disposal in natural water bodies include the smothering, in-filling and other depositional effects on aquatic ecosystems and effects on biological cycling. Containment is a potential problem in large water bodies or sites with moving water. However from a number of perspectives, including potential geotechnical and geochemical advantages, underwater disposal in natural water bodies may be the best, long-term, least risk waste disposal option.

The Federal *Fisheries Act*, which governs the protection of fish and fish habitat in British Columbia, generally precludes waste disposal in natural, fish-bearing water bodies. Due to the potential impacts and possible contravention of the *Fisheries Act*, waste disposal in natural water bodies is usually only considered if it can be supported by very strong evidence of the lack of impact, the confined nature of the disposal site and environmental superiority to all other possible options. Approval is presently only given for deposition in non-fish-bearing headwater lakes. Notably, there is no equivalent legislation which limits the use of terrestrial ecosystems for waste disposal.

While waste deposition into fish-bearing water bodies is generally prohibited, with adequate fisheries compensation, mines may be permitted to drain or bury small natural watercourses or wetlands within the minesite. The Federal Department of Fisheries and Oceans' (DFO) "Habitat Conservation and Protection Guidelines" (DFO, 1994) addresses mitigation and compensation and is used by DFO and the Ministry of Environment, Lands and Parks (MELP) to evaluate the acceptability of these types of impacts to fish-bearing systems. Both agencies should be consulted when mining proposals may impact a natural water body.

6. BLENDING OF PAG AND NPAG WASTES

6.1 GENERAL CONSIDERATIONS

Blending refers to the co-deposition of PAG wastes with materials with excess neutralization potential (i.e., NPAG). 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.

Examples of complete mixing include the addition of crushed limestone to a tailings slurry or when inter-bedded zones of PAG and NPAG in a heading become intimately mixed during excavation.

At most mines, either the geological conditions preclude mixing during excavation or the large volumes of waste make alkaline amendments, material rehandling or a separate mixing process prohibitively expensive. Under these conditions, the PAG and NPAG wastes are likely to be separately excavated and disposed in the blended dump. This creates a degree of spatial segregation (i.e., segregated blend), with physical mixing limited to the intermingling that results during deposition. The type and degree of physical segregation and the configuration of the PAG and NPAG components within a segregated blend are determined by the depositional procedure, the material control and the masses of discretely placed PAG and NPAG (Mehling, 1998).

Blending has some potential strengths as a mitigation tool, including limited maintenance requirements, compatibility with a wide variety of terrestrial end land uses, fewer long-term geotechnical concerns and in some cases, 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. Blending needs may also result in 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.

6.2 NEUTRALIZATION MECHANISMS

Acidity produced in a blended waste can be neutralized by the dissolution of mineral NP and by dissolved alkalinity in drainage. Due to the low solubility of most minerals at high pH, drainage alkalinity will only be a significant source of neutralization if the relative mass of PAG materials is small or the rates of sulphide oxidation are relatively low. Most neutralization is expected to occur when acidity contacts rapidly dissolving, neutralizing minerals, such as calcite.

Neutralization in a blended waste can occur at the site of acid generation or at some downstream location further along the flow path. The immediate neutralization of acid will maintain neutral pH weathering conditions, preventing accelerated sulphide oxidation and maintaining relatively low rates of production for soluble contaminants and further acidity. Under neutral pH conditions, iron will precipitate in-situ and may limit further sulphide oxidation. A neutral pH also maintains relatively low metal solubility and with careful water management, metal loadings in drainage can be low enough for safe discharge to the environment. The maintenance of neutral pH weathering conditions, with all portions of the waste composite producing neutral pH drainage, is expected for intimately mixed blended wastes with an excess of NP.

When acidity from the PAG portion of the blended waste cannot be immediately neutralized, neutralization must occur when the resulting ARD comes in contact with mineral NP or mixes with alkaline drainage further along the flow path. As stated previously, as a result of the physical separation, acidic pH conditions are expected to develop to some degree in segregated PAG material. The effectiveness of a segregated blend in neutralizing PAG acidity will depend on drainage alkalinity additions and the magnitude of available mineral neutralization along ARD flow paths.

Contaminant loadings in the final discharge from a segregated blend will depend on the prevalence of acidic weathering and dissolution conditions, the contaminant species, dissolved concentrations and rate of leaching in the acidic zones, the neutralization process, variations in neutral pH drainage chemistry, the consequent neutral pH solubility of contaminant metals and any post-neutralization drainage dilution. The concentrations of dissolved metals in neutralized ARD will generally be lowered due to the relatively low solubility of hydroxide and carbonate metal species. While most metals are less soluble at neutral pH (an exception is molybdenum which has increased solubility at higher pH), they may still occur in concentrations which exceed authorized discharge limits.

A recent review of available information in Canada and the Appalachian region of the United States, concluded that blending will not prevent localized acid weathering or sulphide oxidation rates in PAG materials unless there is almost ideal mixing with a highly reactive neutralizing material (Mehling, 1998). In studies at Eskay Creek, the failure of a thick overlying NPAG cap to maintain neutral pH conditions in thin layers with a potential for rapid sulphide oxidation is presumably because of the small amount of alkalinity generated in NPAG weathering under neutral pH conditions (Mehling, 1998).

6.3 PROBLEMS WITH DEMONSTRATING EFFECTIVENESS

A blending proposal must be accompanied by strong technical evidence that demonstrates effective ML/ARD prevention/mitigation. This will be a challenging undertaking for segregated blending due to the following:

- The ML/ARD performance of a blended material depends on the complex interactions of a large number of geochemical reactions and hydrological processes, many of which are difficult to predict. For example, where will iron and aluminum precipitation occur and what will be the effects on acid generation and neutralization rates and on the direction and rates of drainage flow?
- Many of the important reactions and processes occur within the dump/impoundment and are therefore very difficult to access and study.
- While mitigation strategies like underwater disposal have been the subject of detailed mechanistic studies, similar studies have not been carried out for blended wastes.
- The PAG and NPAG material in blended wastes vary widely in their physical and geochemical composition, relative proportions, configuration, segregation, degree of physical intermingling and hydrology. Since little forensic work has been conducted on existing waste piles, limited information exists regarding these properties, how they alter with time and how different design criteria will effect the drainage quality.

While the use of blending as a planned mitigation strategy is a relatively recent innovation, most wastes are unintentional blends with at least some proportion of PAG and NPAG material. A common example of this are the waste rock dumps located at the mouths of exploration adits which intersected PAG rock near the ore but were initiated in NPAG ground. In a sense, many rock types are themselves internal blends, with PAG veins sandwiched between less mineralized NPAG material. Unfortunately, historic wastes are generally poorly characterized with little or no documentation of their physical and geochemical constituents. This lack of long-term monitoring, material characterization and dump construction records has proven detrimental to the current use of blending as a mitigation strategy. The importance of factors such as scale and site hydrology make future field monitoring an important part of any operational verification or predictive modeling research exercise.

Future research is required to increase the level of understanding and determine whether blending has the potential for greater use.

6.4 INFORMATION AND DESIGN REQUIREMENTS

A proposal to blend wastes must include detailed materials handling and placement plans, supported by comprehensive material-specific and site-specific testing. A knowledge of the geochemistry, hydrology and consequent long-term contaminant discharge rates is 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.

ML/ARD Characterization of Waste Materials - Thorough static and kinetic testing is required to determine the ML/ARD characteristics of the original rock types, the PAG and NPAG waste components and the resulting blended waste. Important parameters include:

- the quantity and quality of acidic drainage production from the PAG waste and the timing of onset for any predicted ARD,
- the rate of metal release through primary mineral weathering,
- metal solubility in acidic drainage, in neutralized drainage and in the final discharge,
- the effective neutralization potential, rate limitations, physical availability and concentration of NP minerals, and
- the physical properties that affect weathering rates and how these properties might alter with time. Characteristics to consider include particle size, surface area, strength, slakability and porosity of particles.

The particle size and competency of rock and waste types is important because of their determining role in mineral exposure and reactive surface area. A larger proportion of finer-sized particles will increase both AP and NP exposure and the likelihood of anaerobic conditions developing within the waste. Differences in the amount of reactive surface area between similar masses of PAG and NPAG materials must be considered when determining the amount of NPAG materials required for ARD neutralization.

Data submitted in support of a blending proposal must include a prediction of the potential metal release from both the PAG and NPAG wastes and from the blend. Metals vary widely in occurrence, solubility and environmental sensitivity. The rate of metal release from primary minerals will be determined by the mineral, the metal concentration and the rates and forms of physical and geochemical weathering. Due to lower trace metal contents and finer grain sizes, blending at coal mines is considered to have several advantages over blending at metal mines. At metal mines, blending is expected to be more successful in the absence of elements like zinc that persist in solution at neutral pH.

In general, blending is anticipated to be most effective for waste materials that generate only marginally acidic drainage. However due to physical constraints, small amounts of high sulphide waste spread over large amounts of mildly calcareous waste will be more effective in generating neutral drainage than small amounts of highly calcareous wastes mixed with large amounts of low sulphur wastes.

Hydrological Properties of Waste Materials - Individual drainage properties and the hydrological interaction between PAG and NPAG materials will play a large role in determining how blended wastes perform. Physical properties that affect drainage include particle size, pore size, water retention, hydraulic conductivity, compaction, strength and competency. The conductivity and water retention of the various rock and waste types, and how these properties alter over time, are important because of the major role they play in determining dump aeration and hydrology. A larger proportion of finer-sized particles will increase the potential for saturation and diffuse seepage. Large particle size differences between PAG and NPAG strata may result in episodic or localized drainage discharge, limiting the effectiveness of down-gradient NP.

Establishing Site-specific Blending Criteria - Blending plans must specify detailed site-specific criteria for a wide range of design parameters. Design criteria will vary according to the mitigation objectives, the type of design, waste characteristics, depositional constraints, drainage inputs, waste hydrology and the availability of contingency measures to limit unacceptable risk and uncertainty.

Where blending is proposed as a source of neutralization to reduce treatment costs rather than the primary means of environmental protection, the main design objectives will be to maximize ARD contact with available NP and to ensure adequate drainage collection. Less emphasis will be placed on predictions of worst-case water quality and the need to achieve trace element objectives in discharge.

If blending is proposed as the primary mitigation tool for meeting water quality objectives, the proposed design must be effective over the range of potential weathering and environmental conditions (including worst-case predictions) and must be supported by adequate contingency measures to assure environmental protection.

A critical part of the blending plan will be the requirements for waste deposition. The plan must show the proposed materials handling and deposition procedures, and the resulting physical layout of each segment of the waste composite. Since unacceptably high metal loadings may result if only a small proportion of a dump or impoundment has unacceptable drainage chemistry, the blending plan must specify small-scale localized depositional criteria. Important factors include the mass, orientation, degree of segregation and physical mixing of PAG and neutralizing waste materials. An important feature of a successful blend will be the material characterization and quality assurance/quality control (QA/QC) constraints for extraction, segregation, disposal, mixing and the final blend. Tools such as Global Positioning Systems can be used to track material placement.

ML/ARD criteria for the PAG and NPAG wastes, such as minimum NPR and carbonate-NP, must be established for individual PAG and net neutralizing waste strata and the overall blended waste. The blending plan must indicate ML/ARD criteria for probable drainage transects through the dump or impoundment. Given the potential prediction and construction difficulties, NP and NPR criteria for blended composites will likely be more conservative than those established for single homogeneous materials. Static test criteria, determined in part by kinetic test results, are typically used for operational control due to the need for rapid analysis. Testwork results used to establish design criteria will also be used to set permitting constraints on blended wastes. Therefore, information submitted on hydrology, material variability and reaction rates must be sufficient to demonstrate the range in expected performance.

<u>Effective Neutralization</u> **- 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.**

<u>Drainage Reduction</u> **- 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.**

A thorough study of site hydrology is required to determine where surface and groundwater drainage will occur and in what amounts. The location and hydrologic characteristics of different waste materials will play an important role in determining the amount of flow passing through the PAG components. Low conductivity surface barriers, promoting surface or near-surface runoff, can limit leaching by incident precipitation. High conductivity, rapidly draining foundation materials can be used to lower the height of the water table ensuring that lateral groundwater flow occurs well below the PAG waste. Another way of minimizing the relative amount of flow from the PAG portions of a blended waste is to place it at the site location affording maximum discharge dilution prior to the sensitive receiving environment.

<u>Material Characterization and Monitoring</u> **- 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.**

The proponent must demonstrate that required resources and monitoring procedures are in place to guide the blending operations. Post-deposition material characterization will be required to verify the composition of the resulting blended waste. The proposed monitoring plans for materials and drainage must specify monitoring locations, sample types, size, frequency, analytical procedures and QA/QC.

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 shutdown 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.**

Contingency plans are particularly important for a mitigation strategy like blending for which the present understanding is limited. Contingency measures may include separate plans for treating small ARD seeps and/or larger metal-laden neutral pH contaminant discharges.

7. COVERS

7.1 GENERAL CONSIDERATIONS

Engineered covers can be used to reduce the supply of oxygen to sulphide oxidation. They can also be used to reduce 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 10 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.

7.2 INFORMATION AND DESIGN REQUIREMENTS

A cover proposal requires a detailed design and supporting testwork that demonstrates effective 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.

While the focus of the following discussion is mainly soil covers, most of the comments and information requirements also pertain to covers constructed with other unconsolidated or synthetic materials. The following items should be considered in cover design and addressed in a cover proposal:

Mitigation Objectives - The first step of cover design is selection of feasible mitigation objective(s). Proponents must provide a detailed description of the minimum mitigation performance required for environmental protection. For a drainage reducing cover this should include the required reductions in drainage infiltration and overall dump discharge.

After the mitigation objective has been chosen, the proponent must develop an understanding of the components of ML/ARD and the contributing factors that the cover intends to reduce. For a cover whose objective is to reduce metal loadings in drainage, this will include potential sources of metals, present and future weathering conditions, waste hydrogeology, influential climatic conditions, sources of dump drainage and overall site drainage conditions. A review of the factors contributing to the targeted problem and the ability of the cover to reduce them will determine whether a cover is potentially an effective means of achieving the mitigation objective.

One aspect will be the predicted performance of the cover. For example, drainage inputs along with the estimated number of defects in geotextile liners recommended by Giroud and Bonaparte (1989) was used to estimate the flow through a geotextile barrier (Redfern, 1997). The effectiveness of a cover designed to reduce leaching as a means to reduce site metal loadings will depend in part on the proportion of metal leaching that results from groundwater drainage inputs as opposed to surface water infiltration. For logistical reasons, wastes are often placed in topographic depressions or at the bottom of slopes. These areas are often zones of groundwater discharge with high rates of flow during periods of the year. Under these circumstances, leaching will continue even if the cover effectively limits surface infiltration.

In many cases, the combined effect of the cover on leaching and oxidation will be very important. Where there continues to be some leaching either through surface infiltration or groundwater inputs, the effectiveness of an oxygen-ingress-limiting cover in reducing metal discharge will depend on the initial waste solubility and the timing of cover placement relative to the rate of production of soluble weathering products. If the wastes are already strongly weathered prior to cover placement, leaching of residual weathering products will maintain high metal loadings in the discharge, even if the cover effectively limits further oxidation.

Design Principles - The design principle refers to the physical features and mechanisms by which the cover will achieve the mitigation objectives. For example, reduction in the infiltration of precipitation could result from cover features which increase surface runoff, absorption and evapotranspiration. Important processes that a cover should be designed to handle include infiltration, runoff, evaporation, transpiration, erosion, metal movement into the zone of plant uptake and oxygen diffusion. External factors that may affect these processes include dump settling, climate, plant growth and burrowing animals.

Characteristics of Proposed Cover Materials - Covers can be constructed from a wide range of materials including soil, synthetic materials, various organic substances and composites. Possible cover materials will depend on the mitigation objectives, material availability and costs, instillation limitations and site-specific climatic considerations. Major costs may be incurred in purchasing, transportation, installation and monitoring and maintenance. Often the most cost-effective option is to construct a cover using waste materials that exist at the minesite. For example, desulphurized tailings might be used as a geochemically inert, barrier to oxygen diffusion.

To date, the majority of cover work in British Columbia has been with natural soil materials. Benefits of soil covers include cost, compatibility with surface reclamation goals and their predicted longevity. Due to performance and economic considerations, soil covers are usually constructed using unconsolidated materials available in the vicinity of the minesite. Synthetic covers are often simpler to install, more predictable, and a more reliably effective option than natural covers. Disadvantages that restrict synthetic cover use include the high costs and questionable longevity.

While the importance of different design parameters vary according to the cover material, its intended use, and the stresses placed upon it, they generally include a comprehensive list of hydraulic and geotechnical characteristics. For a natural soil barrier, this includes particle size distribution, soil water characteristic curve, hydraulic conductivity and oxygen diffusivity after compaction at different moisture contents.

A Multi-Layer, Capillary Barrier Soil Cover - The present state-of-the-art practice for a drainage reducing soil cover is a multi-layer capillary barrier system consisting of a fine textured layer sandwiched between upper and lower coarse textured layers. Drainage infiltration is restricted by differences in moisture retention between the fine and coarse textured layers and by the low hydraulic conductivity of the fine textured layer (Aubertin et al., 1996). Saturation of the fine textured layer will reduce air movement.

In a multi-layer capillary barrier system, the upper porous, coarse textured layer plays a number of roles including the provision of erosion protection, water storage to replace any losses from the middle layer, a surface for revegetation and evapotranspiration and an initial flow path for excess drainage that was unable to infiltrate the underlying layer. In some cover systems, the upper layer is divided with separate sub-layers provided for plant rooting, root restriction and water flow and storage (Aubertin et al., 1996).

The compact, fine-textured middle layer in a capillary barrier system serves as the primary barrier to water movement. Required properties include a low hydraulic conductivity to restrict the rate of flow and the ability to retain water under tension which restricts drainage loss to an underlying coarse textured layer. If the objective is to reduce air entry, the middle layer should retain a high degree of saturation under all climatic conditions.

The role of the underlying, porous, coarse textured layer is to create a suction gradient that reduces drainage losses from the middle layer and to form a capillary barrier that prevents upward contaminated drainage movement. While the capillary barrier will be strengthened by large contrasts in grain size between the fine and underlying coarse textured layers, this may also enhance the downward migration of fines. In some covers, waste rock is used as the lower coarse layer (Wilson et al., 1997).

Climate - Consideration of climatic variables and the use of climatic data in cover design is essential for effective cover performance (Vanapalli et al., 1997). The collection of detailed on-site climatic data is required both in the design of a cover and for performance monitoring. Important information includes the parameters required for a water balance and the properties of extreme wetting and drying events (including snow melt patterns).

Construction Conditions - An important feature of all covers are the construction requirements. Failures in construction are a common cause of reductions in cover performance and are blamed for the consequent environmental impacts (Danielson and McNamara, 1993). Construction specifications for an engineered cover include the requirements for initial site preparation, excavating and preparing cover materials (i.e., remove large boulders and organic debris from soil), cover construction (i.e., standards for moisture content, compaction, layer depths, and installation of monitoring equipment) and preventing erosion (i.e., runoff collection) required to achieve design objectives. Physical properties such as moisture content, which is critical in the construction of compacted soil covers, might restrict construction during certain seasons or during adverse weather conditions.

Erosion Protection - Covers which reduce drainage infiltration and create greater surface or near-surface runoff will increase the potential for erosion. Erosion protection requires measures to stabilize the cover surface and minimize overland drainage flow. Drainage control is particularly important for surfaces left exposed for a significant period of time before a vegetative cover can be established. A water management/surface stabilization/sediment retention system should be included in a cover design, with resources provided for monitoring, maintenance and repair.

Monitoring - Monitoring is required to determine cover performance during and after construction. Monitoring should include the measurement of critical cover conditions (i.e., QA/QC), climatic conditions and their effect on ML/ARD. Monitoring must also provide sufficient warning when additional design refinements, maintenance or repairs are required.

Long-term Performance **- 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.**

A critical concern with cover technology is the uncertainty regarding long-term performance. The design, monitoring and maintenance proposed must ensure the required longevity and satisfactory implementation of contingency measures, such as replacement, should they be required.

8. DRAINAGE COLLECTION AND TREATMENT

8.1 GENERAL CONSIDERATIONS

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.

Drainage treatment includes a diverse group of processes with a wide range in effectiveness, reliability and impact. Their application can range from the short-term treatment of mill process water prior to decommissioning, to the seemingly perpetual treatment of non-preventable ML/ARD from old mine workings. The expense of long-term treatment forms a large part of the reclamation liability. Operating costs can vary from the negligible expenses associated with drainage polishing in a natural wetland to more than $1.5 million a year for lime treatment and sludge disposal. The requirement to provide a security commensurate with outstanding costs may make drainage treatment prohibitively expensive. A significantly reduced financial security can be a major incentive for using additional mitigation measures to reduce annual treatment costs.

One of the most important requirements for drainage treatment is an effective system for contaminated drainage collection and clean water diversion. Effective drainage collection requires a well designed system supported by comprehensive monitoring and timely maintenance.

8.2 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.**

Factors to be considered in the design of an effective collection system include:

- siting of mine components,
- drainage volumes and discharge locations for mine components that are contaminated drainage sources,
- foundation conditions required to prevent significant drainage losses from contaminated drainage sources and flow pathways,
- suitable location for storage facilities and materials for constructing dams,
- maintenance required to preserve the integrity and design capacity,
- corrosive nature of acid or alkaline solutions, and
- the effects of mining and mine closure on site hydrology.

In terms of risk, the weakest point in many drainage treatment systems is the effectiveness and reliability of drainage collection systems. Drainage collection can be very simple if all drainage is discharged from a single point. It can be very complicated if there are numerous surface and groundwater sources to collect.

Maintenance requirements for the drainage collection system includes vegetation, debris, sediment, ice and snow removal from ditches, maintenance of pumps and clearing debris from culverts and pump intakes. Monitoring will be required to detect exfiltration or surface drainage losses. A geotechnical evaluation is required to assess the potential for seepage loss from mine wastes, mine workings, ditches and ponds. Detailed hydrological studies, including an assessment of the water balance and maximum flows, will be required to show that the system has the necessary capacity to perform under extreme climatic events.

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.**

Information requirements include:

- detailed descriptions of the proposed treatment process, facilities, costs, resource requirements and management needs,
- predictions of treated effluent concentrations and volumes, and
- a demonstration of the effectiveness of the treatment system over the expected range of flows and water quality.

Treatment effectiveness can be established using site-specific, bench- and pilot-scale testing and from previous experience with the proposed methods at other sites. Procedures like lime treatment have the advantage of an extensive track record that can be consulted when predicting material or system performance. Since all materials and sites are somewhat unique, proponents must consider how variations in important parameters will affect treatment performance.

More detailed, site-specific testing will be required for technologies that are not substantiated by comprehensive mechanistic studies or previous use at other similar sites. Demonstrating effectiveness is likely to be a more rigorous process if procedures are complex, less well-known, or are not supported by contingency measures. For example, a proposal for a wetland treatment system will require a detailed assessment of the proposed materials, methods, mitigation mechanisms, and the ability to handle fluctuations in concentration and flow and meet long-term objectives in loading reduction.

An important part of treatment reliability is the degree of operator vigilance and control. System components that permit a high degree of control include well monitored, high density sludge treatment facilities and computerized pumping systems. Passive treatment systems, such as drainage discharge into a wetland, usually afford a much lower degree of operator control.

Detailed monitoring is required to guide treatment management and verify all predictions. This includes the quality and quantity of the treated drainage, chemical amendments, process parameters and the resulting effluent.

Treated Effluent Discharge **- Discharge requirements will depend on effluent quality, quantity, discharge locations and authorized contaminant limits developed from receiving environment objectives.**

The following information should be submitted in support of any planned drainage discharge:

- baseline data including the sensitivity and capacity of the receiving environment,
- the required and available capacity for storage of treated effluent prior to discharge, and
- post-treatment mitigation needs or disposal constraints.

Where treated effluent requires dilution to meet receiving environment objectives, the proposed discharge locations must provide sufficient dilution during the required discharge periods. Available dilution and the need for treated effluent storage prior to discharge will depend in part on the variability in the receiving environment sensitivity and the timing of maximum contaminated drainage flows. Maximum dilution is often available during off-site snow melt (i.e., spring freshet).

Detailed monitoring is required to guide effluent management. Important factors include the various contaminated drainage sources, discharge water quality and loadings, the effectiveness of the initial dilution zone, the available dilution capacity and the proximity and sensitivity of the resources at risk. Proponents are advised to consult MELP for more assistance on this subject.

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.**

For long-term treatment, the proponent must predict the volume of secondary waste that will be produced and ensure the disposal site has adequate storage capacity. In a low density lime treatment system, the volume of treatment sludge may rival that of original waste. The use of a treatment system that creates a geochemically stable, high density sludge reduces many of the concerns with sludge disposal (Kuit, 1980; Zinck, 1997). The disposal plan for secondary waste should also include consideration of post-closure hydrological and ecological developments.

Additional Mitigation Work - Where feasible, proponents are expected to use additional mitigation measures to reduce land alienation, risks, operating costs and other liabilities associated with collection and treatment. At most mines, clean upstream drainage is diverted to reduce the volume of contaminated drainage. Several mines in British Columbia use surface covers to reduce acid and metal leaching and contaminant loads.

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.**

Where long-term collection and treatment is proposed, either as the principal means of protection or as a contingency measure, the proponent must demonstrate:

- the system can be operated effectively for as long as is necessary,

- the requirements for assuring environmental protection, including potential failure mechanisms, associated protection measures and the minimum standards for effective performance, and
- cost/benefits of collection and treatment versus other effective mitigation strategies.

To ensure that the collection and treatment system can be operated despite changes in personnel and that emergency/contingency actions are clearly understood and can be implemented in a timely manner, the proponent must develop a collection and treatment operating manual. The manual should provide all necessary instructions for operation, monitoring and maintenance of the treatment facility and collection system.

Where a large storage capacity for contaminated drainage exists or where there is a predicted delay in the onset of contaminated conditions, treatment facilities may not be required until many years after the cessation of mining. The resources and plans required for post-mining collection and treatment, including security, access, and monitoring needs, must be provided prior to mine closure.

Contingency Plans - Contingency measures are required for possible upset conditions. Typical contingency requirements include:

- sufficient back-up power for effective collection and treatment during all possible conditions (power failures generally occur during extreme climatic events when power demands are highest),
- back-up for portions of the collection system where a failure would be critical to the effectiveness (i.e., back-ups for pumps),
- excess capacity for storage of contaminated drainage in the event the treatment plant shuts down or it is not possible to discharge treated effluent, and
- provision of resources (i.e., reagent materials, personnel, etc.) to enable collection and treatment to continue in the event access is cut-off to a critical portion of the site or to the site as a whole.

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.**

Drainage collection and treatment improves water quality downstream of the treatment point. However, degraded drainage upstream of the collection point will continue to contaminate any watercourses or land it passes through.

In less developed parts of the Province, a major potential land use issue arising from long-term collection and treatment is the long-term requirement for access roads.

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.**

8.3 LONG-TERM ACTIVE CHEMICAL TREATMENT

Long-term lime treatment has been successfully used to create dischargeable drainage at a number of mines in British Columbia. At older ARD-generating mines where other mitigation technologies have to be retro-fitted, lime treatment is usually the cheapest means of achieving receiving environment objectives (Geocon, 1995). Where large volumes of strongly weathered wastes with high concentrations of soluble contaminants exist, drainage collection and active chemical treatment is often the only feasible mitigation strategy.

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:

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

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

c) 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 expected to make long-term collection and treatment a prohibitively expensive mitigation strategy for almost all new mines.

While most forms of mitigation have ongoing maintenance and repair costs, the compounded operating costs for long-term collection and treatment are particularly expensive. The financial securities required of British Columbia mines with long-term collection and treatment have been as much as $39 million. Large securities will significantly affect the economic viability of a mine and should be considered in the feasibility assessment.

8.4 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.

Like other forms of collection and treatment, proposals for commercial leaching operations should include a risk management plan, a detailed engineering plan and analysis of the economic feasibility. Since risk is often strongly affected by the proximity of environmental resources, the siting of leaching facilities may be critical. The presence of contaminated drainage, along with the associated risks and constraints on post-closure land use, should be considered in the overall project assessment.

8.5 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.

There are a variety of passive treatment methods available for ML/ARD remediation including natural and constructed wetlands, anoxic limestone drains and limestone channels. Wetlands remove contaminants through a variety of physical, chemical and biological processes. Limestone drains and channels accomplish remediation by adding alkalinity to drainage, raising the pH and reducing the solubility of metals. The term passive is somewhat inaccurate. While passive treatment systems typically require less frequent attention, they often require regular monitoring and maintenance, and in some cases complete replacement. Due to the great variety of attenuation mechanisms, wetland treatment systems may require more monitoring than a conventional treatment system.

Various passive treatment systems have different advantages and limitations. Unlike conventional chemical treatment systems, passive treatment is usually compatible with some form of productive habitat restoration. Passive drainage treatment may be the best remediation strategy for a site with marginally contaminated drainage where other forms of mitigation like conventional lime treatment would result in large terrestrial disturbance and substantial habitat loss, but only a small reduction in aquatic impact. At the recently approved passive treatment system at the Island Copper Mine, waste dump ARD is injected into anoxic sea water trapped beneath a layer of freshwater in the flooded pit. Island Copper is unique in terms of treatment capacity and because of the environmental protection afforded by the large dilution and fresh water cap.

Regulatory conditions and information/design requirements for passive treatment systems are likely to be similar to those for chemical drainage treatment. A proposal for passive drainage treatment must demonstrate that collection and treatment systems are sustainable for as long as is necessary, and during and after extreme climatic events. The critical periods for many wetland treatment systems are spring runoff or fall rain events when flows are highest and biological activities may be reduced. A wetland system may require an extremely large surface area to achieve sufficient drainage residence times during freshet runoff. Other concerns for wetlands include the re-release of metals with plant decomposition and the low dilution capabilities in the downstream receiving environment at certain times of the year.

Like other forms of mitigation, a company proposing passive treatment must commit to implementing all necessary management, maintenance and repairs and submit a security commensurate with the liability and risk. The financial security will include post-closure operating, replacement and maintenance costs. Thorough monitoring is required to demonstrate effectiveness and sustainability, and to guide future management. This should include inflow and outflow concentrations and loadings, and measurements that show the mechanism of contaminant attenuation and its long-term sustainability.

9. MITIGATION OF SPECIFIC MINE COMPONENTS

9.1 MODIFICATIONS TO TAILINGS

Milling and depositional procedures can be modified to produce tailings which have a reduced ML/ARD potential. Possible measures include:

- Finer grinds or deposition procedures which create tailings with reduced pore size, increased moisture retention and reduced conductivity. An increase in the height of the water table and a reduction in the rate of oxygen entry will reduce the depth and rate of sulphide oxidation. Thickened tailings deposition was used to raise the height of the water table at the Kidd Creek Mine in Ontario (Woyshner and St-Arnaud, 1994).
- Addition of a flotation circuit to the mill to remove iron sulphides, producing a large mass of benign rougher tailings and a smaller amount of sulphide-rich tailings. An important aspect of this will be the provision of an acceptable disposal plan for the sulphide-rich tailings. The effectiveness of a sulphide float in rendering the majority of tailings NPAG will depend on factors such as the fineness of the grind, sulphide mineralogy and NP.
- Addition of an NP amendment. Possible amendments to the tailings slurry include lime to provide highly soluble, short-term NP and crushed limestone to produce a NPAG composite. Amendments can also be selectively spread on portions of a tailings beach where sulphides concentrate as a result of differential settling.
- Selection of ore with better acid base accounting (ABA) characteristics and stockpiling it until the end of milling to create a benign NPAG surface tailings layer.

9.2 MODIFICATIONS TO OPEN PITS AND UNDERGROUND WORKINGS

There are several measures that can be used to reduce the ML/ARD potential in mine workings. These include the following:

Measures to Minimize Surface Area - The reactive surfaces of open pit and underground mine workings can be divided into mine walls and unconsolidated materials. The distinction is important from the perspective of ML/ARD because there is an exponential increase in the proportion of reactive surface area when unconsolidated material is created from bedrock.

Consequently much of the reactive surface area in mine workings may occur in unconsolidated materials (i.e., talus and abandoned waste and ore stockpiles) even if they represent a very small proportion of the overall mass.

Mines should construct their workings in a manner that minimizes the production of potentially problematic talus and remove previously blasted material with the potential for generating ML/ARD before access is cut-off. The ML/ARD potential will depend in part on future drainage conditions, such as flow and flooding. At a number of British Columbia underground mines, the primary source of metals and acidity in the drainage is from inaccessible ore stockpiles in zones of concentrated groundwater flow. Drainage should be diverted around areas of significant potential ML/ARD production.

Most of the reactive surface area associated with mine walls occurs along fractures. Fracture and talus production can be reduced by:

- controlled blasting near final pit walls,
- decreasing the angle of final pit slopes,
- locating the final mine walls in stable ground away from fractured or faulted rock, and
- by decreasing water pressure that could accelerate mass wasting.

Management of 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.**

See section on Underwater Storage (page 30).

Drainage Considerations **- The post-mining hydrology of mine workings that are a ML/ARD concern must be predicted through detailed site monitoring and hydrologic modeling prior to mine development and verified by operational and post-mining monitoring.**

Due to their subterranean location and high conductivity, mine workings often act as conduits for groundwater and have high flow rates. Important drainage considerations include the effects of mine excavation on regional flow patterns and the possible interception of new water sources. Mining practices may change critical hydrological parameters by connecting or exposing isolated fractures, with possible impacts on the height of the water table, flooding of backfill and mine walls and the flow of drainage through potential sources of ML/ARD. Facets of mine design that may have a major impact on drainage rates and the ability to flood include whether adits decline or incline, the proximity of underground workings to the surface and the removal of crown pillars. At the Britannia Mine, infiltration through collapsed glory holes at the top of the mountain contributes much of ARD that is eventually discharged through lower elevation portals (Price et al., 1995).

See section on Underwater Storage.

9.3 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.

In the past, materials have been incorrectly predicted to have no ARD potential based on a visual assessment of sulphide content, the type of ore deposit or rock and an overestimation of the impact of a cold climate on weathering. Once waste deposition has occurred, it is difficult to fix mistakes in ML/ARD prediction. This difficulty is even more pronounced when the problematic materials are an integral part of facilities such as a tailings dam which cannot be dismantled and are difficult to modify. Thus it is very important that comprehensive prediction test work be carried out prior to material use.

Wastes proposed for mitigation work must be compatible with stated function and proposed mitigation. The constraints and requirements will depend on the function, location, environmental conditions and contribution to cumulative risk and liability. For example, different criteria will apply to waste materials used upstream versus downstream to support the low permeability till core of a flooded impoundment. The criteria for potentially problematic materials proposed for construction uses, such as road building within a flooded impoundment, will depend on the time to ARD onset and the available contingency mitigation measures. Detailed monitoring will be required to measure the progress of weathering and, for the example of road building within a flooded impoundment, the security must be sufficient to move the wastes to an underwater location if the mine closes prematurely.

10. GEOTECHNICAL AND HYDROLOGICAL CONSIDERATIONS

10.1 GENERAL REQUIREMENTS

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.

10.2 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.

Important hydrological information for mine components that are a potential source of ML/ARD may include:

- a water balance, including drainage input and output locations, water quality and rates,
- volume and composition of stored drainage,
- height of the water table,
- magnitude of probable maximum floods for different return periods,
- a detailed description of the upstream and receiving environment, and
- hydrological properties of the surficial materials and, in some cases, bedrock.

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.

The determination of probable maximum flood should be based on the site-specific run-off and climate conditions in the watersheds, including possible storm events and their duration, and rain-on-snow and snow melt events. In most parts of British Columbia, the major hydrologic concern is with the magnitude of flow during snow melt. Large accumulations of snow followed by rapid temperature increases or rain-on-snow events can create the potential for extreme flooding events. Other important factors to consider include possible upset conditions such as avalanches or landslides upstream in the watershed. For proposals to flood pits and underground workings, especially those with backfilled waste, a proponent must identify fractures and drill holes that have the potential to act as flow paths and determine their effect on future contaminant discharge and flooding.

Site hydrology plays a major role in geotechnical design and vice versa. The design, monitoring and maintenance requirements for water management facilities are discussed in the geotechnical section below.

Where there is a ML/ARD concern, the possible impact of site hydrology on the mitigation and effluent discharge requirements should be considered when selecting the waste disposal location. Factors to consider include the proximity to sensitive resources, the ability to collect drainage and the isolation from surface and groundwater flow. While the placement of wastes in topographic depressions or at the bottom of slopes is often cost effective from a materials handling point of view, it increases the probability of groundwater leaching and could potentially increase long-term ML/ARD costs. Groundwater discharge within a dump or impoundment may only occur during certain periods of the year and can be very difficult to prevent. In order to detect seasonal variation, groundwater studies should include a survey of wetland soils and vegetation.

Mining can have a significant impact on site hydrology. For example, a lower water table may result if mining exposes fractures or connects mine workings to porous strata. Post-closure requirements for monitoring and maintenance will depend on the type of facilities and the risks.

Where there is significant uncertainty regarding future hydrological conditions and their impact on ML/ARD, long-term monitoring will be required.

10.3 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 1-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.

In order for water management and mitigation structures to perform according to geotechnical design objectives, they must be properly constructed, maintained and, if necessary, repaired. This will require QA/QC procedures, comprehensive monitoring, and timely maintenance and repair. Contingency plans must be available to handle improbable climatic events and other potential upset conditions, along with adequate monitoring to allow their implementation in a safe and timely manner. Where snow melt is a concern, comprehensive snow course monitoring should be carried out during critical periods of the year to allow the timely provision of contingency measures, such as snow clearing and drainage diversion. At Equity Silver Mine, ice buildup can greatly reduce the ability of ARD collection ditches to operate at design capacity during a rain-on-snow event. To avoid this problem, snow is removed from the ditches.

Generic geotechnical information requirements are outlined in the "Application Requirements for a Permit Approving the Mine Plan and Reclamation Program Pursuant to the Mines Act" (BCMEM, 1998). Specific geotechnical requirements for the different forms of ML/ARD mitigation, such as underwater storage, blending, covers, and treatment are described in previous sections.

Important factors to consider include flow paths, zones of concentrated groundwater discharge and foundation conditions. The investigation of foundation conditions must include an evaluation of bedrock stability in addition to that of the overlying surficial materials. At several mines, failures have occurred in weak strata or along failure planes due to the additional loadings produced by stockpiled mine wastes. A potential for deep-seated foundation failure will be missed if geotechnical studies are limited to near-surface materials.

10.4 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, 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 watercourses 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 MELP Environmental Impact Assessment personnel should be consulted regarding specific information requirements.

Provincial water quality criteria are listed in Nagpal et al. (1995). Methods for deriving site-specific water quality objectives are outlined in MacDonald (1997).

11. BRITISH COLUMBIA MINE REGULATION

Mining can be an extremely productive use of the land, generating significant wealth for the Province, while occupying a very small proportion of the Provincial land base. Mining also has the potential to contaminate land and water resources. Therefore, in addition to maximizing returns to the Provincial economy, the Provincial Government's mining policies require the protection of surrounding environments and, to the extent possible, reclamation of the minesite. Each mine must conduct an operational program of environmental protection. Where excavated wastes have a significant potential for ML/ARD and mitigation works must be constructed, periodic long-term monitoring and maintenance is usually required to ensure they function effectively.

11.1 PERMITTING AND MINE APPROVAL

The Mines Branch, MEM, and the Pollution Prevention Program, MELP, share the Province's responsibility for regulating ML/ARD at all proposed, new and existing minesites. Minesites are regularly inspected by MEM and MELP staff to ensure compliance with ML/ARD permit requirements.

Mining is regulated by MEM under the *Mines Act* and the Health, Safety and Reclamation Code for Mines in British Columbia (BCMEI, 1997). 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* which prohibits the introduction of waste which may substantially impair the usefulness of the receiving environment. Based on the requirements of the various approvals and permits under the *Waste Management Act*, specific receiving environment and discharge objectives (usually water quality and loading) and discharge and environmental monitoring programs are established. The newly enacted *Contaminated Sites* amendments to the *Waste Management Act* sets conditions for the management of contaminated soil and water, including provisions for the re-evaluation of the site and the remediation and monitoring program. MELP also enforces the provisions of the *Water Act*, which regulate the use, storage and diversion of water on a minesite.

Focus of MEM regulatory work is with excavation and materials handling including the mine plan, and construction of waste storage sites. Primary concern of MELP is with discharges, water management and receiving environment objectives. However there is significant overlap. MELP receiving environment objectives are part of the definition of negative impacts to land and watercourses that MEM uses to set ML/ARD constraints on materials handling and waste disposal. ML/ARD criteria established by MEM play a large role in determining whether a mine meets MELP permitted discharge limits. 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.

Information submitted in support of a Work System and Reclamation Permit is reviewed by an inter-agency Regional Mine Development Review Committee (RMDRC) chaired by MEM. Participation in these regional-based technical review committees vary with land tenures and projected environmental impacts but generally includes the Federal agencies of Environment Canada and Fisheries and Oceans, and the Provincial ministries responsible for environmental protection, water management, fish, wildlife, agriculture and forests. The British Columbia Reclamation Advisory Committee, comprised of representatives from MEM, MELP, Forests and Agriculture, is responsible for Provincial policy and regional consistency in reclamation regulation.

Proposals for new, large mine developments or mine expansions (>100,000 tonnes of coal per year or >25,000 tonnes of mineral ore per year) are reviewed under the Province's *Environmental Assessment Act* (EAA). Projects below the designated thresholds can be reviewed under the EAA if the project has the potential for significant adverse effects and it is judged to be in the public interest (BCEAO, 1995). EAA project review committees are organized by the Environmental Assessment Office and consist of all interested government agencies and First Nations. Development size thresholds that trigger the EAA are currently under review.

The EAA has a two or three-stage review process. The first stage, the Application, begins when the proponent submits a prospectus that broadly describes the proposed project and environmental setting and provides a preliminary identification of potential effects, issues and proposed mitigation measures. The information is reviewed to identify potential major impacts and concerns. If the project and mitigation are considered to be feasible and the impacts appear to be acceptable, the Project Committee recommends the application be accepted.

The second stage in EAA process is the production and review of the Project Report. If no significant concerns remain, the project may proceed directly to the third stage. Projects which have significant uncertainty regarding their environmental impact and mitigation must address these issues in more detail. Production of a Project Report is invariably required for mining proposals. Proponents entering the second stage of the process are given a customized set of information requirements (Project Specifications) based on the major impacts and concerns identified in the review of the Application.

The objectives of a Project Report are to identify potential impacts, demonstrate the capability for avoidance, mitigation and compensation, and assess whether the resulting project will be acceptable according to Provincial and Federal land use and environmental standards. Where there is a significant potential for unacceptable impacts, the proponent must carry out a comprehensive assessment and provide scientifically defensible evidence supporting their conclusions. Due to unforeseen environmental conditions or new developments by the proponent, some of the information requirements in the Project Report become redundant and other additional issues must be added.

At the end of the second stage of review, the Environmental Assessment Office reports the conclusions of the Project Committee, including any dissenting opinions, to the Ministers of MEM and MELP. From the perspective of ML/ARD, if the mine proposal demonstrates that a proponent has the necessary understanding, site capacity, technical capability, resources and intent to operate a mine in a manner that reduces contaminant discharge to levels which allow the attainment of receiving environment objectives in the affected watercourses, permits site decommissioning and reclamation, and minimizes economic risks to the Province, the Ministers of MEM and MELP will give the proponent a Project Approval Certificate. Typically, Project Approval Certificates include recommendations and conditions for construction and operation of the mine.

After a Project Approval Certificate is granted, regulatory agencies may issue the various permits and licences necessary for mine operation. Permit application requires submission of detailed designs for construction, monitoring and maintenance of all mining, waste handling, discharge, reclamation and environmental protection features. Permits and licences issued by MEM and MELP set discharge limits, receiving environment criteria and objectives, material handling and deposition requirements and mitigation measures.

Mining projects that are too small for inclusion in the EAA process apply directly for a *Work System and Reclamation Permit*, under Section 10 of the *Mines Act*. Permit applications are reviewed and, if satisfactory, approved by the RMDRC.

11.2 FINANCIAL SECURITY

Financial security is required as a condition of all *Mines Act* permits. 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.

Security requirements are addressed at each stage of mining operations. Following a detailed technical review, the RMDRC will recommend an appropriate level of security as a condition of the reclamation permit. The level of security will increase or decrease as outstanding liability and reclamation obligations change during mine operation. The security will be set at a level that will pay for the following:

- construction, inspection, monitoring, maintenance and repair of drainage collection and ML/ARD mitigation structures,
- operation of a drainage treatment plant and disposal of secondary wastes if required,
- costs associated with conventional reclamation, including replacement of soil, recontouring, seeding, planting and fertilizing,
- regular evaluation of the receiving environment, and
- site drainage and material monitoring, and ongoing research needs.

The level of detail required and the accuracy of closure cost estimates vary with the stage of mining and significance of closure issues. Potential impacts, general liabilities and conceptual costs must be outlined in the EAA Project Report and more detailed costs provided with the permit application. During the early phases of mining, some aspects of the reclamation plan will remain conceptual. As mining progresses, closure needs will become more accurately defined, plans will be refined and more accurate cost estimates can be prepared. Reclamation plans must be re-evaluated every five years or whenever significant changes occur to the mine plan. Detailed closure plans, including a thorough technical evaluation of potential environmental effects, should be prepared approximately two to three years prior to closure so that the necessary work can be carried out during the last years of mining. Liability estimates and closure schedules should be refined and updated prior to undertaking any new programs.

11.3 OPERATIONAL MONITORING

Informed materials handling, deposition and drainage management is required at all mines. Operational monitoring is required to validate predictions, fill information gaps, guide operational procedures, identify errors and omissions, and support various aspects of the closure plan. Operating mines are required to maintain a detailed inventory of the location, mass and ML/ARD potential of all wastes and exposed materials. This information should be regularly updated and readily accessible to guide site management and regulation. Following mine closure, many sites will have ongoing ML/ARD concerns and monitoring will be an important part of the operation of mitigation facilities. Specific monitoring requirements are outlined in the sections addressing various prediction and mitigation procedures.

11.4 ANNUAL RECLAMATION REPORTS

An annual report is required as a condition of all reclamation permits. The report must describe all reclamation activities, ML/ARD mitigation work, the inventory of waste and exposed materials, drainage monitoring, ML/ARD testwork, sampling and analytical procedures. Annual reclamation reports must also describe in detail the mining activities, material disturbance, excavation and handling and waste disposal of the previous year, and anticipated future changes to the mine plan. Paper and digitized versions of cumulative waste characterization and drainage monitoring records should be appended.

11.5 ML/ARD PREDICTION AND PREVENTION PLANS

All proposed, operating and closed mines with the potential for ML/ARD should have an approved ML/ARD prediction and impact prevention plan. The plan must address the information requirements, concerns and constraints outlined in these guidelines. The plan should be a working document that allows for revisions and additions as mining progresses, mitigation occurs and the level of understanding increases. To enable timely reviews, the following framework for presenting information is suggested:

I. ML/ARD Prediction Testwork

1. Geology
2. Minesite Hydrology and Water Chemistry
3. Static Test Results
   - ABA
   - Elemental Composition
   - More Refined Testing of Mineralogy, Particle Size and Other Properties
4. Kinetic Test Results
   - Humidity Cell
   - Site Drainage Monitoring
   - Characterization of Field Weathering
   - Field Test Pads
   - Other Kinetic Test Information

II. ML/ARD Prediction and Prevention Plan for Each Mine Component

For each unique waste unit or mine component the following must be described or provided:

1. Materials Handling and Deposition
2. Evaluation of ML/ARD Potential
3. Mitigation Measures including Contingencies
4. Ongoing Testwork and Planning
5. Waste Production and Facility Development Schedule

Paper and digitized copies of all raw data must be appended. Figures and tables should be clearly presented. Reports should specify all test methods and identify the laboratories which conducted the analytical work.

All reports must be authored by qualified persons with sufficient training and experience in the pertinent aspects of ML/ARD. Authorship and qualifications must be clearly identified in all reports submitted to MEM.

Regulatory agencies should be consulted about the acceptability of any information intended for regulatory use prior to the initiation of expensive, time-consuming work.

11.6 HISTORIC MINESITES WITH METAL LEACHING AND ARD CONCERNS

Under the *Mines Act*, the responsibility for preventing ML/ARD impacts from historic mining operations rests with the current owner of the mineral rights, whether or not this owner caused the problem. Under the *Waste Management Act*, MELP may assign responsibility for current ML/ARD impacts to past and/or current owners.

11.7 EXPLORATION

Companies engaged in coal and mineral exploration activities are required to submit their program proposals to MEM for approval. Proposals which involve mechanical disturbance are referred to interested government agencies and First Nations for review. A Work System and Reclamation Permit is necessary for all mechanical exploration, and a reclamation bond is required prior to its issuance (BCMEM, 1998).

Where an exploration program creates the potential for ML/ARD through bedrock excavation or earth movement, a ML/ARD program is required. The program must include prediction and, if necessary, preventative mitigation and monitoring. The necessity for a ML/ARD program depends on the environment and the characteristics of the rocks, but usually requires the disturbance of more than 1,000 tonnes of material. A small rock mass will not be a problem unless there is a large supply of soluble metals and little or no attenuation or dilution available between the discharge point and a sensitive environment.

Examples of the types of exploration activities that may result in significant ML/ARD include the construction of an exploration adit, large road cut, drill pad, or the removal of a bulk sample. Geochemical prediction and prevention work will not be required for exploration activities such as drilling, overburden trenching, soil sampling or other activities where significant bedrock exposure does not occur. The impact of metal leaching from large masses of drill core or mineralized overburden generally can be avoided by isolating the storage sites and locating them away from sensitive resources.

Prediction information must be provided in advance of the proposed excavation. This information is required to enable prevention through prediction and design, to avoid costly or long-term mitigation wherever possible, and to allow prevention measures to be designed, reviewed and implemented without delays or costly material rehandling. Prediction requirements include the identification, description, mapping and ML/ARD characterization of each geological unit pre- and post-excavation. Consideration must be given to the attenuation and dilution available prior to potentially contaminated drainage reaching sensitive resources.

Where there is a potential for significant ML/ARD, the company must provide and follow waste disposal plans and meet receiving environment objectives. Acceptable long-term environmental impact prevention methods include avoidance through non-excavation, appropriate siting of the disposal area, blending to create a non-ARD producing composite and underwater disposal. Often the best mitigation strategy is avoidance or minimized excavation of the problematic material. For example, it may be possible to relocate an adit or road cut into more benign rock.

ML/ARD impacts may also be prevented by decreasing the contribution of drainage to ML/ARD. Where metal leaching is minimal, it may be possible to reduce loadings to acceptable levels by locating wastes in an area of low flow or by using measures to divert clean waters. Potentially ML/ARD generating materials should never be disposed of in areas of concentrated groundwater flow (i.e., a groundwater collecting adit) or at a depth where the water table fluctuates seasonally.

Where there is a delay prior to the application of permanent prevention measures, such as backfilling into a declined adit or placement in a mined-out pit, short-term mitigation methods such as alkaline additions may be used. Covers and short-term drainage treatment may also be acceptable in some instances.

Where a significant mass of material is excavated, post disturbance monitoring is required to verify the elemental composition and ABA characteristics. Some form of ongoing monitoring may be required for the drainage coming from materials whose ML/ARD potential remains uncertain.

The assessment of ML/ARD potential will likely require an iterative process of sampling, analysis and evaluation, similar to that used to determine other geological characteristics such as ore reserves. Ideally, the two processes should occur concurrently. By addressing ML/ARD during exploration, a prospective mine can avoid delays associated with further data collection, utilize the most cost-effective procedures for prediction, and reduce their liability and risk.

Permit conditions for exploration work are set by MEM based on advice from the RMDRC. In cases where the success of prevention measures cannot be assured, financial security must reflect the potential prevention/mitigation costs and risk to the environment. Where a potential for ARD is identified, more detailed site and receiving water monitoring may be required to determine the potential environmental impacts. If environmental risk is too great, the RMDRC may recommend rejection of the permit application.

12. COMMITMENT TO IMPROVED PRACTICES AND REGULATION

MEM will endeavor to be transparent in its regulating practices and include all stakeholders in its technical reviews. The cooperative efforts of the British Columbia Government, mining industry and environmental groups are highly regarded in the rest of Canada and has helped British Columbia become a world leader in ML/ARD prediction and prevention. MEM will continue to assist in the improved understanding and development of ML/ARD technology and revise policies and guidelines accordingly.

12.1 RESEARCH

To assist the British Columbia mining industry in complying with present reclamation requirements, MEM carries out a program of research, information sharing and technology transfer aimed at developing and encouraging the use of cost-effective solutions to major environmental problems. A major part of this program focuses on ML/ARD.

To review research and facilitate technology transfer, MEM coordinates and provides funding for the British Columbia Acid Mine Drainage Task Force, and organizes an annual ML/ARD workshop held each fall. In 1997, MEM helped organize the Fourth International Conference on ARD in Vancouver by participating as a major sponsor and organizing field tours and short courses.

MEM has been an active supporter and participant in all activities of MEND, the national ARD research program. MEM will continue this practice through its participation in the MEND 2000 program. In 1997, MEM coordinated or acted as a technical advisor for seven ARD and two metal leaching contract research projects. MEM has also organized a multi-stakeholder committee which addresses issues regarding molybdenum and reclamation.

The problems of ML/ARD are not easily solved. However, work conducted during the last decade has greatly enhanced our knowledge and ability to predict and mitigate ML/ARD.

REFERENCES

Arnesen, R.T. and Iversen, E.R. (1997). The Lokken project - flooding a sulphide ore mine. Proceedings, *Fourth International Conference on Acid Rock Drainage.* Vancouver, BC. Volume III, pp. 1093-1107.

Aubertin, M., Chapuis, P., Aachib, B., Bussiere, B., Ricard, J.F., et Tremblay, I. (1996). Evaluation en laboratoire de barrieres seches construites a partir de residus miniers. *Mine Environment Neutral Drainage Program*. Report 2.22.2a.

Baker, F., Cook, D., Deem, J., Letient, H. and Walsh, H. (1996). Matachewan mines tailings dam - from failure to rehabilitation. *Canadian Dam Safety Association Conference*. Niagara Falls. pp. 105-118.

BCEAO. (1995). Guide to the British Columbia Environmental Assessment Process. *B.C. Environmental Assessment Office*.

BCMEI. (1997). Health, Safety and Reclamation Code for Mines in British Columbia. *B.C. Ministry of Employment and Investment*. (note: *Ministry of Employment and Investment* was the former home of the present *Ministry of Energy and Mines*).

BCMEM. (1998). Mineral Exploration Code - Part 11 - Health, Safety and Reclamation Code for Mines in British Columbia. *B.C. Ministry of Energy and Mines*. p. 66.

BCMEM. (1998). Application requirements for a permit approving the mine plan and reclamation program pursuant to the *Mines Act* R.S.B.C. 1996, C.293. *B.C. Ministry of Energy and Mines*. p. 14 plus appendices.

BCMEM and BCMELP. (1998). Policy for metal leaching and acid rock drainage at British Columbia minesites. *B.C. Ministry of Energy and Mines and B.C. Ministry of Environment, Lands and Parks*. p. 17.

BCMEMPR. (1993). Interim policy for acid rock drainage at minesites. *B.C. Ministry of Energy, Mines and Petroleum Resources*, July 1993. p. 12. (note: *Ministry of Energy, Mines and Petroleum Resources* was the former home of the present *Ministry of Energy and Mines*).

Danielson, L. and McNamara, A. (1993). The Summitville Mine: what went wrong. *Colorado Mined Land Reclamation Board.* p. 52 plus appendices.

DFO. (1994). Habitat conservation and protection guidelines. *Department of Fisheries and Oceans.* p. 25.

Errington, J.C. (1991). The regulation of acid mine drainage. Proceedings, *Second International Conference of the Abatement of Acidic Drainage*. Volume 2, pp. 89-99.

Feasby, G. and Tremblay, G. (1995). New technologies to reduce environmental liability from acid generating mine wastes. Proceedings, *Sudbury '95 Mining and the Environment*. Volume 2, pp. 643-647.

Geocon. (1995). Economic evaluation of acid mine drainage technologies. *Mine Environment Neutral Drainage Program.* Report 5.8.1. p. 38.

Giroud, J.P. and Bonaparte, R. (1989). Leakage through liners constructed with geomembranes: part I geomembrane liners. Geotextiles and Geomembranes. 8. pp. 27-67.

Koyanagi, V.M. and Panteleyev, A. (1994). Natural acid rock drainage in the Red Dog-Hushamu-Pemberton Hills area, Northern Vancouver Island (92L/12). in Geological Fieldwork 1993. *B.C. Ministry of Energy, Mines and Petroleum Resources*. Paper 1994-1, pp. 119-125. (note: *Ministry of Energy, Mines and Petroleum Resources* was the former home of the present *Ministry of Energy and Mines*).

Kuit, W.J. (1980). Mine and tailings effluent treatment at the Kimberley, B.C. operations of Cominco Ltd. *CIM Bulletin*. December 1980. pp. 105-112.

Lapakko, K., Wessels, J. and Antonson, D. (1995). Long-term dissolution testing of mine waste. *Minnesota Department of Natural Resources. Report to United States Protection Agency.* p. 85.

Lett, R., Jackaman, W. and Sibbick, S. (1996). Spring water and spring sediment geochemistry of the Gataga Mountain Area. *B.C. Ministry of Energy, Mines and Petroleum Resources*. Open File 1996-30. (note: *Ministry of Energy, Mines and Petroleum Resources* was the former home of the present *Ministry of Energy and Mines*).

MacDonald, D.D. (1997). Methods for deriving site-specific water quality objectives in British Columbia and Yukon. *B.C. Ministry of Environment, Lands and Parks*. p. 45.

Mehling, P. (1998). Blending and layering waste rock to delay, mitigate or prevent acid rock drainage and metal leaching: a case study review. *Mine Environment Neutral Drainage Program*. Report 2.37.1 p. 88 plus appendices.

Morin, K.A. and Hutt, N.M. (1997). Environmental geochemistry of minesite drainage: practical theory and case studies. *Minesite Drainage Assessment Group*. p. 333.

Nagpal, N.K., Pommen, L.W. and Swain, L.G. (1995). Approved and working criteria for water quality - 1995. *B.C. Ministry of Environment*. p. 45.

Norecol, Dames and Moore. (1994). Long-term kinetic acid generation studies: Cinola Project, British Columbia. *Mine Environment Neutral Drainage Program*. Report 1.19.1. p. 132 plus appendices.

Pons, L.J., Van Breemen, N.J. and Driessen, P.M. (1982). Physiography of coastal sediments and development of potential soil acidity. in Acid Sulphate Weathering. *Soil Science Society of America.* Special Publication Number 10, pp. 1-18.

Price, W.A. (1997). Draft guidelines and recommended methods for the prediction of metal leaching and acid rock drainage at minesites in British Columbia. *B.C. Ministry of Employment and Investment*. p. 141 plus appendices. (note: *Ministry of Employment and Investment* was the former home of the present *Ministry of Energy and Mines*).

Price, W.A. and Errington, J.C. (1995). ARD guidelines for minesites in British Columbia. *B.C. Ministry of Energy, Mines and Petroleum Resources*. p. 29. (note: *Ministry of Energy, Mines and Petroleum Resources* was the former home of the present *Ministry of Energy and Mines*).

Price, W.A., Schwab, T. and Hutt, N.M. (1995). A reconnaissance study of acid mine drainage at the Britannia Mine. *B.C. Ministry of Energy, Mines and Petroleum Resources*. p. 89. (note: *Ministry of Energy, Mines and Petroleum Resources* was the former home of the present *Ministry of Energy and Mines*).

Redfern Resources Ltd. (1997). Project report for Tulsequah Chief Mine. July 1997.

Vanapalli, S., Barbour, S.L. and O'Kane, M. (1997). Review of soil cover technologies for acid mine drainage - a peer review of the Waite Amulet and Heath Steele soil covers. *Mine Environment Neutral Drainage Program*. Report 2.21.3.

Wilson, G.W., Newman, L., Barbour, S.L., O'Kane, M. and Swanson, D.A. (1997). The cover research program at Equity Silver Mine Ltd. Proceedings, *Fourth International Conference on Acid Rock Drainage.* Vancouver, BC. Volume I., pp. 197-121.

Woyshner, M.R. and St-Arnaud, L.C. (1994). Hydrogeological evaluation and water balance of a thickened tailings deposit near Timmins, Ontario, Canada. *International Land Reclamation and Mine Drainage Conference Paper.* Pittsburgh, PA. pp. 1075-1092.

Zinck, J.M. (1997). Acid mine drainage treatment sludges in the Canadian mineral industry: physical, chemical, mineralogical and leaching characteristics. Proceedings, *Fourth International Conference on Acid Rock Drainage.* Vancouver, BC. Volume IV, pp. 1693-1708.