List of Potential Information Requirements in Metal Leaching/ Acid Rock Drainage Assessment and Mitigation Work

MEND Report 5.10E

This work was done on behalf of MEND and sponsored by:
The Mining Association of Canada, MEND and
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DIVISION REPORT / RAPPORT DE DIVISION

LIST OF POTENTIAL INFORMATION REQUIREMENTS IN METAL LEACHING AND ACID ROCK DRAINAGE ASSESSMENT AND MITIGATION WORK

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Mine Effluents Program

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INTRODUCTION

Metal[1] leaching and acid rock drainage[2] (ML/ARD) produced by sulphide minerals and their by-products are the most costly and potentially environmentally damaging issue facing the mining industry. Due to the need for proactive problem detection, the long-term nature of ML/ARD issues, the many processes in flux, limited operating experience and large multi-disciplinary information requirements, it is also a very challenging issue. Since the depth and breadth of the knowledge required can sometimes be overwhelming, it is possible to overlook critical pieces of information. In addition, many properties are difficult to measure and there is a tendency to focus on the most familiar or easily measured factors. An example of this is the work on dry covers, which commonly focuses on the micro-scale performance of the cover with less attention being paid to more important, but difficult to measure properties such as the volume of runoff or the geochemistry of the underlying wastes.

The objective of this document is to improve ML/ARD assessment and mitigation work by providing a comprehensive list of the potential information requirements and factors to consider. The list is intended to make the technical specialist aware of the general issues and the generalist practitioner aware of detailed information requirements. The list was first put together as a guide for authors of case studies. It has been modified to serve as a general guide for the mining industry, regulators and the public reviewing their work, as well as educators and students.

While the list will help ensure all relevant issues are addressed, it is only intended as a starting point. Every mine site has unique environmental, geological and operational conditions. Best management practices for ML/ARD are the tools and procedures needed to develop a site-specific understanding of the natural environment, the mine site, the materials involved, the environmental protection requirements, and the resulting opportunities and constraints. For any particular site, many potential factors or information requirements within this list may not be relevant. Similarly there will be instances where there are additional information requirements and factors to consider.

When developing or reviewing mining plans, this document can be used to identify outstanding information requirements, factors to consider, information or factors that are not applicable, and where data collection or planning is underway or completed. Where no work or no further work is required on an item, it is important to explain why. Various factors can influence practices and it is very useful to document the rationale for decision-making; for example where mitigation decisions are made based on material characterization and vice versa. In the list of information requirements, mitigation and material characterization have been separated. In practice, the two are usually integrated.

This document is not intended as a substitute for individuals with a comprehensive knowledge of the site and the appropriate technical training and experience responsible for the ML/ARD aspects of the site. Nor is it intended to replace regulatory requirements. Users are encouraged to adapt the generic suggestions to their own site and requirements, incorporating appropriate site-specific performance measures. Work requirements and conclusions regarding ML/ARD may

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[1] The definition of metal is broadened to include metalloid elements, such as arsenic, which are also products of sulphide mineral weathering.

[2] Acid rock drainage (ARD) is also commonly known as acid mine drainage (AMD) and acidic drainage (AD).

change after the mine plan, materials handling, mitigation options and the cumulative risk, liability and land use impact of the entire mine have been reviewed.

The information provided here is based on the opinions of the author and should not be construed as endorsement in whole or in part by the various reviewers or by the partners in MEND (the Government of Canada, Provincial Governments, the Mining Association of Canada, contributing mining companies and participating non-governmental organizations). The user of this guide should assume full responsibility for ML/ARD assessment and mitigation, and for any action taken as a result of the information contained in this guide.

Natural Resources Canada is committed to improving existing practices. Comments on or suggested improvements to this document are welcome and should be submitted to the author at bprice@nrcan.gc.ca.

Acronyms

ABA:	Acid-Base Accounting
AP:	Acid Potential
ARD:	Acid Rock Drainage
NP:	Neutralization Potential
NPR:	Neutralization Potential Ratio (NP/AP)
PAG:	Potentially ARD Generating
NAG test	Net Acid Generation test

Accurate terminology is required for effective communication and readers are encouraged to consult the glossary of terms produced by Price, Morin and Hutt and available on the MEND (MEND.NRCan.gc.ca) and INAP (www.inap.com.au/inap/homepage.nsf) web sites.

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GENERAL INFORMATION REQUIREMENTS

There are a large number of objectives in metal leaching and acid rock drainage (ML/ARD) work. The overall objectives are to minimize the environmental risks and liability. This requires a prediction of the chemistry of mine drainage and the risk of unacceptable water quality, and implementing cost-effective mitigation. General information requirements in ML/ARD typically include:

- General site information, including location, access, topography, climate and ecology
- Site history, including an overview of mine development, mining and processing, waste materials and site components
- Geology and mineralogy, including identity and description of all geological materials excavated, exposed or otherwise disturbed by present and past mining activities
- Site hydrology and hydrogeology
- Soils and other geotechnical aspects of the site.
- Environmental and reclamation objectives, including species sensitivity, distribution and potential mechanisms of exposure, regulatory history and current conditions, end land use objectives, discharge limits and receiving environment objectives
- Information sources, including literature reviewed
- Figures (site plan and maps of location, topography and drainage) and tables

The description of general site conditions should include generic information that pertains to the overall site. It is expected that the majority of the ML/ARD information will be provided in the subsequent description of specific waste materials (e.g., waste rock) or site components (e.g., backfilled tailings in underground workings).

MATERIAL CHARACTERIZATION AND ML/ARD PREDICTION

An analysis of present composition and prediction of future drainage chemistry should be conducted for each geological material (e.g., rock type and surficial material) and waste type. The selection of samples, sample preparation, assays, test procedures, sampling procedures, and data interpretation should be based on the availability of representative materials, project needs and other site-specific requirements, such as probable weathering environment and geological make-up. Available analytical procedures may be limited in some parts of the world.

The assessment of materials should show the distribution/variability of key geochemical parameters (such as acid-base accounting results and metal concentrations in solids or leachates), potential discrepancies between results and reality (e.g., laboratory determined AP and NP versus AP and NP available in the field), and, where applicable, the timing of significant geochemical events, such as the onset of ARD or significant metal leaching. Depending on the phase of project development and the available information, the assessment should show pre-mining, operational, post-mining and future results and predictions, including loadings and resulting environmental impacts.

It is important to remember that the primary purpose for the geochemical assessment is to guide management decisions. The significance of contaminant release and inaccuracies in prediction will depend on loadings, available dilution/attenuation and the sensitivity of the receiving environment. At each stage of the test program, one needs to consider the purpose of the test work and whether the results will impact site management, liability or the risk to the environment. In some cases, the provision of contingency mitigation measures coupled with operational testing during mining will be more effective than additional pre-mining prediction test work, which is likely to be inconclusive or of limited significance to the overall mine plan.

The following is a list of generally recommended information and analytical needs and procedures for the presentation and interpretation of the results.

Geology and Mineralogy

Geological Properties

- Rock types and surficial materials
- Mineralization and effects of hydrothermal alteration and surficial weathering processes
- Description of different geological units, including visual properties and their spatial distribution
- Rock strength (e.g., slaking in water)

Plan views and cross sections of the site should be used to show the spatial relationship between the various rock units, different forms of mineral alteration, outline of underground workings and/or pit, and ore versus waste.

Mineralogy

- Petrographic methods (e.g., staining) and results, including proportion, grain size and spatial distribution (e.g., in rock mass or concentrated along fractures or veins) of different minerals, and portions of samples that the petrographic analysis was unable to identify (e.g., grains too small)
- X-ray diffraction (XRD) method, detection limits and results, including proportion of different minerals, with a particular emphasis on carbonate, silicate, sulphide and water-soluble mineralogy
- Microprobe method and results
- Other sub-microscopic methods, such as scanning electron microscope, and results

Microprobe analysis is used to determine the composition of minerals not readily identified by optical methods or XRD, including the composition of carbonate and solid solution minerals. It is also used to identify the mineral source for potential contaminants and whether elemental composition can be used to estimate % mineralogy (e.g., use of Ba to estimate % barite).

Static Tests: Measurement of Material Composition

Sampling

- Materials sampled (e.g., drill core, drill cuttings and < 2 cm fraction of post-blast material), sampling procedure (e.g., composites of grab samples taken every metre along a 5 m transect or cross section of drill cuttings), numbers of samples, sampling locations, sample volumes or mass, and amount of material purportedly characterized by each sample

- Sample description, including measures of statistical representativity of the population
- Exposure of test material to weathering prior to sampling
- Sample preparation, such as drying, sieving, crushing, grinding or storage in an oxygen-free environment
- Number of samples collected from each geological unit

Plan views and cross sections of the site are typically needed to show the spatial distribution of samples within rock units, different forms of mineral alteration and variability in key ML/ARD properties. Diagrams should outline the underground mine and/or open pit, and boundary between ore and waste.

Elemental Content

a) Total Concentration
   - Digestion and analysis(es)
   - Comparison with typical crustal variability or regional background

Comparison with crustal variability or regional background is used to identify elements occurring in relatively high concentrations. Depending on the weathering and leaching conditions, these elements may be of no environmental concern.

b) Water-Soluble Concentration
   - Analytical methods, including sample pre-treatment, ratio of solid to extractant, type of extractant, time of leaching and number of repetitions, and degree of agitation
   - Interpretation of results, including predicted loadings, geochemical modelling of solubility constraints and identification of potentially problematic weathering or leaching conditions

Potential solubility concerns include changes in drainage chemistry (e.g., changes in redox), unusual mineralogy or previous oxidation and/or leaching due to natural weathering (e.g., supergene processes) or delays in mitigation.

Acid-Base Accounting

a) Sulphur Analyses (total-, sulphate-, organic- and sulphide-S) and Acid Potential (AP)
   - Corresponding mineralogical information
   - Analytical methods and calculations, including how sulphide-S measured and AP calculated
   - Concentration of sulphide-S in minerals potentially generating different amount of acidity per unit S than pyrite
   - Presence of coal, mudstone, peat or plant material, indicating the presence of organic-S
   - Concentration of acid-leachable and non-acid-leachable sulphate-S and whether they are small enough to use total-S or total-S minus acid soluble sulphate-S to calculate AP, non-acid-leachable sulphate species include barite (Ba), celestite (Sr) and anglesite (Pb),
   - Concentration of acid sulphates (e.g., jarosite and alunite)
   - Potential for sulphide occlusion from oxygen or drainage
   - Potential for galvanic controls on sulphide oxidation

b) Bulk or Titratable Neutralization Potential (Bulk-NP)
   - Supporting mineralogical information (carbonate composition and types of silicates)
   - Analytical methods
   - If some variation on the Sobek procedure was used, the fizz rating and how the acid addition compared with resulting NP and estimated Ca and Mg carbonate content
   - Potential contribution to NP measures from Ca and Mg carbonate, non-neutralizing Fe and Mn carbonate and differently reactive silicate minerals
   - NP measured in samples with an acidic pH

c) Carbonate Neutralization Potential (Carbonate-NP)
   - Relevant mineralogical information
   - Analytical methods
   - Concentration of Ca and Mg carbonate versus net non-neutralizing Fe and Mn carbonate

d) pH
   - Sample preparation and its influence on pH measurement
   - Analytical methods, including sample pre-treatment that may mix weathered surfaces with fresh material and the ratio of solid to extractant
   - Results of rinse versus crushed pH
   - Whether materials are already acidic

e) NAG (Peroxide) Test Results
   - Analytical methods
   - Correlation with mineralogical and various sulphur, carbonate and acid base accounting results

Kinetic Tests: Measurement of Reaction Rates and Drainage Chemistry

- Pre- and post-test composition of test materials
- Drainage chemistry (pH, alkalinity, hardness, SO_4, Fe, Al, Mn, Ca, Mg, K, Na, other base cations, $(Ca+Mg)/SO_4$ and trace elements in leachate), flow rates, loadings, solubility constraints (results of geochemical modelling) and potential sources of elements in drainage, significant changes and predicted time to significant changes
- Potential sulphide occlusion from oxygen or drainage
- Galvanic controls on sulphide oxidation and metal leaching

<u>Humidity Cell, Column Tests and In-Situ Field Tests</u>

- Comparison between test materials and the materials they represent
- Test procedure, including preparation of test materials and rate of leaching
- Climate data for field tests
- Duration of test and changes observed
- Estimated rate of sulphide oxidation, sources of NP, rate of metal release from oxidation and dissolution of primary minerals, solubility constraints on contaminant concentration and time to exhaustion of NP
- Cell, column or test pad dismantling procedure and analyses done on material, including formation of secondary materials
- Potential impact of differences between laboratory and field conditions

Site Drainage Monitoring

- Monitoring locations (e.g., seeps, collected mine drainage and pit lakes) and mine components contributing to the drainage
- Parameters measured, and frequency and duration of monitoring
- Correlation with climate data

Assessment of Different Waste Materials and Site Components

Where possible, outline volumes and approximate mining sequence for different materials, and how and where they will be, are or were handled and disposed. Factors to consider will vary depending on the waste material and site component or depositional environment. For example, break down of larger particles and mixing with the underlying material are potential issues when waste rock is used to surface roads. Potential waste materials include waste rock, tailings, various by-products such as cycloned sand produced from tailings, low-grade ore, treatment wastes, construction materials, etc. Site components from present and past mining activities, including waste rock dumps, impoundments, mine workings (open pits and underground workings), temporary stockpiles and roads.

Waste Rock and Waste Rock Dumps

- Pre-mining prediction
    - Pre-mining prediction is usually based on an analysis of exploration drill core.
    - How representative is the analysis of drill core or cuttings (whole rock) of the composition of different areas of the mine workings or particle size fractions of the resulting waste rock and tailings?
    - Exploration usually focuses on ore, and there may be no drill core available to predict the composition of waste rock at the edge of the mine workings, where there is potential for features such as a distal pyrite halo.
    - Composition of particle size determining drainage chemistry (e.g., finer sized, reactive portion of waste rock) may be different from whole rock
- Results during mining from sampling of pre-blast drill cuttings
- Results during mining from post-blast sampling prior to removal of waste rock from pit or after placement on dumps, including relative mass and concentration of AP and NP in fines versus coarser particles
- Post-disposal weathering, including changes in pH, carbonate content, soluble weathering products and oxygen concentration
- Thermal properties and pore gas composition of waste rock dumps, such as temperature and oxygen concentration

Tailings

- Prior to mining, results from an analysis of drill cores intersecting ore and bench-scale and pilot-scale metallurgical test work
- During mining, results from the analysis of ore, whole tailings and different potential tailings fractions including cleaner and rougher tailings, cycloned tailings sand used for underground backfill or dam construction, and desulphurized tailings

- Amendments added during processing
- Potential segregation during deposition and composition of tailings beach and slimes
- Post-disposal weathering, such as changes in pH, carbonate content, soluble weathering products and oxygen consumption
- Depth of water table and oxygen depletion, and consequent constraints on sulphide oxidation
- Production of thiosalts

The production of thiosalts during milling and subsequent ARD production in the tailings effluent is an issue with some high sulphide ores at a number of mines in Eastern Canada and at least one mine in British Columbia. It would therefore be prudent to check for them during the metallurgical test work.

<u>Mine Workings – Open Pits and Underground Mine</u>

- Composition of mine walls and degree of fracturing
- Composition, mass and location of backfill, fractured bedrock (e.g., ore broken apart by blasting but not removed) and talus
- Hydrology, including location and rates of flow, height of the water table, and timing and location of discharge
- Weathering, drainage chemistry and loadings at different locations

Typically backfill and talus contribute significantly more reactive surface area and are thus more important determinants of drainage chemistry than mine walls and fractures.

Interpretation of Geochemical Results

<u>General Considerations</u>

A common concern is how much information to provide. Unfortunately, the devil is often in the details and therefore a comprehensive explanation of details is generally required (e.g., how samples were collected and whether analyzed samples are representative of the overall population). Only a small portion of the material may be sufficient to produce significant ARD or metal leaching. Consequently, variability and distribution of parameters such as NPR (NP/AP) and metal concentrations are typically more important than central tendency or average composition. Depending on the situation, descriptive statistics such as the 10th and 90th percentile and median are a useful way to describe the variability, but are no substitutes for plots showing the distribution of data. Sensitivity analysis can be used to determine whether additional information is required. Spatial variability is important in determining when geochemically different materials are mined and whether segregation is possible.

Plan views and cross sections of the site are typically used to show the spatial relationship of variability in ML/ARD properties and their correlation with rock units and different forms of mineral alteration. Diagrams should show sampling locations, the outline of the underground workings and/or pit, and the location of the ore versus waste materials.

Identifying Potentially ARD Generating Materials

It is important to recognize that the primary source of toxic ity is metals and that unacceptably high metal leaching may occur with neutral pH drainage. At other sites, water quality is only a concern if the wastes generate ARD. However, even where neutral pH drainage is a concern, the occurrence of ARD typically results in much higher metal solubility and weathering rates, and therefore the identification of ARD generating materials is important.

In ML/ARD test work, commonly the first step in assessing whether the neutralizing minerals in a sample are sufficiently plentiful and reactive to neutralize the acidity generated from the oxidation of sulphide minerals is to calculate the acid potential (AP) and neutralizing potential (NP). The ARD potential is then predicted from the NP:AP ratio (NPR). Assuming the AP and NP are accurate and there is exposure to air and leaching, ARD is judged likely if the NPR is < 1, uncertain if the NPR is 1 to 2 and of low probability if the NPR is > 2.

- Determine parameters and procedure to use, including whether corrections should be made to laboratory sulphur analyses, and then calculate acid potential (AP)
- Determine parameters and procedure to use, including whether corrections should be made to lab determined NP, and then calculate neutralization potential available in the field (NP)
- Calculation of NPR (NP/AP)

A key part of the assessment of potentially ARD generating materials is the way in which AP and NP are measured and the discrepancies with acid generation and neutralization in the materials under the mine site conditions. In order to be quick and repeatable, procedures used to measure AP and NP are a crude approximation of the large number of factors and processes that contribute to acid generation and neutralization in the field. The subsequent calculations involve a number of assumptions that may be incorrect. Consequently, corrections may be required to take into account site-specific conditions and divergence from the assumptions regarding mineralogy. Corrections or safety factors may also be used to account for sampling limitations, the heterogeneity of key properties, and the composition of sample (e.g., drill cuttings created from whole rock) versus actual reactive portion of the material (e.g., dump fines).

Although traditionally a part of ABA, the calculation of the NNP (NP minus AP) is usually a waste of time.

Identifying Non-Potentially ARD Generating Materials

The decision about how to handle the non-PAG material will depend on whether neutral or alkaline pH leaching is a concern[3]. If neutral pH metal leaching is not a concern, potential objectives in identifying non-potentially ARD generating (non-PAG) material include limiting costs and risks associated with mitigation of potentially ARD generating (PAG) materials (e.g., size of the dam if the material must be flooded) and finding construction materials. Tasks involved include setting criteria for what is PAG versus non-PAG for each different geological material and determining whether the not-PAG material can be separated. PAG versus non-PAG

[3] It is important to note that depending on the metals present, weathering rates, loadings and the receiving environment, neutral pH may a major environmental concern.

criteria are typically based on NPR and require an assessment of the sources of AP and NP, potentially confounding factors (e.g., composition of waste rock fines versus drill core whole rock results), and how to operationally measure the parameters used in the criteria (sampling procedure and frequency, analysis procedures and whether corrections should be made to calculated NP, AP or the NPR).

In addition to resulting drainage quality, use of non-PAG material also depends on whether non-PAG material can be segregated from PAG. This requires an assessment of the spatial distribution of non-PAG, and how to operationally distinguish and segregate it from PAG material (e.g., how to operationally estimate the NPR).

Predicted Drainage Chemistry and Metal Loading

Predicted drainage chemistry and metal loadings depend on:

- Weathering environment (see waste rock and tailings)
- Surface area effects (e.g., relative proportions and composition of fine and coarser particles)
- Rate of leaching and drainage discharge from wastes and mine workings, including impact of rebound in water table following mining
- Predicted ML/ARD potential, the proportion and spatial distribution of materials judged likely to produce ARD and/or significant metal leaching, if potentially acid generating (PAG), predicted time until ARD onset
- Predicted metal release and solubility constraints, including supporting results of various kinetic tests and geochemical modelling
- Downstream alkalinity, dilution and metal attenuation

Potential Environmental and Regulatory Impacts

Environmental impacts depend on species sensitivity, distribution, and duration and form of exposure. Relevant information includes predicted loading and drainage chemistry, chronic and acute toxicity test results, field observations of species activity and population health, reclamation objectives, discharge limits and receiving environment objectives

Pre-mining metal loading may be important in determining receiving environment and reclamation objectives. Metal loadings from adjacent less mineralized areas are required to determine cumulative stresses on the system, another potentially important factor in determining receiving environment and reclamation objectives.

Time to Onset of ARD

The objectives in determining the time to onset of ARD are to set criteria for minimum time prior to flooding or implementing other remedial measures (such as processing of low grade ore or placement of engineered covers) to prevent significant additional weathering and/or to assess the impact of delays. This requires an estimation of the rate of sulphide oxidation (ug/kg/unit time sulphate-S), the amount of acid produced, the subsequent decline in NP and the resulting time to NP depletion. Where neutral pH leaching is not an issue, time to onset may also be important in determining when impacts may be expected from unflooded PAG materials. The relevance of ARD onset for different rock units will depend on the impact.

MITIGATION MEASURES

General Features

- Design objectives, including extent to which contaminant loadings are or will be reduced, how environmental objectives will be achieved, compatibility with mine plan, complementary mitigation measures, reclamation plan and relevant biogeoclimatic features of the site
- Construction details and operating history, including waste handling, modifications, upgrades, maintenance and monitoring results
- Water management, including drainage input and discharge location(s), flows and drainage chemistry
- Areas of significant uncertainty, including potential changes, their management implications, contingency plans and studies aimed at reducing uncertainty and guiding or improving future management
- Long-term performance
- Regulatory requirements

The environmental objectives will play a major role in the selection of mitigation measures and their design.

Most ML/ARD mitigation facilities or structures must be designed, constructed, operated and financed in a manner that allows them to perform indefinitely. Successful long-term performance requires pro-active detection and resolution of problems prior to significant environmental impacts. This requires:

- a conservative design;
- ability to handle future geochemistry, hydrology, ecology, etc.;
- monitoring, maintenance, repair, replacement and contingency plans;
- regularly updated operating manuals and databases for monitoring results; and
- the financial resources to conduct the above.

Dealing with future changes in site hydrology and waste geochemistry is an important aspect of pro-active mitigation. Where sulphidic wastes will become increasingly more oxidized or changes in site hydrology may increase leaching, potential increases in metals and acidity and the possible need for additional environmental protection measures should be assessed.

Provision of adequate resources is important because of the potentially large costs. Where possible provide existing and estimated future capital and long-term operating costs for each aspect of the mitigation system, including facilities, operating costs (e.g., lime, power, personnel, pumps, maintenance, monitoring, secondary waste disposal and contingencies in the event of upset conditions).

Flooding of Mine Wastes and Workings

<u>Impoundment</u>

- Type of impoundment (e.g., constructed tailings impoundment, pits, underground workings and natural water bodies)

- Impoundment design, construction and operation of impoundment structures, such as dams, spillways, bulkheads, and grouting of drill holes, fractures and decant structures
- Monitoring and maintenance measures to ensure long-term geotechnical stability throughout the entire range of possible site conditions, including maintaining capacity of key diversion structures, preventing undesirable beaver activity (e.g., flooding dam foundations or blocking spillways), and monitoring to determine when maintenance is required

<u>Flooded Wastes</u>

- Waste types (e.g., waste rock, tailings and treatment products), quantities, handling and disposal locations
- Waste characterization, including potential for ARD or significant ML if left exposed
- Concentration of potentially-soluble contaminant species with present drainage chemistry and predicted changes in factors such as pH, redox or leaching[4]

This information can be used to determine what material requires flooding, required storage capacity, maximum exposure prior to flooding and need for supplemental remediation measures. Potentially soluble species include products of pre- and post-excavation weathering and precipitates created when wastes or drainage are added to the impoundment.

<u>Water Balance</u>

- Predicted and resulting input and output rates
- Size and depth of water cover
- Contingency water sources

<u>Physical Mobilization</u>

- Suspension during deposition, only important in an open system
- Remobilization by wave action, ice movement and flow across the impoundment
- Mitigation measures, including increasing depth of the water cover, non-mineralized covers and use of berms or baffles to reduce fetch

<u>Delay in Flooding</u>

- Amount of aerial exposure prior to flooding
- Predicted time to ARD and build-up of significant soluble acidity and metals
- Impact on chemistry of water cover and potential for future contaminant discharge

The information can be used to determine flushing of oxidized wastes, maximum permissible exposure prior to flooding, whether there is a need for supplemental measures prior to flooding and triggers for their use. Additional measures include minimizing waste elevation, separate disposal of problematic material, monitoring of exposed materials, addition of lime and plans to move wastes or accelerate flooding.

<u>Incomplete Flooding</u>

- Where only partial flooding (e.g., exposed mine walls or beach adjacent to dams) will occur
- Resulting impact of aerial weathering on impoundment drainage chemistry

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[4] It is important to quantify the "short-term" (one-time) load of soluble chemicals versus the ongoing leaching that can occur in submerged waste – they have very different implications for assessment and mitigation.

Supplementary Remedial Measures

- Pre-treatment of drainage or waste components prior to disposal
- Chemical amendments to waste or water column (e.g., lime to neutralize acidic waste)
- Addition of oxygen consuming or diffusion barriers (e.g., cover flooded waste rock with tailings) to minimize oxygen entry and release of deleterious contaminants

Management of Impoundment

- When, where and how discharge will occur
- Regulatory discharge requirements
- Measures to minimize loadings to the environment and maximize dilution
- Measures to conduct drainage across or around the impoundment
- Consideration of ecological succession, sedimentation, alternate uses of storage area, changes in water balance and changes in land use

Chemistry of Water Cover and Impoundment Discharge

- Composition of waste and rates of input
- Composition and rates of drainage inputs, such as process water, pore water (e.g., through consolidation of wastes), runoff from other wastes, groundwater, precipitation and discharge of other water sources (e.g., sewage)
- Previous or predicted changes within wastes and water cover (e.g., development of reducing conditions in oxidized wastes or decreasing pH as a result of acid inputs from precipitation, nitrification of ammonium or unflooded materials)
- Previous or predicted contaminant attenuation within wastes (e.g., precipitation of trace metals as sulphides by sulphate reducing bacteria or co-precipitation with iron hydroxides) and water cover (e.g., uptake or adsorption by biota)

Solute release into overlying water cover and discharge from the impoundment will depend on the composition of wastes and the drainage. Solute release is determined by the composition of particle surfaces and pore water. In unweathered materials, the composition of the surfaces is similar to the interior of the particles. Unweathered waste rock and tailings have relatively high alkalinity (created by blasting and handling in the case of waste rock and crushing and grinding in case of tailings). The pH of unweathered waste rock will be similar to the abrasion pH of the exposed minerals. The pH of tailings is usually similar to that of process water. Process additives may have large impact on the water chemistry.

Weathering prior to deposition can alter the composition of particle surfaces and pore water, and the resulting chemistry of the water cover. After waste deposition in the impoundment ceases, alkalinity of the water cover is often observed to decrease due to the decreased flushing of wastes, lower pH of precipitation and runoff, and reaction of materials in the impoundment (e.g., acid produced by oxidation of ammonium to nitrate). Long-term metal release from flooded wastes will depend on a large number of site-specific factors. Many primary products are more stable in anoxic or low redox environments and some secondary products of oxidation are more stable in oxic or more oxidizing environments.

Information and design requirements and challenges with underwater storage are discussed in Price 2001. The information on longer-term performance, especially for waste rock, is limited. Experience at Elliot Lake, Red Lake and Equity Silver illustrate some of the issues. Potential remediation options include: applying some sort of barrier at the end of mining to limit diffusion;

minimizing seepage losses from within the flooded waste; adding lime continually in small amounts to maintain above neutral pH and relatively high alkalinity.

Measures to Reduce Infiltration of Drainage and/or Oxygen Entry

This includes dry covers and other measures, such as ditches, designed to divert drainage inputs.

Overall Mitigation Objectives

- Performance target (e.g., limit leaching)
- Required reduction in contaminant loading (e.g., 100 times reduction in Zn loadings)

Design Principles

- Physical features (e.g., soil cover)
- Mechanism(s) by which strategy will achieve the mitigation objectives (e.g., reduced hydraulic conductivity)
- Assumed leakage and deterioration

Cover Design and Construction Materials

- Components of the cover and their characteristics
- Source of materials
- Design and construction constraints, such as standards for coarse fragment and moisture content of soil

Cover Construction Methods

- Description of cover construction, including thickness of lifts, number of passes for compaction, equipment used for construction, and QA/QC on material quality, depth and compaction
- Duration of cover construction and cost ($/ha)

Upstream Interception Structures

- Location
- Relevant geotechnical, hydrogeological and geomorphological conditions
- Design and construction methods

Water Management

- Contaminated drainage output from the waste
- Clean water diverted by the cover or upstream interception structures
- Associated monitoring and maintenance

Vegetation

- Impact of vegetation on cover performance (e.g., evapotranspiration and erosion control)
- Species selection and compatibility with long-term cover performance
- Required monitoring and maintenance
- Measures to limit damage from tree-throw, roots or associated wildlife
- Species longevity
- Management of natural plant colonization

Resulting Performance of Contaminant Source

- Total contaminated drainage and individual seep chemistry, rate of flow, loadings and location from underlying waste
- Changes in composition of waste and pore water (weathering)
- Variation in height of water table, thermal properties and composition of gas

The assessment needs to consider the issue of timing and the lag times that will be associated with weathering processes and the slow flow of water in the subsurface.

Performance of Cover

- Potential drainage inputs (snow and rainfall) and volume of diverted runoff and evapotranspiration
- Monitoring results for cover, including measurements of hydraulic conductivity, moisture content, suction, small-scale infiltration into lysimeters, vegetative cover and root growth

Maintenance

- Maintenance of vegetative cover (e.g., fertilization) and management of natural plant invasion
- Measures to detect, prevent and repair deterioration from settling of waste, chemical precipitation, chemical weathering, desiccation, freeze thaw, erosion, root penetration, tree-throw, burrowing animals and human activity (e.g., ATVs)
- Equipment use to clear/repair diversion ditches and sections of cover.
- Proposed contingency measures

Drainage Treatment

Including all forms (e.g., lime treatment, anoxic limestone drains, pit lake fertilization, etc…) and duration of treatment.

Contaminated Water Sources

- Potential contaminated drainage sources
- Discharge locations
- Predicted and measured annual and long-term variability of flow, chemistry and acid and metal loadings

Drainage Collection and Storage Systems

- Layout and design (infrastructure), including location with regards to mine components
- Climatic/geotechnical/hydrological information that show its capacity
- Pre-treatment storage required to handle flows that exceed treatment capacity
- Monitoring and maintenance required to ensure systems work as planned
- Contingency plans for mechanical breakdown, power outages, access problems and higher than design flows
- Operator vigilance

Treatment Process

- Description of treatment process(es), including required conditions, such as pH and redox
- Facilities

- Composition and rate of addition of amendments
- Process control
- Effluent quality
- Maintenance and monitoring, including operator vigilance
- Operating costs (reagent, lime, power, labour)

Upset Conditions

- Design conditions when collection or treatment system is unable to handle inputs (e.g., higher than design events)
- Predicted deterioration (e.g., plugging or coating of flow-through sulphide reduction system or alkaline drain)
- Potential results, including quality, duration and quantity of discharge, dilution and attenuation in receiving environment, and impact
- Contingency plans for upset conditions

Contingency plans typically include back-up power and pumps, spare parts, enough reagents for periods when supply is cut-off (e.g., access cut-off) and back-up storage for times when contaminated drainage volumes exceed treatment plant capacity.

Treated Effluent Discharge

- Discharge requirements, including discharge limits and receiving environment objectives
- Effluent quality, quantity and discharge locations
- Infrastructure, including post-treatment storage required for periods when drainage treatment exceeds permissible discharge rate

Disposal of Secondary Waste Products

- Predicted and subsequent quality and quantity of any secondary wastes
- Disposal plan, including physical and geochemical stability, and monitoring of the drainage from the disposal site
- Operating costs (past, present and future) for handling and disposal of secondary waste products

Biological and Other Lower Operating-Cost Treatment Strategies

Information and design requirements for biological and other lower operating-cost treatment strategies are similar to those for more traditional measures such as lime treatment. The questions that need to be addressed include:

1. At how high a metal load or flow rate can the system reliably meet permissible discharge concentrations, and for how long and at what cost?

2. What is required in terms of process control, secondary waste disposal, equipment, personnel, monitoring and maintenance, and discharge? Thorough monitoring is required to demonstrate effectiveness and sustainability, and to guide future management decisions. This should include measurements that show the mechanism of contaminant attenuation, whether it is sustainable and plans for how the matrix will be disposed of when flow-through systems plug or otherwise need to be replaced.

Addition of NP During Waste Production and Deposition

This includes mixing or blending of PAG and non-PAG wastes and limestone additions to PAG wastes. Often these measures are used in conjunction with measures to reduce leaching.

- Material characterization, including results of physical, chemical and mineralogical test work on proposed materials, composition and magnitude of reactive fraction of blended wastes, and acceptability of neutral pH drainage chemistry
- Design, including criteria set to prevent ARD and significant metal leaching, NP addition, material handling and manner of physical mixing, constraints set on manner of material handling, disposal and disposal site, safety factors, process control (e.g., identification of different materials in the field) and any supplemental mitigation, such as measures to divert drainage.
- Pre- and post-deposition material characterization, including sampling, sample preparation, analysis, communication of results and time taken
- Compatibility of proposed design with the mine geology, waste production schedule (e.g., relative proportions of PAG and not-PAG rock types excavated during different phases of mine development), materials handling and the availability of disposal sites

Desulphurization of Tailings

- Characterization of ore and whole tailings, including results of physical, chemical and mineralogical test work
- Requirements of desulphurized material, including disposal objectives, criteria to prevent ARD and significant metal leaching, and data used to set criteria
- Requirements for disposal of removed sulphides, including criteria to prevent ARD and significant metal leaching (e.g., permitted exposure prior to flooding)
- Desulphurization process, including modifications to mill process (e.g., procedures for sulphide flotation), reagent additions, rates of throughput, process controls (e.g., in-process stream monitoring and laboratory analyses)
- Test work, including methodology and results of bench-, pilot- and field-scale test work, and effects of differences in ore on composition of desulphurized material
- Operational requirements, including limitations on ore types, constraints set on the desulphurization process, materials handling and deposition of products (e.g., requirements for stockpiling of product), type and frequency of monitoring, time taken to detect upsets, actions to be taken (e.g., supplemental NP additions or use of engineered covers to limit metal leaching or ARD), resources required and persons responsible

DEALING WITH UNCERTAINTY AND SUFFICIENCY OF INFORMATION

Management decisions are based on available information regarding pertinent conditions, objectives, costs and societal needs. There is never complete understanding and a critical part of any ML/ARD program is identifying and dealing with uncertainty. For this reason, it is important to provide all possible outcomes or interpretations of monitoring and material characterization, not just the presently most probable or manageable hypothesis. Similarly when developing mitigation plans, it is important to document the uncertainties and show how this will be monitored and managed.

Sensitivity analysis and risk assessment should be conducted at every stage of a ML/ARD program to determine the sufficiency of available information and the impact of possible inaccuracies on the overall environmental risk and liability. Some of the issues to be evaluated include potential impacts on predicted waste volumes, the capacity for waste segregation and storage, availability of construction materials, expected drainage chemistry and the ability to meet discharge limits and receiving environment objectives. The results of sensitivity analyses and risk assessment can be used to determine operational monitoring requirements, and to establish where additional safety factors or contingency protection measures may be necessary.

The ML/ARD program should assess the consequences of events that could occur over the life of the facility, including construction, operation and post-closure periods. Often there is significant uncertainty regarding future drainage chemistry and mitigation performance. Contingency measures are often the most cost-effective means of dealing with this uncertainty. Contingency plans may also be developed to address possible upset conditions or when a pre-mature shutdown would preclude the planned mitigation. Contingency planning typically requires input from various departments including safety, environmental, operations, maintenance and corporate personnel. Contingency plans should include monitoring programs to track performance and to ensure timely implementation of contingency measures. Another important part of contingency planning is ensuring that adequate resources are available.

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APPENDIX A: ORGANIZING INFORMATION FOR WASTE MATERIALS AND SITE COMPONENTS

One of the challenges in presenting ML/ARD work is how to avoid confusion, when there are so many factors to consider, and frequent overlaps and linkages between materials and within site components (e.g., waste rock dumps eventually moved to the tailings impoundment or column test results applied to several site components). Organizing information and selecting headings can be difficult because many items can be placed under several headings and some overlap is usually unavoidable. In some instances assessment information work will pertain to more than one waste or site component and needs to be described in a separate section at the start. Other test work will be specific and it would be better to place it in that specific section.

Examples of how ML/ARD information was organized for selected materials and site components at the Johnny Mountain and Snip Mines are provided below.

<u>Waste Rock (Johnny Mountain)</u>
Disposal Locations (dumps, airstrip, roads)
ML/ARD Potential

- Pre-mining and operational assessments
- Weathering and resulting drainage chemistry
- Present assessment

Components of the Mitigation Plan

- Underwater disposal in impoundment
- In-situ mitigation measures
- Proposed future actions

<u>Tailings Impoundment (Snip)</u>
Design and Geotechnical Considerations
Composition of Tailings (Variable PAG)
Composition of Waste Rock (Variable PAG)

- In dam
- In impoundment

Components of the Mitigation Plan

- Water balance
- Cover with soil and flood
- Proposed future actions

<u>Underground (Snip)</u>
Design and Operational History
ML/ARD Potential

- Mine walls
- Backfilled waste rock
- Backfilled cycloned tailings
- Overall assessment

Components of the Mitigation Plan

- Flooding lower workings
- Upper workings
- Contingency plans for management/mitigation of drainage (tailings impoundment)

Monitoring and Maintenance