ENVIRONMENTAL MANAGEMENT PLANS: A KEY TOOL IN ENSURING SUCCESSFUL LONG-TERM ENVIRONMENTAL MANAGEMENT AT CLOSED MINE SITES WITH ML/ARD[1]

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Abstract. Mines with metal leaching and acid rock drainage (ML/ARD) often require long-term mitigation, monitoring and operator vigilance to ensure environmental protection. One of the biggest challenges to meeting long-term environmental protection goals is retaining the collective corporate, regulatory and community memory of site conditions, history of mining activities and mitigation requirements for the site. An Environmental Management Plan (EMP) can help ensure successful management by documenting key aspects of a mine site, as well as its mitigation, monitoring and maintenance requirements. EMPs are intended to be living documents that track important changes for the purpose of guiding site management decisions. EMPs are being developed for several mines in British Columbia, Canada and include items such as active chemical treatment and cover maintenance.

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Introduction

Mine sites with metal leaching and acid rock drainage (ML/ARD) or the potential for ML/ARD often require long-term mitigation, monitoring and operator vigilance to ensure environmental protection. One of the biggest challenges to meeting long-term environmental protection goals is retaining the collective corporate, regulatory and community memory for the mine site. This includes retaining knowledge of factors such as site conditions, the history of mining activities, the details of mitigation strategies, and monitoring and maintenance needs (Price, 2002).

During active mining, available financial and staffing resources are always greater than during mine closure. However, management of environmental issues such as ML/ARD does not stop at closure. Many key properties and processes that affect ML/ARD continue to be in a state of flux after mining ceases (British Columbia Ministry of Water, Land and Air Protection, 2002). The effectiveness of ML/ARD mitigation strategies can be very sensitive to changes in biological, geochemical and physical conditions.

Effective long-term environmental protection requires adaptive management strategies. The changing of key mining company staff, consultants, government regulators and community representatives presents a significant challenge (and potential risk) to effective site management. The key to dealing with this challenge is to maintain the important base knowledge of a mine site, upon which future decisions can be made. Oral history alone cannot ensure successful, long-term management.

This paper presents a regulator's perspective on some of the key challenges in the long-term management of ML/ARD and concludes that comprehensive environmental management plans (EMPs) can enhance environmental success.

British Columbia, Canada Regulatory Principles

In British Columbia, mining and exploration activities are regulated in a manner that supports the Province's goals of sustainable resource development, which includes reclamation, environmental protection and the minimizing of economic risks, liability and alienation of land and water resources (British Columbia Ministry of Energy and Mines, 1998a).

Mines are evaluated on a site-specific basis as each possesses a unique geological and environmental setting. The British Columbia regulatory approach to ML/ARD is strongly weighted towards prevention through prediction and design. For example, if a prediction program identifies the potential for ML/ARD, a mitigation program must be designed that meets the provincial goals of environmental protection and minimizing liability, risk and the alienation of land from future productive use. Mitigation strategies that prevent ML/ARD (e.g. water cover) are preferred over methods that reduce ML/ARD (e.g. dry cover). Chemical treatment of drainage is typically considered a mitigation of “last resort” due to on-site impacts, high cost and environmental risk. The British Columbia regulatory approach also places an emphasis on having adequate information to make informed decisions. In the absence of sufficient information, regulators exercise a cautious approach and establish regulatory criteria that are based on conservative assumptions (Price and Errington, 1998).

Most ML/ARD mitigation strategies must be designed, constructed and operated in a manner that allows them to perform indefinitely (Price, 1999). Contingency measures are required whenever the uncertainty in prediction or mitigation could result in unacceptable environmental risks. In addition, financial security (surety) commensurate with ML/ARD liabilities is required. The form of financial security can vary depending on the site and the permittee. Liabilities include the costs associated with long-term monitoring, maintenance, and collection and treatment of contaminated drainage.

In British Columbia, more than 60 mine sites and advanced exploration sites have the potential to generate sufficient ML/ARD to significantly impact the environment (Fig. 1). These sites require on-going mitigation or they require further assessment to determine what the ML/ARD mitigation requirements of the mine sites are. For example, several older and remote mine sites do not have recent environmental monitoring to know if adverse effects are occurring. Also, many important processes that influence ML/ARD and mitigation performance (such as weathering, hydrology and ecological changes) fluctuate over time and the full extent of ML/ARD mitigation requirements and costs are not yet known (British Columbia Ministry of Water, Land and Air Protection, 2002).

More than 50 of the 62 mine sites shown in Fig. 1 are permanently closed or are on care and maintenance status. Figure 1 also shows a breakdown of British Columbia mines based on the type of deposit and whether the principal water quality concern is ARD or the leaching of metals under neutral pH conditions. Notably, treatment costs for neutral metal leaching can rival that of ARD generating mines in British Columbia. Several sites that treat for neutral metal leaching have annual operating costs in excess of 1.5 million dollars.

Environmental Management Plans

There is an increasing need for comprehensive, formalized plans to deal with the management of mine sites with ML/ARD or the potential for ML/ARD. Currently, most sites have a mix of internal company documents and/or individual reports and plans undertaken to fulfill specific regulatory requirements. While these documents are inarguably of value, they often deal with a single component of mitigation or a specific issue at a mine site, and do not provide a holistic view of mine site issues and their management. The authors advocate that the establishment of a comprehensive Environmental Management Plan (EMP) can be an extremely important and powerful tool to ensuring long-term environmental protection.

The key goal of an EMP is to document aspects of a mine site that are important to its successful management. It should track important changes to components of the system, with the purpose of guiding site management and site management decisions. An EMP should be a living document (or a series of documents) that is continuously used, improved and updated. Ideally, it should allow qualified persons unfamiliar with the site to take over and successfully manage the closure program. Ultimately, an EMP should aim to achieve seamless transitions between caretakers of a mine for as long as the site needs to be managed.

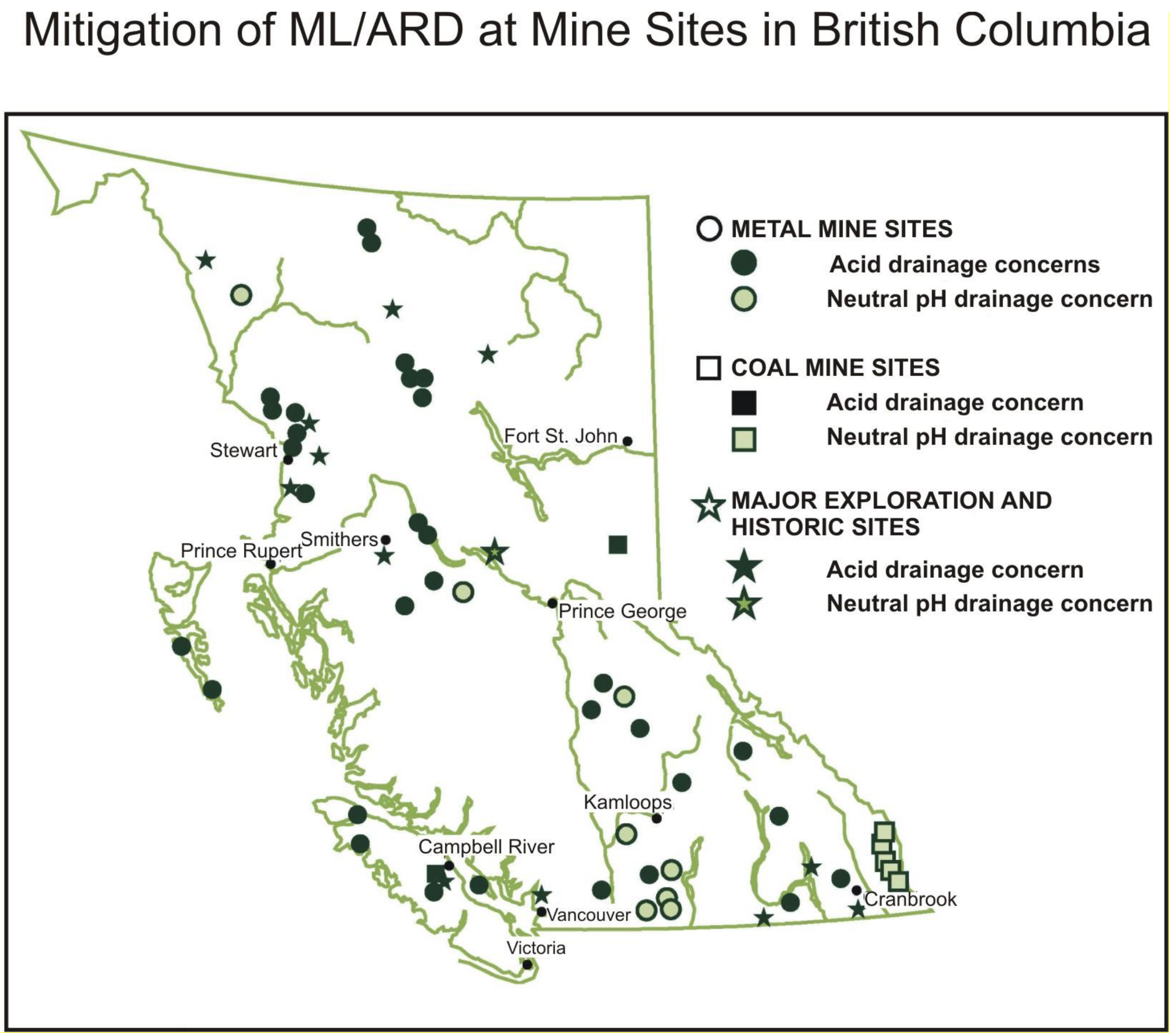

Figure 1: The ML/ARD status of permitted mines and selected exploration and historic mine sites in British Columbia (modified from British Columbia Ministry of Water, Land and Air Protection, 2002).

Components of an Environmental Management Plan

The contents of an EMP will depend on factors such as the ML/ARD mitigation strategies and the characteristics of the site, and will therefore be different for every mine site. Five key components of an EMP are background data, an assessment of risks and uncertainties, monitoring programs, contingency plans, and resources to carry out contingencies.

The core component of every EMP should be the information about the mine's history and its relation to the environment. Background information such as detailed descriptions of the site; an inventory of materials, their characteristics and disposal locations; and the climatic and hydrological conditions of the site form the foundation of an EMP. Other important aspects to include in the background data are the as-built descriptions and design details of mitigation systems and their monitoring and maintenance requirements.

Information in an EMP should be based on management requirements, potential limitations and uncertainties of mitigation strategies, and possible changes in conditions or processes that could render mitigation less effective. As a start, the following should be asked in relation to each aspect of mitigation or component of the mine site.

1. What could go wrong and what are the consequences? - (Assessment of Risks)
2. How are potential problems to be detected or performance confirmed? - (Monitoring Program)
3. What actions need to be taken if a problem is detected? (Contingency Plan)

Answering these will help determine what additional items to address in an EMP.

Water Cover Technology EMP Example

To illustrate what information may be needed in an EMP, consider the example of a water cover over reactive wastes to minimize ML/ARD. Important background information for such mitigation was evaluated by Price (2001) and includes:

- waste characteristics - mass, volume, particle size, chemical composition, and ML/ARD potential;
- disposal site characteristics - storage capacity, discharge requirements, geotechnical conditions, water balance, water quality, rate of flooding and potential re-suspension; and,
- design of mitigation - which materials require flooding, storage capacity, soluble constituents prior to flooding, extent of flooding, time to flooding, depth of water cover, geotechnical and hydrological aspects of the design.

These comprise the core data to be retained for the site. The three framework questions above help scope requirements for the EMP. Table 1 lists potential problems with water covers, and outlines monitoring strategies and contingency actions for problems that are detected.

For example, important issues for reactive wastes stored under a water cover include their physical and geochemical stability (Price, 2001). The physical stability can be compromised by hydrological and geotechnical factors. The geochemical stability of wastes can be affected by factors including changes in hydrological conditions (e.g. water balance, climate), biological processes (e.g. natural ecological recovery, sedimentation, metal uptake) and physical processes (e.g. re-suspension by wind or ice).

Waste rock reactivity (oxidation) will be higher in an aerated water column. Reducing conditions over an oxidized surface layer can also lead to metal fluxes to the water cover. Changes in water chemistry can result from process water inputs, drainage inputs, inputs from the destabilization of sludges, or increased soluble loadings from exposed tailings beaches or exposed mine surfaces (e.g. pit high walls).

Table 1: Examples of potential components of an EMP for a hypothetical mine site that utilizes a water cover over mine wastes to minimize ML/ARD. Modified from Price (2001).

Potential Components of an Environmental Management Plan for a Water Cover as a Mitigation Strategy for ML/ARD		
Assessment of Risks	**Monitoring Program**	**Contingency Plan**
Changing hydrological conditions	Site climate data, water balance, inspections for beaver activity, additional factors that can change the hydrology (logging, upstream water users)	Supplemental water diversions or inputs, increase depth of water cover, maximize dilution, secondary storage, drainage treatment, modifications to prevent beaver activity, removal of beaver
Oxidation of surface of wastes and remobilization of contaminants	Water quality	Install O_2 consuming or diffusion barrier over wastes, enhance SO_4^{-2} reducing bacteria to promote sulphide formation, biological adsorption and assimilation of contaminants through enhanced primary productivity
Reduction of oxidized surface layer of wastes and remobilization of contaminants	Biological monitoring and water quality monitoring	Increase O_2 influx by directing water through impoundment, enhance reducing environment to promote SO_4^{-2} reduction, other measures to change redox conditions, barrier to isolate wastes, drainage treatment
Biological uptake of contaminants	Biological monitoring and water quality monitoring	Physical barrier to prevent uptake by vegetation and micro organisms, nets to preclude migratory bird access, prevention strategies for fish migration and spawning
Re-suspension by waves, ice, stream flow, and seiching causing remobilization of contaminants	Site climate data and water quality monitoring	Establish physical barriers to decrease wave action, increase depth of water cover, install isolation barrier over wastes
Increased contaminant loads from tailings beach or mine walls or due to changes in input drainage chemistry, process waters, or destabilization of sludges or secondary wastes	Water quality monitoring	Isolation barrier for wastes, chemical additions to water cover, redirect surface flows to decrease contact with wastes or increase dilution, other forms of drainage treatment

Monitoring may need to include items such as climate, water balance (hydrology), water quality, biological features and visual inspections. Depending on the results, various actions could be warranted. Contingency actions could include modifications to hydrological conditions by diverting or adding input water, or increasing the depth of the water cover to add dilution or isolate wastes from wave action.

An inert barrier placed over wastes can minimize oxidative or reductive dissolution and can limit pathways for biological uptake and re-suspension. Redox changes can be achieved by adding O_2 or increasing available organic matter to promote reduction. Drainage treatment by conventional lime treatment and/or other methods to achieve contaminant reduction may also be required as a contingency plan.

Other important inclusions for an EMP are contingency plans and the resources to implement contingency actions. In the water cover example this might include material sources, equipment needs, contractors, and financial resources.

Ideally, planning will remove much uncertainty prior to closure. Items such as an isolating barrier over the wastes or an additional raise of a tailings dam could be prohibitively expensive if not identified and implemented at, or soon after, closure when operational staff and equipment are still present on site.

Island Copper Mine, British Columbia, Canada EMP Example

Mines in British Columbia are required to manage ML/ARD issues at their sites for as long as is required to assure environmental protection. Provincial mining regulations require that mines that have on-going mitigation, monitoring or maintenance requirements submit a closure management manual that documents important site information and tracks changes that could affect environmental performance. Several Provincial Ministry documents also provide policy, guidance and generic information requirements that are useful for developing an EMP (see British Columbia Ministry of Energy and Mines, 1998a, 1998b; Price and Errington, 1998).

Several closed mine sites in British Columbia are presently developing EMP's, or components of them. The Island Copper Mine is an example of a mine that is developing an EMP to manage a non-traditional ML/ARD treatment system and other environmental issues.

The Island Copper Mine is a porphyry Cu deposit that was mined by open pit methods from 1971 until 1995. The main issue at the site is the ML/ARD that originates from waste rock dumps. Water from the waste rock dumps is collected in a series of ditches and directed to one of two injector points where water is introduced deep within the flooded open pit.

The open pit was flooded with seawater, and subsequently rainfall and runoff were directed to the pit lake to create a fresh water cover. This created a stratified or meromictic lake. The long-term mitigative goal for ML/ARD treatment is to precipitate metal sulphides under anoxic conditions in the water column. Although this has not yet been achieved, the pit lake is currently acting as a low cost treatment system where different metal removal processes occur in different meromictic layers of the lake.

Studies indicate that regular application of liquid fertilizer to the surface of the pit lake reduces metal concentrations in the surface layer as phytoplankton appears to adsorb and possibly assimilate the metals. In the middle layer of the pit lake water column, $Al(OH)_3$ and hydrous Fe_2O_3 precipitation and redox cycling occur, and both appear to remove substantial amounts of trace metals from the system. Sulphide precipitation by SO_4^{-2} reducing bacteria appears to have been initiated directly at the bottom of the pit lake at the sediment water interface.

The mine has been developing an EMP to manage closure. The following paragraphs detail some of the base information, key uncertainties, monitoring and contingencies for the pit lake treatment system.

Near the end of mining, base environmental information was gathered for the site. This included a summary of all the ML/ARD studies conducted at the mine (Morin and Hutt, 1996). An assessment of drainage chemistry was completed for the waste rock dumps (Morin and Hutt, 1994) and a follow-up report on recent trends in drainage chemistry was produced (Pelletier et al., 2001). Other important information on the climate and hydrology of the site was also documented.

The key uncertainties concerning treatment performance of the pit lake are its biogeochemical and physical stability over time. The biological, geochemical and physical processes that occur in the lake are intimately linked. On-going monitoring includes the chemistry of contaminant inputs to the system as well as biological, chemical and physical parameters of the pit lake.

In addition to regular monitoring, many research projects have been undertaken to address the uncertainties and risks associated with the pit lake treatment system. These include a fertilization study to determine the biological response and chemical effects of fertilization (Pelletier et al., 2002a), studies to determine biological and sediment oxygen demands (Rescan 1999; Pelletier et al., 2002b), an assessment of pit lake porewater and sediment geochemistry (Pelletier et al., 2002c), dye studies to assess ARD plume dynamics (Muggli et al., 1999), and a remote inspection of injectors to determine the functioning of dispersion/injector systems (Pelletier and Wen, 2001). Other relevant studies included the modeling of pit lake evolution (Rescan, 2002), the physical stability of the meromictic system (Fischer, 2001), a metal mass balance for the pit lake (Pelletier et al., 2002d) and a biogeochemical model of pit lake metal removal processes (Pelletier et al., 2002e).

A goal for the Island Copper mine is to have an operations manual to address pit lake treatment methods. The innovative approach for treating ML/ARD at Island Copper is supported by provincial regulators. However, due to the unproven nature and uncertainties of the proposed technologies, the provincial government has requested the development of measures to improve the current treatment system as well as contingency plans in case the current mitigation strategy proves to be inadequate. These have been developed and have recently been submitted to government for review. Emergency response plans to some issues are also being drafted.

A series of manuals have been developed to address other on-going site management requirements. The manual dealing with field operations and sampling outlines field sampling methods, station locations, sample preparation and storage, quality assurance/quality control (QA/QC) procedures, chain of custody forms, procedures for calibration of field equipment, operating procedures for automated samplers and other stationary equipment devices, data downloading methods, and field procedures for diverting injector flows and for sump and pump operations (Horne, 2002a). Similar levels of information are included in the manuals covering laboratory methods (Horne, 2002b), laboratory quality (Horne, 2002c), and laboratory procedures (Horne, 2002d).

Integral components of the mitigative works at the site are the ML/ARD collection systems. Given the need for vigilance to ensure functionality, a manual was developed to address ditch inspection and maintenance procedures (Horne, 2002e). Included in this manual are directions for undertaking inspections, areas to be inspected, items to watch for, frequency of inspections, additional triggers for inspections (e.g. heavy rainfall, seismic events), maintenance procedures, resources required (e.g. equipment, materials, local contractors, contaminant sediment disposal areas), reporting methods and procedures for follow-up of items identified. Protocols for reporting incidents to regulatory authorities are also included in the manual.

The recording of core site information and the on-going assessment of risks and uncertainties at the Island Copper mine has led to the identification of important mine site issues and the development of strategies for their on-going monitoring and management. The approach has also been helpful in identifying areas that require more research to resolve uncertainties associated with the mitigation strategies proposed for long-term ML/ARD management.

Conclusions

The retention of essential site knowledge is an important component of successful environmental management. As well, the dynamic nature of mine sites and their environments after closure can have negative impacts on the effectiveness of mitigation strategies and can pose significant challenges to successful long-term management.

An EMP is a tool to maintain critical knowledge of a mine site and track important changes in processes that control ML/ARD. An EMP, combined with an adaptive management approach, is the key to achieving long-term environmental success.

The development of EMP's is clearly in the interests of all stakeholders. EMP's will aid mining companies in demonstrating that their mines will continue to be operated in a diligent and effective manner. It also provides neighboring communities with a level of comfort that environmental protection needs will continue to be met over the long-term.

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