Canadian Mining Innovation Council

Environmental Analysis of the Mining Industry in Canada
Disclaimer

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However, this report is a scoping study and, accordingly, all environmental issues mentioned in this report should not be understood as an exhaustive list of all environmental issues but the issues CMIC had deemed worth exploring as part of its mandate.
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Front row : Mark Thorpe (Chair), Philippa Huntsman-Mapila, Gilles Tremblay, David Kratochvil

Missing: Bob Holmes, Claudio Andrade, Marc Butler, Rick Meyers, Stephane Robert
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2. Sommaire

Le présent document vient appuyer l’analyse réalisée par le comité directeur de la gestion environnementale (comité) du Conseil canadien de l’innovation minière concernant le dossier environnemental de l’industrie minière au Canada.

Le document présente un bref résumé des sujets prioritaires mis au jour à la réunion du comité directeur qui s’est tenue le 19 juin 2012, à Toronto. Il ne s’agit pas d’une liste exhaustive de tous les enjeux environnementaux potentiels du secteur minier au Canada.

Chaque section expose le résumé, les outils et les données propres au domaine abordé afin d’aider le comité à établir des fonds d’action pour accroître au maximum le potentiel d’amélioration. Après la compilation des enjeux, les membres du comité ont été appelés individuellement à donner leurs idées sur les innovations pouvant changer progressivement la façon dont l’industrie minière traite la gérance de l’environnement.

Voici les principales priorités de recherche future issues des discussions avec les membres du Conseil.

- Changements climatiques – Évaluer les risques de vulnérabilité et les possibilités associés aux impacts des changements climatiques – Modèles d’analyse technique
- Prévision des effets des changements climatiques sur la biodiversité (cartographie des espèces fragiles) – Planification foncière et minière en fonction de ces changements, surtout en régions froides
- Recherche sur la toxicité du sélénium et les mécanismes de mobilisation
- Drainage des roches neutres et lessivage de l’arsenic/du sélénium
- Drainage rocheux acides/parcs à résidus – Accélérer l’acidification pour produire des sites bénins à l’intérieur d’un court intervalle de temps et éventuellement produire des acides utilisables
- Biodiversité – Approches novatrices du génie des systèmes naturels pour la remise en état des mines après leur fermeture – Comprendre les liens entre l’hydraulique et la biodiversité
- Meilleures connaissances et méthodes de mesure et de caractérisation des émissions de MP2.5
- Activités minières sans rejet
- Réutilisation et recyclage de l’eau douce
- Gestion des résidus

Selon les priorités soulevées par les membres du Conseil et les enjeux fournis dans le corps du rapport, la prochaine étape consiste à définir les recherches et les études précises sur lesquelles se pencher, dans un livre blanc, afin de modifier progressivement la façon dont l’industrie minière canadienne traite les questions d’environnement.
2. Executive Summary

This document was developed to support the Environmental Stewardship Steering Committee (committee) of the Canadian Mining Innovation Council—Environmental Analysis of the Mining Industry in Canada.

The report presents a summary of the priority topic areas identified by the steering committee during the committee meeting on June 19, 2012 in Toronto. It is not an exhaustive list of all the potential environmental issues in Canadian mining. Each section provides a topic summary, description of tools and data used in that specific area to aid the committee in developing further action fund to have the most potential for improvement. Following a compilation of the issue summaries, committee members were called individually to provide their ideas on areas of potential innovation that could lead to a step change in the way the mining industry deals with environmental stewardship.

The following were the key points raised as priority areas for future research, in conversations with Council Members:

- Climate change – Assess vulnerability risk and potential opportunities associated with climate change impacts. Technical analysis models.
- Predicting the biodiversity effects of climate change (sensitive species mapping). Land planning and mine planning to respond to these changes. Specifically in cold climate areas.
- Selenium toxicity and mobilization mechanism research.
- Neutral rock drainage and leachability of arsenic/selenium.
- Acid rock drainage/tailings impoundments – accelerate acidification process to produce benign sites within a short period of time and possibly produce a useable acid product.
- Biodiversity – Innovative approaches to natural system engineering for post closure rehabilitation – understanding the links between hydraulics and biodiversity.
- Better understanding, methodologies for measurement and characterization of PM2.5 emissions.
- Zero discharge mining operations.
- Reuse and recycling of freshwater.
- Tailings management.

Based on the priority items identified by the council members and the summary of the issues provided in the body of the report, the next step is to define specific research projects and studies that could be investigated in a White Paper to drive a step change in the way the Canadian mining industry deals with environmental issues.
3. Identified Mining Related Environmental Issues

3.1 Map of Identified Environmental Issues

The diagram below outlines how the environmental issues covered in this report are related. Most sections of the report focus on environmental issues (underlined in table). However, one section focuses on a tool (Comprehensive Environmental Management) and one focuses on an impact (Biodiversity).
SELECTED MINING ENVIRONMENTAL ISSUES:

- Greenhouse Gases (GHG)
- Climate Change
- Acid Rock Drainage (ARD)
- Toxicity: Metal Leaching (ML) and Heavy Metals Contamination
- Erosion and Sedimentation
- Tailings Management
- Groundwater Vulnerability

MEDIUM AFFECTED:
Air, Water, Land

IMPACT TO:
Biodiversity
Human Health and Social Conditions

TOOLBOX

- investment in Efficiency Renewable Energy Use
- Structural Adaptation
- Characterization Drainage Prediction Prevention Tools
- Water Treatment with or without Resource Recovery
- Dust Management
- Excavation and Disposal In-Situ Treatments Containment Techniques
- Surface Stabilization Run-Off Control Outlet Protection Sedimentation Traps & Barriers Stream Protection
- Tailings Management Plans

Comprehensive Environmental Management

Water Management Plans
Groundwater & Borefield Management
Salinity Management and Remediation
Aquifer Storage and Recovery (ASR)
Managed Aquifer Recharge (MAR)
Wastewater Reuse
Acid Sulphate Soil (ASS) Management
3.2 Greenhouse Gases and Climate Change

3.2.1 Topic Summary

3.2.1.1 Global and Canadian Regulatory Regimes

The Mining Association of Canada (MAC) has addressed issues of Energy Use and Greenhouse Gas (GHG) Management in the mining projects of its’ members through its Towards Sustainable Mining (TSM) initiative (MAC, 2011). The Energy Use and GHG Management Protocol was recently updated to reflect current Canadian policies and practices. While MAC has provided the industry with a framework and clear guidelines, a major issue identified as a lack of consistency between global, federal, and provincial regulations and compliance mechanisms, which may have competitiveness impacts for Canadian operations. Overlapping and inconsistent federal and provincial regulations make progress in GHG reductions more complex and lengthy (MAC, 2011). It is preferable to have one low-cost reporting system under a single federal GHG regulatory regime (Mining Weekly, 2012), with legally-binding regulations and a compliance system applicable across Canada to more accurately compare reductions in GHG emissions.

On the international scale, slow progress on climate change policy has served to hinder individual countries’ initiatives to develop their own policies. With repeated failures to come to a post-Kyoto deal during UN Climate Change Conferences of recent years, (Vidal & Harvey, 2011), guidance and regulated targets beyond Canada’s borders in the near future are unlikely. To provide a framework for GHG reductions in the mining industry, it is important that applicable guidance and regulations across Canada are aligned into a single reporting and management requirement.

3.2.1.2 Carbon Credits, Global Markets and Economic Considerations

It is evident that the world is progressively moving towards a more carbon-conscious economy, and that energy usage in the developed world will probably be directly linked to carbon accounting. Mining is an energy intensive business, therefore planning for a mining project should provide a long-term view for energy management as uncertainty over the availability and cost of electricity are increasing (Mining Weekly, 2011). Higher metal prices have resulted in previously marginal projects becoming economically viable to develop, however the greater effort required to extract metal in these projects may result in higher energy requirements per unit of production thereby potentially increasing GHG emissions. As it is unlikely that a cap and trade system or a carbon tax will emerge...
in Canada or the US in the near future (MAC, 2011), mining companies will be then mandated to comply with the applicable Canadian federal and provincial legislation.

Though the government has opted to impose rules on key industrial sectors that are major emitters of carbon (e.g., coal-fired electricity generators and oil sands developments), it has rejected a cap and trade system and carbon tax (MAC, 2011), (Woods, 2011). A key reason for this decision is argued to be a result of the closely linked economies of the U.S. and Canada. As the U.S. government has put aside any possibility of a cap and trade system in the near future, Canada will not be taking on any conflicting policies (Woods, 2011) or establishing legislation that would put Canadian operations at a competitive disadvantage.

This decision to not implement a Canada wide regulatory regime for carbon is further strengthened by complications apparent in the European Union’s Emissions Trading System (ETS), the first large emissions trading scheme in the world (Ellerman & Buchner, 2007). The design of such a system has proved to be difficult, with its broad allocation of free permits and special exemptions have caused it to collapse at one point (MAC, 2011). Although it has recovered to some extent it has not been successful in reducing emissions according to some industry observers (Corporate Europe Observatory, 2011).

Provincial initiatives that have been progressed include:

- Quebec implemented the first carbon tax in North America in 2007 (Marshall, 2008), and British Columbia followed suit in 2008 (Ministry of Finance, 2011).
- Quebec will implement a cap-and-trade system, beginning January 2013, to encourage a low-carbon economy (Richmond, 2012).

### 3.2.2 Tools and Data

#### 3.2.2.1 GHG Reduction Technologies

Most of today’s promising GHG reduction technologies, such as those in the low-carbon or renewable energy area, and carbon capture and storage (MAC, 2011), as well as GHG reduction programs, are currently more expensive than conventional options (Jaccard & Rivers, 2008). Though installation of these technologies could be costly, the long-term benefits include savings on energy and avoiding expensive carbon prices should they be invoked by host governments (Orok, 2002).

Improvements in energy conservation and reductions in GHG intensity were made in the smelting and refining processes of the mining sector (68% reduction in greenhouse gas emission intensity during the past 20 years), in part because of switching fuels and investing in efficiency improvements (MAC, 2011). Investment in energy efficiency will be crucial for today’s older and deeper mines that require more energy to extract ore (MAC, 2011). Areas of interest include improving capabilities in compressed air, ventilation, metering, and energy management in extraction operations (MAC, 2011). This is a particular point of interest for mines in northern Canada that lack electrical grid capacity (MAC, 2011).

Various groups and alliances have developed GHG reduction technologies, such as regeneration heat technology by Nevada Clean Magnesium. This process uses a thermodynamic fluid instead of water to recover energy from
what were previously waste heat sources (Clean Mining Alliance, 2012). The European Commission has also presented compressed air energy storage as an emerging technique in the industry. Air is compressed using energy (usually electricity from the power grid at off-peak times) and that energy is later used to generate energy as needed (European Commission, 2009).

As a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), Canada is obligated to prepare and submit an annual national greenhouse gas (GHG) inventory covering anthropogenic emissions by sources and removals by sinks. The National Inventory Report (NIR), which is prepared by Environment Canada, contains Canada’s annual greenhouse gas emission estimates dating back to 1990. The GHG Marginal Abatement Costs tools help determine the marginal abatement costs of potential GHG emission abatement options.

3.2.2.2 Climate Change Adaptation – Areas of Focus

Climate change adaptation in the mining industry will probably become an essential part of the project planning process, especially for projects in the northern regions of Canada. Climate change affects water patterns, hydrogeology, weather patterns, and ecosystem processes (ICMM, 2011); all of which play a role in the mining lifecycle.

Specific potential effects may include:

- Erosion induced by greater frequency and intensity of precipitation and/or permafrost thaw of slopes, berms, and mine pit walls.
- Rising average temperatures and extreme weather events (wind storms) may damage snow fences which protect tailing impoundments.
- Harmful wind effects (Arctic North Consulting, 2009).

If average temperatures increase, the winters may not be as long, therefore affecting the construction and operation of winter roads in the north.

Possible engineering solutions, including better permafrost modelling and efforts to extend access include structural reinforcement and retrofitting. Options may also include enhancing thickness through surface flooding or spray ice, intelligent transport systems (automated), reducing ground warming by insulation, or terracing to increase stability (Arctic North Consulting, 2009).

Containment facilities (tailings) may be affected by warmer temperatures leading to ARD, altered freeze-thaw cycles exposing previously frozen tailings, increased evaporation of water covers on tailing ponds exposing raw tailings, higher intensity precipitation causing saturation of tailings impoundment, increased levels of erosion, and wind and wave action of extreme weather events causing the re-suspension of tailings and formation of ice dams (Arctic North Consulting, 2009). Permafrost thaw may affect the structural integrity of on-site buildings. Changes in water availability may affect overall operations (Arctic North Consulting, 2009).

At the national scale, the Climate Change Adaptation Project: Canada (CCAP) was launched in 2008 to identify and implement practical, meaningful, and cost-effective adaptation solutions to the most challenging effects of climate change facing Canada. The five top priority sectors for Canada to focus efforts in the area of climate change adaptation were...
identified as:
1. City infrastructure
2. Biodiversity
3. Freshwater
4. Aboriginal communities
5. Agriculture

3.2.3 References


ICMM. (2011). The Role of Mining and Metals in Land Use and Adaptation.


3.3 Acid Rock Drainage (ARD) - Metal Leaching (ML) of Tailings and Mine Waste

3.3.1 Summary

3.3.1.1 Issue Summary

Acid Rock Drainage-Metal Leaching (ARD/ML) is a natural oxidation process that can occur when rock surfaces containing sulphides are exposed to air and water, changing the characteristics of the water that infiltrates or runs off these areas. When metals and other contaminants leach from waste rock which contains no sulphides at neutral pH conditions, then this is referred to as Metal Leaching (ML). As water becomes more acidic, its capacity to leach other elements from the rock, such as metals, increases. This effect is accelerated by the action of acidophilic bacteria that are activated at decreased pH. The resulting acidic drainage may contain increased levels of harmful constituents. For some abandoned mine sites, it is estimated that the process may last hundreds, even thousands of years. Contaminated water drains away from the mine site and may affect the receiving environment (rivers, lakes, coastal areas, and groundwater) and the associated ecosystems and anthropogenic use of the contaminated resource.

Mining activities may potentially exacerbate this phenomenon by exposing large surface areas of rock to water and oxygen. Rock is exposed on the walls of open pits and underground structures—but often the most extensive exposed rock surfaces are in waste rock dumps as well as tailings. Contaminated drainage is recognized as the largest environmental risk facing the mining industry and, to a lesser extent, the public through abandoned mines. Acid rock drainage can severely degrade water quality, can kill aquatic life, and make water virtually unusable (Mining & Water Pollution in BC, 2006).
3.3.1.2 ARD/ML in Canada

Acid drainage represents a technical challenge because of:

- On-going changes in the understanding of the ARD process.
- Long-term performance requirements.
- A need for proactive detection and resolution of potential acid generation concerns.
- Difficulties in predicting the potential for extensive ARD.
- High costs for ARD prevention and treatment.
- The multidisciplinary and highly specialized nature of ARD work.

The requirement for long-term performance of ARD control and mitigation solutions means that structures, such as dams and ditches, must be capable of withstanding extreme climate and seismic events. Therefore, the design criteria must be of the highest standard, long-term monitoring and maintenance are required and, consequently, the costs for such work is high (Price, 2003).

Effective mitigation is an important issue for neighbouring communities. Community concerns include understanding the ARD problem, the long term performance of mitigation structures, the accuracy of projected mitigation costs, and that the business responsible for generating the ARD has sufficient financing for post-closure remediation and is committed to preventing environmental and community effects (Price, 2003).

3.3.1.3 Global Guidance for Acid Rock Drainage

Organizations such as the World Bank, International Finance Corporation (IFC) and World Health Organization (WHO) provide standards of practice for acid drainage management. Project funding agencies and banks also have an influence on the standards that bank-funded mining companies must maintain because a significant number of the large international banks have adopted the World Bank/IFC Equator Principles, which has the objective of achieving Global Best Practice in environmental management of mining projects.

The IFC Environmental, Health and Safety Guidelines for Mining provide general guidance on the prevention and control of ARD, including the design, operation, and maintenance of tailings facilities, geochemical characterization, impact assessments, and mine closure and post-closure, as well as financial feasibility and closure assurance requirements. Voluntary standards established by industry organizations and associations, such as the International Council of Mining and Metals (ICMM, 2003), the International Institute for Environment and Development (IIEP), the Minerals Council of Australia (MCA) and the Mining Association of Canada (MAC, 2004) can also be of assistance in determining management and mitigation strategies for potentially acid generating materials as well as facilities that are generating ARD.

The International Network for Acid Prevention (INAP) is a global industry formed group that is focused on tackling this issue and hosts the International Conference on Acid Rock Drainage (ICARD) every three years. Many countries have formed regional organizations as partners with INAP, such as Mine Environmental and Neutral Drainage Programme (MEND) in Canada that
focuses on Canadian national and/or regional information needs.

INAP have completed a variety of research projects (1) that include ARD management guides, characterization of wastes, databases and performance of various covers. In addition, INAP members sponsored the development of the Global Acid Rock Drainage (GARD) Guide.

MEND have also collaborated with industry and partners to complete a list of their own projects (2) in prediction, prevention and control, treatment, monitoring, case studies and facilitation of workshops.

### 3.3.1.4 Canadian Regulatory Regime, Canadian Programs and Guidelines

Several categories of legislation exist in Canada that influence or affect ARD management in mining. Some of the most relevant legislation, policies, and guidelines are as follows:

- **Federal Regulation**: MMER (Metal Mining Effluent Regulations, 2002).
- **Guidelines for Metal Leaching and Acid Rock Drainage at Mine Sites in British Columbia** (Errington, 1998).
- **Policy for Metal Leaching and Acid Rock Drainage at Mine Sites in British Columbia** (BC MEM, 1998).
- **Guidelines for ARD Prediction in the North** (Kirsten, 1992).

Two Canadian programs focus on acid drainage prevention and control:

- **Mine Environment Neutral Drainage** (MEND): Since 1989, the MEND program has worked to develop technologies to prevent and control acidic drainage. As a result of these programs, the liability due to acid drainage decreased by at least $400 million, a return on an investment of $17.5 million over 8 years (MEND). However, acidic drainage remains the most serious environmental issue facing the mining industry, government, and the public, with potential liability reaching hundreds of millions of dollars (MAC, 2009).

- **National Orphaned/Abandoned Mines Initiatives** (NOAMI), a joint industry-government working group, assisted by other stakeholders, to review the issue of abandoned mines (NOAMI).

### 3.3.2 Tools and Data

#### 3.3.2.1 Current Best Available Technologies (BAT)

Acid rock drainage management extends throughout the mining life cycle from exploration to mine closure. An overview of methodologies used for ARD management of waste-rock and tailings is presented below; however, it is not a complete compilation of all existing methods (European Commission, 2009).

Characterization tests allow for the prediction of the short, medium and long-term dissolution/weathering characteristics as well as the geotechnical behaviour. The most commonly used mineralogical analysis tools are visual description, petrographic analysis, X-Ray Diffraction (XRD), and Scanning Electron
Microscopy (SEM) to provide an understanding of the sulphur contents within the ore and waste material.

Drainage chemistry can be predicted with static and kinetic ARD tests. Static tests can be completed quickly, such as Acid Base Accounting (Sobek), Net Acid Production (NAP) and Net Acid Generation (NAG) tests. The three most commonly used methods for determining kinetic acid drainage characteristics are humidity cells, columns, and lysimeters.

Many preventive methods focus on minimizing the sulphide oxidation rate with wet, dry, or oxygen consuming covers. Depyritisation aims at removing sulphide minerals, and adding buffering minerals, minimizing the bacterial activity or minimizing the mineral surface area available for weathering also assist in slowing the rate of acid generation.

Drainage treatment may be passive (e.g., constructed wetlands, open channels/anoxic limestone drains, or diversion wells) or active (e.g., lime addition).

Strategies for closed or abandoned mines usually aim to prevent the oxidation reactions from occurring, preventing the transport of these products beyond the site boundaries in quantities that affect the receiving environment, or both. Depending on the source of the ARD, drainage treatment may still be necessary, even after a cover has been put in place.

### 3.3.2.2 Areas of Focus

In 2001, a technology gap analysis report for ARD management was mandated by the MAC, Environment Canada and Natural Resources Canada (Stephen, 2002). The identified gaps in ARD research and development in Canada were the following:

- Mine hydrology and geochemistry and the ability to predict effluent chemistry.
- Characterization and prediction of waste rock seepage chemistry, including waste rock hydrology and hydrogeology and the behaviour of weakly reactive and marginally potentially acid generating waste rock.
- Blending of waste rock and/or tailings for hydrological or geochemical reasons.
- Availability of alternatives to soils as cover materials for reactive tailings.
- Understanding of the long-term performance of all technologies, and particularly dry covers.
- Ability to characterize, predict, and manage the behaviour of chemical elements occurring in (neutral) drainage (Metal Leaching) (e.g., arsenic, antimony, cadmium, molybdenum, selenium, zinc).

### 3.3.3 References


European Commission. (2009). Reference
### 3.4 Toxicity

The mining of metals may potentially affect the surrounding natural environment (land, air and water systems) to varying degrees due to the nature of the mining activities. The challenge for mining companies is to discover, extract and process the ores and minerals and prevent or minimize the effect on the natural environment. Humans and the surrounding ecosystem can be impacted by not only the physical effects of mining, but also the toxicological impacts of minerals mined, chemicals used, and by-products of the overall refining process. Mining companies have invested considerable time and effort into reducing emissions into the environment, both to comply with changing environmental regulatory requirements, as well as to satisfy goals of corporate social responsibility.

This chapter is intended to provide a brief
overview of toxicology as relevant to the mining industry, and identify data gaps that need to addressed in future research.

The life cycle of mining consists of exploration, mine development, mine operation, decommissioning and land rehabilitation. At each of these stages, there are mechanisms for potential releases of chemicals into the environment via a vector which may potentially adversely receptors such as people and the surrounding ecosystem.

Measuring and understanding the nature of emissions or effluents from mining industries is a key step in deciding where and when environmental control technologies are needed. The transport, fate and bioavailability of mining compounds posed to the environment are integral parts of assessing the overall ecological and human health risks.

Mining operations produce dust, which may sometimes contain heavy metal particulates. The primary air pollutant of concern at mining sites is particulate matter as identified by the United States Environmental Protection Agency (EPA) and Environment Canada. The EPA has established National Ambient Air Quality Standards for particulate matter with a diameter of less than 10 and 2.5 microns, and Canadian government (CCME) released Canada Wide Standard (CWS) for fine particulate matter. Other significant air emissions are produced from both mobile and stationary sources. These emissions include sulphur and nitrogen oxides. They are most often controlled by the use of filters, scrubbers, and other pollution control devices. Information on these emissions is routinely collected in Canada, Australia, and the USA and submitted to the national databases (such as NPRI of Environment Canada).

Tailings and waste rock at metal mines usually contain trace concentrations of heavy metals. Fugitive dust would also contain such metals, and areas immediately downwind could accumulate heavy metals concentrations greater than the background levels as coarse particles settle out of suspension in the air. Occasionally, wind has caused cyanide sprays on heap leach piles to blow short distances and caused localized damage. Consequently, more operators are turning to drip application of cyanide solutions, a solution with multiple advantages in arid environments since this also minimizes evaporative losses.

The inherent risk from dust depends upon the proximity of environmental receptors, the susceptibility of the receptor, and the type and form of ore being mined. High levels of arsenic, lead, and radionuclides in windblown dust would be expected to pose the greatest risk.

Particulate from smelter flue stacks may pose significant human health and environmental risks (in general, smelter emissions are no longer a significant concern in the United States and Canada). While smelter flue dust collected before stack emission is recycled at most active smelters, windblown flue dust at inactive and abandoned smelters has caused significant environmental damage.

Understanding the uncertainties due to emission inventory gaps will help health risk and toxicology studies. For example, there are some exemptions of extractive mining activities in the national reporting framework. The release of substances to the air in dust from extraction and crushing operations, exposed areas, overburden, waste rock and tailings storage areas are not required to be reported in Canada and USA. The release of substances in water discharged from extraction operations (cooling and process waters and mine-waters), and in runoff and Acid Mine Drainage (AMD) from overburden, waste rock, tailings and ore storage areas, and exposed areas is an exemption.

By making good estimates of air emissions,
advanced air quality dispersion and deposition modelling systems can assist in understanding air dispersion, transport and deposition in the nearby vicinity and regional scale. Leaching of metals and process chemicals (e.g., ARD/ML) is also a significant pathway for release of toxicologically relevant chemicals into the environment surrounding mining and processing operations. Properly modelling and monitoring all potential releases of chemicals into the environment is a key element of any evaluation of human health and ecological impacts from mining operations.

While the underlying toxicological mechanisms are similar, the methodologies and assumptions used in human health and ecological risk assessments have their differences, including discrete and differing data gaps. As such, both human health and ecological fields are discussed separately below.

### 3.4.1 Human Health

Toxicology is defined as the study of the adverse effects of chemical and physical agents on living organisms. The most important factor that influences the toxic effect of a specific chemical is the dose, or degree to which an organism is exposed to a chemical. While the science of toxicology as it pertains to humans is constantly evolving and advancing, much is known about the toxicology of most of the by products of mining—particularly metals. However, there are still a number of areas which represent data gaps in the understanding of how many of these contaminants move in the environment, and ultimately within the human body.

#### 3.4.1.1 Bioavailability/Bioaccessibility of Metals

The past decade has seen a considerable research push into better understanding the degree to which soil/dust particulate-bound metals disassociate from these particulates within the digestive tract to be available for absorption across the gastric wall and into the blood stream. This is termed the “bio-accessibility” of the metal, and is one element in determining how “bio-available” (and ultimately toxic) a metal potentially may be. The more bioavailable a metal is, the higher the concentration that will make it to the target tissue/organ within the body to cause the adverse health effect. Bioaccessibility is typically measured through the use of laboratory in vitro testing, and validated against results determined through animal dosing (e.g., in vivo testing). However, currently only the methods for bio-accessibility testing of arsenic and lead have been suitably validated through in vivo testing to the satisfaction of most regulatory agencies. Until methods applied for other common mining-related metals have been suitably validated, it is difficult to appropriately use bioaccessibility results for these metals as part of a human health risk assessment of potential impacts. While work in these research areas is ongoing (e.g., various initiatives such as BARC, BARGE, etc.), further research is still needed.
3.4.1.2 Diesel Related Exposures

The potential occupational and environmental impact of diesel emissions in the mining industry has seen a significant increase in research interest following the publishing of the recent findings of the Diesel Exhaust in Miners Study (DEMS). Based on these and other scientific findings, the International Agency for Research on Cancer (IARC), which is part of the World Health Organization (WHO), recently reclassified diesel engine exhaust as carcinogenic to humans (Group 1), based on sufficient evidence that exposure is associated with an increased risk for lung cancer. The implications of these results on underground mining operations, and the health of the workers, is significant and warrants further study to reduce uncertainties in the evaluation of health impacts, as well as in support of development of new technologies that reduce harmful emissions to the environment.

3.4.1.3 Biomarkers of Exposure and Effect

Research is ongoing to identify better biological indicators of toxicological impacts before they result in any adverse health impacts. This is key from an occupational and an environmental point-of-view, as part of this research involves the development of more efficient and potentially less intrusive bio-monitoring methodologies. The use of urinary arsenic and blood lead bio-monitoring studies are being increasingly employed in community-wide human health risk assessments to provide a better indication of actual biological effects, rather than theoretical risks predicted as part of a human health risk assessment. Further research is required to determine effect mechanisms and bio-monitoring tools to quantify effects (e.g., dermatitis effects of metals such as nickel and cobalt).

3.4.1.4 Rare Earth Metals

As consumer needs for rare earth metals increase (e.g., for items such as smartphones, wind turbines, hybrid vehicles, etc.), the need to better evaluate the health risks of related emissions from the mining and refining of these metals will be required. Few detailed studies of the toxicology of these metals have been completed, as such little is understood as to the health impacts of these metals emitted into the environment as a by-product of mining activities.

3.4.1.5 Speciation of Metals in Various Media

It is well understood that human exposures of different species of the metals have differing health implications for certain metals and metalloids. An example is nickel sub-sulphide, a minor emission product of some nickel smelting processes, that is considered an inhalation carcinogen, while nickel sulphate is another more significant nickel smelting emission product but is less toxic. A conservative assumption that all nickel emissions from such
3.4.2 Ecosystem Health

3.4.2.1 Aquatic

The impact of mining on the ecosystem is an area of concern to the public, government and the mining industry. At present, Canada’s Metal Mining Effluent Regulations (MMER) require effluents to not be acutely lethal and that any deleterious substance present does not exceed authorized limits. In addition, mining companies are regulated, under the MMER, to conduct Environment Effects Monitoring (MMER EEM), which is an extensive program to establish whether effluents have any detrimental impact on the receiving environment. Despite this extensive monitoring there are a number of concerns regarding the discharge of mine effluents.

An environmental issue facing the mining industry is the presence of metals, reagents and other by-products of processing in mine effluents, at concentrations which may have negative impacts on the ecosystem. In some cases, sub-lethal toxicity testing, as part of MMER EEM, may be used to assess the efficiency of toxicity reduction actions, as was done for the pulp and paper sector. Therefore, it is important for mine sites to have a good understanding of the cause of observed effluent toxicity for the interpretation of biological monitoring studies, and if necessary, to orient the potential remediation measures. Often, discharged metals contained in final effluents will be assumed to be the primary cause of toxicity, however, there are cases that attribute mine effluent toxicity to other, non-metallic, effluent constituents such as major ions, flotation reagents, wastewater treatment chemicals or processing by-products.

The deleterious substances listed under MMER do not encompass a number of trace elements or substances that have the potential to cause environmental effects, for example selenium and molybdenum. These are naturally occurring trace elements that are often released to the environment at relatively low concentrations. There is concern over the potential chronic effect of selenium on ecosystem health due to bioaccumulation into the food chain. More in-depth studies into data-poor metals, or metals of concern not currently regulated under MMER is needed.

The EEM program may detect potential effects within the receiving environment but there is often debate over the identification of source, particularly in heavily contaminated areas where other point and non-point discharges of deleterious substances co-occur. In addition, it is also challenging to isolate current effluent effects from historical contamination. Further work is required to establish techniques to better isolate current effluent effects.

The current guidelines for metals in aquatic environments are based on a metals potential to cause harm in isolation e.g., they do not account for interactions that occur in mixtures. More
work is needed on metal mixtures, particularly investigating interactions that may increase (synergistic) or decrease (antagonistic) toxicity.

Finally, most water quality criteria are presently based on total metal concentrations. However, studies are increasingly showing that toxicity is often more directly related to the predicted free metal concentrations than to the total metal concentration (e.g., Di Toro et al., 2001; Reiley, 2007).

To have effective metals criteria, one must understand how metals behave in the natural environment. Although metals can undergo a variety of transformations and chemical reactions, they are persistent and conservative in the environment. The speciation, or chemical form, of a metal has an impact on its environmental behaviour and effects. The bioavailable fraction of metals includes metal species that are environmentally available and are absorbed or adsorbed by an organism.

As the detection limits on chemical instrumentation allows for increasingly low detection limits allowing guidelines to be lowered, there is the need to ensure that new guidelines and regulations are based on the science of an element’s potential toxicity, bioavailability, bioaccumulation, and environmental fate and transport.

3.4.2.2 Terrestrial

There are currently scientific gaps with regard to terrestrial toxicology. Metal bioavailability in terrestrial ecosystems and the potential for toxicity are not well understood. In addition, the methodologies to assess the chemical speciation, bioavailability and toxicity of metals in soils need further development and standardization. There are many potential areas for research in terrestrial toxicology for example the investigation of the influence of varying soil parameters, such as pH on the uptake of particular metals by plants or organisms living in soils needs further study.

3.4.3 References


Reiley, MC. 2007. Science, policy, and trends of metal risk assessment at EPA: how understanding metals bioavailability has changed metals risk assessment at US EPA. Aquatic Toxicology. 84:292-298
3.5 Biodiversity

3.5.1 Preserving and Rehabilitating Biodiversity from the Impacts of the Mining Industry

Biodiversity is the variation of organisms within a given species, ecosystem, and/or biome. The number of species and the variety of genetic material available within a population determines the diversity within an ecological system (The Royal Society of Canada, 2012). This variety, or biodiversity, in turn promotes species adaptation and evolution to various ecological pressures that a population may encounter, such as climate change. In addition to a species chance for an adaptive response to new environmental pressures, the richer the biodiversity the greater the ecosystems productivity, amplifying the opportunity for new medical discoveries and economic developments (Shah, A., 2011). Since the species within an ecosystem are interdependent on each other, if the biodiversity of a particular species is affected the consequence may be an effect on another species or even an entire ecosystem (Shah, A., 2011). This delicate balance of biodiversity within ecosystems is disrupted through human development activities on a daily basis. Mining extraction and processing activities are likely to impact the biodiversity within the ecosystem(s) through disruptions to land, soil, air and water. The following communicates the importance of the associated impacts to biodiversity from the mining industry and provides suggestions where potential research gaps are indicated.

3.5.2 Overview of Mining and Biodiversity

Mining activities may potentially affect biodiversity through various physical processes associated with exploration, construction, operations and closure of a project. For instance, the removal of surface features during extraction and changes in land-use potentially alters and/or removes critical habitat to species populations (Lloyd, M.V., et al. 2002). Additionally, there are potential downstream effects from ore or mineral processing such as contaminants, transported by erosive processes (e.g., wind and water), from the operations sites to adjacent ecosystems potentially amplifying biodiversity affects throughout the environment (IFC, 2012; ICMM, 2006). Other mining industry generated impacts on biodiversity result from noise and other anthropogenic effects associated with project development and operations.

Recent trends in mining suggest exploration is increasingly being proposed in more remote and environmentally sensitive biodiversity-rich ecosystems that were previously unexplored and undeveloped for minerals (ICMM, 2006), thereby requiring rigorous management and
mitigation strategies to protect biodiversity. The potential impacts of mining on biodiversity may include, but not be limited to:

- **Potential Impacts on Terrestrial ecosystems:** Loss of habitat through fragmentation and land/soil degradation, loss of rare or endangered species, effects on sensitive or migratory species, effects of induced development on biodiversity.

- **Potential impacts on aquatic ecosystems:** Altered hydrologic regimes altered hydrogeological regimes, increased levels of heavy metals, acidity or sedimentation, increased turbidity, risk of groundwater contamination.

- **Potential changes to erosion and sedimentation processes:** May create barriers to migratory species, affect spawning grounds if runoff is uncontrolled, and reduce light penetration to aquatic vegetation.

- **Social interface with biodiversity:** Loss of access to fisheries, loss of access to fruit trees and medicinal plants, restricted access to forage crops and grazing, and increased hunting pressures.

### 3.5.3 Regulatory Guidelines

#### 3.5.3.1 International Guidelines

At the 1992 Earth Summit in Rio de Janeiro, the United Nations Convention on Biological Diversity (CBD) was signed by 157 governments; it has since been ratified by 188 countries (Canadian Biodiversity Strategy, 2012). The three objectives of the CBD are:

1. Conservation of biological diversity.
2. Sustainable use of its components.
3. Fair and equitable sharing of the benefits arising from the use of genetic resources (BCD, 2001).

At the Rio Earth Summit in 2002, parties to the CBD committed themselves to a more effective and coherent implementation of these objectives. They set to achieve a significant reduction of the current rate of biodiversity loss at global, regional and national levels by 2010 as a contribution to poverty alleviation and to the benefit of all life on Earth (CBD, 2001).

Various international organizations such as the World Bank, International Finance Corporation (IFC) and the International Council on Mining and Metals (ICMM) have developed specific biodiversity good practices for the mining industry. For example, the Equator Principles apply IFCs Performance Standard 6 - Biodiversity to all investments in excess of $10 million (IFC, 2012). These practices provided practices to be implemented to ensure the conservation and overall sustainability of biodiversity throughout all stages of a mining project’s life cycle.

#### 3.5.3.2 National Guidelines

In response to CBD, Canada developed the Canadian Biodiversity Strategy (Environment Canada, 1995) and is developing a national action plan in response to the CBD. The publication, implementing the Canadian Biodiversity Strategy (Government of Canada, 1997), provides a framework for action at all levels that enhance Canada’s ability to ensure
the productivity, diversity, and integrity of natural systems and, as a nation, to develop sustainably. In addition, Environment Canada has completed a comprehensive scientific assessment of biodiversity (Environment Canada, 1994).

In 1993, the Assessment of the Aquatic Effects of Mining in Canada (AQUAMIN) was initiated in response to Environment Canada’s commitment to update and strengthen the Metal Mining Liquid Effluent Regulations (MMLER). The objective of AQUAMIN was to examine the effectiveness of the MMLER by conducting an assessment of the environmental effects of mining, and to formulate, on the basis of this assessment, recommendations in three key areas:

1. Amendments to the MMLER.
2. The design of a national environmental effects monitoring program for metal mining.
3. Information gaps and research needs (Canadian Biodiversity Strategy, 2012).

The Canadian Biodiversity Strategy presents the final findings and recommendations from AQUAMIN and is an important reference to aid in the design of a national environmental effects monitoring program for metal mining. Launched in 2004, the Mining Association of Canada “Towards Sustainable Mining” (TSM) initiative provides a useful tool in assessing biodiversity conservation management performance (MAC, 2004).

3.5.4 Biodiversity and Development of Mining Projects

As the pressure on natural resources grows and advanced mining processes are developed, better and more sophisticated systems are necessary to ensure biodiversity impacts are controlled. (ICMM 2006) When a new project is developed there are generally three stages, these include: exploration, planning and construction. These stages have associated mining and mining related activities which impact the environment and its biodiversity. Some of the key activities include exploration drilling, land clearing, construction of roads, mining and infrastructure developments, installing pipes and power lines, transport and use of hazardous materials (ICMM 2006). Understanding the processes involved in project development, establishing baselines, developing community interactions, conducting ongoing monitoring and mitigation are critical steps in maintaining biodiversity of a site and are essential for successful project development.

In order to identify and manage the potential effects on biodiversity from a project there needs to be early and rigorous screening to categorize the biodiversity context of the project and identify protected areas. A review of legal provisions, baseline surveys by licensed and trained personal, field studies and regular ongoing consultation with stakeholders are critical requirements (ICMM 2006).

Prior to project development it is important that companies try to improve the level of environmental awareness of project personal. Training Project personnel on the importance of biodiversity can ensure that appropriate technologies and leading mining practices are used.

The most successful projects are generally those that are able to efficiently use resources and tools to assess project impacts and therefore develop best management and monitoring programs to minimize, avoid, mitigate or offset these impacts.
3.5.4.1 Tools, Techniques and Best Practices

Assessment and planning, integrative management and monitoring performance are all steps that are required to efficiently manage biodiversity of a project site at the development phase. There are additional specific tools, techniques and best practices that enable companies to achieve effective biodiversity management and some of which are discussed below.

- **Training:** A tool developed by the Prospectors and Developers Association of Canada (PDAC) called the E3 Program, was designed to support junior mining companies in addressing all environmental issues such as biodiversity (ICMM 2006). Being able to identify the environmental and social issues on a project at an early stage allows for more time and effort to focus on developing appropriate mitigation strategies, and is also a key strategy to determine high risk issues that will need to be addressed for community and regulatory approval (ICMM 2006).

- **Baseline:** Prior to any project development, environmental baseline studies need to be completed to assess the biodiversity context of the proposed project area. Often diversity indices are used which provide a quantitative measure for the rarity and commonness of species in a community. The Shannon Weiner biodiversity index and the Simpson index are two examples of indices that biologists use to quantify both abundance and evenness of the species present at a site (Clarke and Warwick, 2001). The ability to quantify biodiversity in this way is an important tool required for understanding community structure, assessing impacts during and after a project, and benchmarking against other ecosystems.

- **Landscape/Catchment Level Planning:** During exploration and mining activities, it is important to do landscape/catchment level planning as it allows companies to address the indirect and direct impacts of their activities prior to development. Mining companies need to ensure that they are effective in assessing and planning prior to project development as this will ultimately be a function of the projects overall success.

- **Stakeholder Engagement:** Liaising with the government, communities, indigenous peoples, researchers, NGOs and others, is crucial when developing biodiversity management programs that achieve the best outcomes. (Australian Government 2007). Significant benefits can be attained by utilizing the construction and technical expertise of the company’s construction team together with local communities. Stakeholders can give important and relevant insight into areas where conservation and mitigation efforts need to be focused.

- **Environmental and Social Impact Assessments (ESIA):** The ESIA is a leading tool used in mining projects to ensure the projects are designed to support sustainable development. The purpose of the ESIA is to assess the impacts, identify potential risks, consider alternatives, provide mitigation strategies and develop management systems to minimize the impacts. An Environmental Management System (EMS) is another technique implemented to measure the effectiveness of management plans, conservation and rehabilitation practices throughout the project’s life cycle (ICMM 2006).

- **Biodiversity Banking and Offset:** These tools provide systematic and consistent frameworks for counterbalancing (offsetting) impacts of development. Biodiversity offsets can be considered to be “conservation actions intended to compensate for the residual, unavoidable harm to biodiversity caused by development projects, so as to ensure no net loss of biodiversity” (ten Kate et al. 2004).
• The Integrated Biodiversity Assessment Tool (IBAT): IBAT, which was developed through a partnership among BirdLife International, Conservation International, and International Union for Conservation of Nature (IUCN), and the United Nations Environment Programme World Conservation Monitoring Centre, is another tool used for assessing biodiversity of a site. The tool is designed to provide businesses with up-to-date biodiversity information through both visual mapping and a report format (MAC 2004).

Listed above are just a few of the tools, techniques and best practices that are currently being adopted and developed by mining companies to manage environmental and biodiversity impacts during project development. These need to be implemented throughout the life of the project including development, operations and closure.

3.5.5 Biodiversity and Operations of Mining Projects

The operations phase of a mining project may span decades, as opposed to the traditionally shorter construction phase. It is therefore imperative that during the operations phase, biodiversity be properly managed, monitored and documented. It is also important to explore opportunities for the protection and enhancement of biodiversity during the operations phase. Appropriate management of biodiversity is a key requirement for achieving an ecologically sustainable development of a mining project and to maintaining a “social licence-to-operate”. Through implementing geographic information systems (GIS) to monitor changes in project impacts to water, air and noise, in turn monitoring impact to biodiversity, one can monitor against the project’s environmental management system in the operations phase of the project (ICMM, 2006). Some existing techniques to minimize impacts to biodiversity from mining operations include: site monitoring and auditing, limiting land disturbance, minimizing/optimizing the project footprint, and planning for rehabilitation (ICMM, 2006). However, gaps seem to exist in the proper management of biodiversity during the project operations phase.

There are considerable gaps in the understanding of the level of resilience in an ecosystem and other aspects of biodiversity. How much and what kind of external pressures an ecosystem can tolerate before its biodiversity is significantly degraded, and how long it will stay degraded, is not yet well understood (Lloyd, et al. 2002). Because of this gap, precautionary conservation measures and adaptive management based on rigorous monitoring that is done in the pre-construction phase of a project cannot be reduced and should be strictly enforced (Lloyd, et al. 2002; ICMM, 2006).

One of the major constraints to the effective management of biodiversity is the scarcity of existing scientific data regarding the way biodiversity changes in response to disturbance. To date, much of the potentially useful information from large-scale management activities taking place during operations of a mining project has been rendered unusable due to a lack of formal experimental design such as a lack of controls and replication, changes in techniques and technologies over time, and a lack of basic before and after monitoring datasets (Lloyd, et al. 2002; ICMM, 2006). Due to the absence of reliable data, and in
turn linkages within ecosystems, it cannot be suggested that there are reliable indicators of biodiversity and it may be that certain components of biodiversity can only be assessed using direct measures (Lloyd, et al. 2002).

3.5.6 Biodiversity and Post-Closure of Mining Projects

The purpose of closure planning is to ensure that mining operations are closed in an environmentally and socially responsible manner and that appropriate funds are allocated for this purpose. The overall objective of post closure planning is to ensure sustainable post-mine land use through stakeholder engagement, rehabilitation, and pollution prevention measures, and to minimize the long-term liability to the project owner. Objectives and targets for managing biodiversity impacts during the post-closure phase of a project include restoration, rehabilitation and enhancement opportunities. Achieving objectives and targets for biodiversity in closure are dependent on baseline information and datasets collected from project pre-development. The key aspects include regulatory requirements and guidelines, consultation with stakeholders, land disturbance impacts and post mining land-use planning.

To effectively manage the impacts to biodiversity in closure planning it is essential that community engagement plans drive sustainability in a way that the best overall environmental, economic and social outcomes are achieved. Waste rock piles, tailings, heap leaching facilities are examples where some prior planning could add significant biodiversity enhancements that are generally not evaluated in sufficient detail. These examples emphasize the potential opportunity for future research to be developed. With effective mitigation strategies in place, high costs associated with extensive ecosystem rehabilitation and reconstruction may be avoided.

A number of mining companies are addressing the fact that some ecosystems take a significant time to rehabilitate after the project, for example hollows in trees, logs and stumps, piles of branches, and tall perches which provide a niche for species. In order to address this, there is an opportunity to reintroduce habitats, like hollows in trees, to assist in the succession of native fauna within the post-mined environments (Sainsbery et al. 1999). A significant gap in the current available research is that it is not well understood the length of time it takes for an environment to rehabilitate to the level it was at the start of the development phase of a project. Techniques and tools on how to accelerate this process need to be developed and implemented. With effective mitigation strategies in place, high costs associated with extensive ecosystem rehabilitation and reconstruction may be avoided. The examples mentioned above, emphasizes a potential opportunity for where future research needs to be developed.

3.5.7 Conclusions

Tools and techniques such as environmental management systems, stakeholder engagement programs, mitigation and rehabilitation strategies, environmental and social assessments all aim to ensure that sensitive habitats, and in turn biodiversity, is protected. These tools allow
companies to clearly understand the interface between mining activities and biodiversity.

Measuring biodiversity and understanding the roles and interactions between species and their populations is key in determining what the environmental constraints are, and what drivers are necessary, to increase biodiversity within a given ecosystem. Developing a biodiversity strategy and forming partnerships with leading conservation organizations such as Earthwatch Institute, BirdLife International, Fauna and Flora International and the Royal Botanic Gardens, Kew, etc., is a step in the right direction to minimize risk and find enhancement opportunities for biodiversity (MAC, 2004).

Current research suggests several focus areas for further biodiversity research, which are indicated below (ICMM, 2006; Australian Government, 2007):

- Monitoring and associated research as essential components of good practices in rehabilitation for biodiversity establishment.
- Involvement of the local stakeholder community in operational, rehabilitation and closure monitoring.
- Ecosystem development and sustainable management of ecosystems for enhanced biodiversity.
- Biodiversity offsets and biodiversity enhancement opportunities.
- Advanced land-use planning and land management aiming to protect or enhance biodiversity.
- Improved establishment of floristic diversity through better topsoil handling and seeding methods.
- Recognition that biodiversity and rehabilitation require management solutions which ensure that values are existing at mining closure and/or enhanced.

There is a huge opportunity to improve the interaction between mining developments and biodiversity objectives. There has not been enough “out of the box” thinking to take advantage of the synergies that are available in these areas. The lack of training, environmental awareness and objectives in the mining industry are probably some of the most significant impediments to being able to bridge the gaps between mining operations and managing biodiversity. Implementing effective mitigation and conservation strategies at the early stages of project development will ultimately reduce the time and costs associated with rehabilitating biodiversity at closure of a mining project.

### 3.5.8 References


Sainsbery, G.E., Grant, C.D. and Simpson, J. (1999). Effect of habitat logs on the succession of small mammal species within RZM’s sand mining rehabilitation near Newcastle, NSW. Australian Centre for Mining Environmental Research, Brisbane

http://www.globalissues.org/article/170/why-is-biodiversity-important-who-cares#Speciesdependoneachother

3.6 Erosion and Sedimentation

3.6.1 Summary

Though erosion and sedimentation are naturally occurring processes, mining and mine-related activities amplify their effect, and may negatively affect the surrounding environment. In the absence of adequate prevention and control strategies, erosion can carry excessive amounts of sediment into streams, rivers, and other surface waters (Environmental Mining Council of BC, 2012) and aeolian movement can affect broader terrestrial ecosystems. Though the issue is addressed by the federal government in the context of water quality and management, and by other levels of government in the context of construction, there are few programs and guidelines in place that highlight erosion and sedimentation as an environmental mining issue.

3.6.1.1 Process

Erosion and sedimentation are opposite but joint processes that may occur when large amounts of material are disturbed during mining operations (Montana State University, 2004), (Environmental Mining Council of BC, 2012). Erosion is defined as the detachment and subsequent removal of rock or surface material, while sedimentation is the process of depositing this material in another location distal to the source (Montana State University, 2004). Sediment from tailings dams, waste rock dumps or spent ore storage piles, and other earthen structures may be transported by water erosion to the downstream receiving environment (US EPA, 2003). Sedimentation will then occur at some point downstream as the material is deposited when the water flows are no longer sufficient to maintain the material in suspension. Mining-related activities such as road construction, and clearing of areas can expose soils, increasing the amount of sediment in surface runoff reaching the downstream receiving environment. Other secondary effects of erosions are an increase in runoff due to the development of drainage channels on exposed slopes and the subsequent change on hydrology in riverine systems (US EPA, 2003).

3.6.1.2 Impact

Erosion and associated sediment deposition has a profound effect on aquatic ecosystems. The impact of sedimentation on substrates and aquatic vegetation includes loss of aquatic habitat for flora and fauna. With higher peak stream flows, stream banks and bed materials will erode, primary flow channels will widen, and channels will deepen and straighten, altering...
the slope of the channel (US EPA, 2003). These changes in stream morphology, including increased flow velocities, may affect fish passage to upstream areas during higher stream flows (US EPA, 2003).

High erosion upstream and excessive sedimentation downstream can cause clogging of riverbeds, and can smother vegetation, aquatic organisms, and their habitats (Environment Canada, 2011), (Environmental Mining Council of BC., 2012).

Surrounding soil organisms and vegetation are also affected. Soil movement (transport of sediment) will result in the transport of nutrients away from sites affecting local topsoil structure and nutrient cycling within the developing ecosystem (Montana State University, 2004). Vegetation is thus subject to degradation, and soil organisms are exposed to habitat changes.

3.6.2 Tools and Data

3.6.2.1 Erosion and Sediment Control (ESC) Planning

The objective of an erosion and sediment control (ESC) Plan is to identify the characteristics of the site that will have an effect on the erodibility of the soils at a site and the sensitivity of the downstream receiving environment to sedimentation. It should outline where and how Best Management Practices (BMPs) should be employed (The City of Calgary, 2001). Effective ESC planning can minimize the amount of controls and BMPs needed during operations, and therefore the overall cost.

3.6.2.2 ESC Best Management Practices (BMPs)

Erosion prevention best management practices (BMPs) are activities, procedures, and management practices that effectively and economically control problems of erosion and sedimentation (US EPA, 2003). BMP systems control erosion and sedimentation by targeting stages in their processes and, consequently, minimize potential sources of sediment (US EPA, 2003). BMPs aim to minimize the extent of land disturbance, protect soil surfaces once exposed, and control the amount and velocity of runoff carrying sediment by diverting incoming flows and impeding internally generated flows (US EPA, 2003). Examples of BMPs include:

- Surface stabilization.
- Runoff control and conveyance measures.
- Outlet protection.
- Sediment traps and barriers.
- Stream protection.

3.6.2.3 Analytical Software and Models

The following list of software and models were provided by the EPA Region 10 for new metal mining operations in the United States, and serve as examples of tools for erosion and sedimentation analysis (US EPA, 2003):
• AGNPS - Agricultural Non-Point Source Pollution Model.
• ANSWRS - Areal Non-Point Source Watershed Response Simulation Model.
• WEPP - Water Erosion Prediction Project Hydrology Model.
• GSTARS - Generalized Stream Tube Model for Alluvial River Simulation.
• HEC-6 - Scour and Deposition Model.
• Sedimot-II - Hydrology and Sedimentology Model.
• SEDCAD+. 
• Remote Sensing and Geographical Information Systems (GIS).

3.6.3 References


Environmental Mining Council of B.C. (2012). Acid Mine Drainage; Mining & Water Pollution Issues in BC.


3.7 Water and Groundwater Supply

3.7.1 Summary

Large volumes of groundwater are either discharged, or are used by the mining and petroleum sectors for the extraction and concentration of metals and non-metal minerals, the extraction of light and heavy crude, and generating electricity required for mining and the associated supporting operations (Environment Canada, 2004). Groundwater use and supply are an important environmental issue for the mining industry. The process of dewatering during mining will contribute to both the volume reduction and recharge of aquifers (Environment Canada, 2004).

Canadian groundwater management is situated between a lack of regulation and available management mechanisms, along with insufficient groundwater information (CCME, 2010).
3.7.1.1 Metal and Non-Metal Sectors

Before the excavation process, metal and non-metal mines may be dewatered causing a change in the local water table to allow the excavation to continue without excess water flowing into the working areas (Environment Canada, 2004). Drawing down the water table and diverting runoff to other watersheds may reduce the volume of water available for other uses (e.g., fisheries). In regions such as the Northwest Territories and parts of Ontario and Quebec, dewatering of deep mines can result in the extraction of saline waters and discharge of this water at the surface (Environment Canada, 2004). During mine closure, the water is allowed to recover, and the previously dry underground areas and open pits will refill, causing additional changes to the groundwater regime until equilibrium is established (Environment Canada, 2004).

3.7.2 Tools and Data

3.7.2.1 Data

The government of Canada has initiated the Groundwater Geoscience Program, which assesses Canada’s aquifers and makes the data available through the Groundwater Information Network (GIN) (NRCan, 2011). Groundwater information is provided via Open Geospatial Consortium (OGC)-compliant Web services (WMS, WFS) and Groundwater Markup Language (GWML) (Sharpe, Brodaric, Boisvert, Logan, & Russell, 2009). The GIN connects water well databases from British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Québec, Nova-Scotia, and Yukon, and provides some key general aquifer information from NRCan (GIN, 2012). The program identifies and maps key regional aquifers, builds a national groundwater database, and produces maps of natural quality in regional Aquifers (Rivera, 2006). Up to 2009, 12 of 30 key regional aquifers have been mapped and evaluated for, and seven additional aquifers will be completed by 2014 for the third phase of the project.

Other groundwater data are available from most provincial government agencies; this includes water well records, pumping test data, hydrogeological maps and studies, water quality data, groundwater level monitoring data, information on groundwater extraction, geophysical logs, groundwater vulnerability mapping and capture zone analysis (CCME, 2010).

Groundwater is largely managed by the provincial Ministries of the Environment. The regulation of groundwater supply and protection falls primarily under provincial jurisdiction, so they provide the overall strategy, applicable laws and regulations, technical studies, support, funding, and public education required to manage groundwater (CCME, 2010). Though there is no systematic national database of groundwater levels, provincial datasets provide good spatial coverage (The Expert Panel on Groundwater, 2009).

Local municipalities vary considerably in their groundwater management (CCME, 2010).
3.7.2.2 Tools

Tools and methods used to assess and control groundwater exposure may be developed under the conditions of approval for mining operations and are determined for each project. Possible work and management tools include the following:

- Hydrogeological mapping.
- Geophysical investigations.
- Water management plans.
- Groundwater resource and borefield management plans.
- Salinity assessments, management and remediation.
- Numerical modelling (groundwater and surface water).
- Aquifer storage and recovery (ASR), managed aquifer recharge (MAR), wastewater reuse.
- Acid sulfate soil (ASS) assessment and management.

3.7.3 References


3.8 Integrated Environmental Management

3.8.1 Summary

Mining operations are complex facilities that process large quantities of natural resources and may have intense local social and environmental effects, as shown in previous sections of this report. Clients, stakeholders and shareholders are increasingly demanding environmentally sound services, and environmental legislation is getting stricter. Social pressures are also building up from the growing array of interested parties, such as environmental and minority non-governmental organizations (NGOs), academia and neighbors, as well as a continued development of corporate social responsibility from within the mining industry. Satisfying these pressures means satisfying a range of stakeholders, which leads to environmental management in mining becoming a complex topic. Mining, however, has a traditional industry in Canada and much of Canada’s economy (growth, development, employment, income etc.) depends on mining and the mineral industry (Hilson & Nayee, 2002). Therefore mining growth and development needs to be managed in a way that addresses the environmental risks in an effective and sustainable way, so allowing it to contribute to the economic development in a manner acceptable to the broader Canadian population. The best and simplest way to address these issues then, acknowledging that there are multiple stakeholders involved, is to ensure any adopted solution is clearly understood and transparent. Environmental Management Systems (EMSs) offer these benefits and more by providing a systematic, standardized and transparent fashion to deal with environmental impacts related to mining.

The integration of environmental management systems into industrial operations is not new to the mining industry, but broad, comprehensive implementation supported by industry association that can facilitate the formalization and encourage the process can allow the Canadian mining industry to be at the forefront of recognizing and meeting stakeholder expectations for environmental and social protection and development.

3.8.1.1 Environmental Management Systems (EMS)

An environmental management system (EMS) is a component of the overall mine management system existing within an organization. The EMS generally provides for continuous improvement in the management of the environmental aspects of an operation. Specifically, an EMS includes organizational procedures, environmental responsibilities, and processes, helps an industry comply with environmental regulations, identify technical and economic benefits, and ensures
that environmental policies are adopted and followed (Barrow, 1999). An EMS aims to ensure that an organization’s environmental targets and objectives are being effectively pursued (Hilson & Nayee, 2002) through a plan, do, check, act, and review model. In summary, an EMS is an industrial tool that enables an organization to systematically control its level of environmental performance, while helping management identify potential environmental impacts arising from activities, set appropriate environmental objectives, establish programs to achieve corporate environmental goals, and review activities to ensure that corporate environmental policy objectives are properly carried out (Bergeron, 1997).

3.8.1.2 Benefits of an Environmental Management System

The benefits of an EMS are to:

- Track, improve and manage compliance requirements and environmental issues.
- Improve environmental performance and target setting.
- Satisfy client/stakeholder demands; increase shareholder value.
- Have better trained staff, contractors, and suppliers.
- Gain competitive advantage and credibility.
- Have consistent documentation.
- Reduce risks, incidents, liability, and costs, (reduced risk of environmental incidents).
- Continuously improve control, assurance, and accountability.
- Protect and enhance brand value and reputation.

3.8.1.3 Application to Mining and Opportunities for Improvement

To take advantage of the benefits and meet the challenges discussed above, mining organizations of all sizes should be encouraged to implement comprehensive EMSs as a recognition of these issues. To external stakeholders this represents a step toward achieving cleaner industrial production, and internally this amounts to mitigating environmental risk. However, helping operations take this step is where innovation, research and development would be most effectively used. Often these organizations already are equipped with some environmental tools in place, but are hesitant to implement leading-edge environmental practices such as an effective EMS due to a number of reasons including: a lack of the level of resources (finance, training, technology) required, and hesitant to invest in environmental practices as they are too heavily influenced by mineral price fluctuations, or a top management unwillingness due to lack of familiarity or support. Therefore, if tools and resources can be developed to support EMS implementation that are tailored to the mining industry, readily available and easily accessible with little cost to the organization, the benefits of an EMS can be achieved without each individual organization having to invest in the process from scratch with little or costly guidance. Specifically, it is believed the most benefit would achieved by:

- An increased effort to improve the process for communicating and providing the required tools for medium or junior scale mining companies to develop a comprehensive EMS that do not have the resources to develop an EMS from scratch.
• Increase the development, availability, and access of high-quality EMS training programs tailored specifically for the mining industry.

### 3.8.1.4 Providing a Mining Specific EMS Toolkit

Methods and procedures specific to the mining industry are constantly developed for each site. Most major companies draw on their corporate or past project EMS standards and templates to develop site specific procedures for new developments due to the often commonalities. The ability to harness this trait amongst mining documentation and procedures and providing it to the Canadian Mining Industry would have multiple benefits.

Benefits of having a mining specific EMS toolkit available to Canadian industry members include:

1. Allows mining companies to focus resources on other site specific environmental issues. Procedures around dust management, fugitive emissions, and fuel spills for example could be a part of the toolkit that is based on common issues amongst the mining sector.

2. Would appeal directly to medium- and junior-sized mining companies which is a group that can often be overlooked. Increasing the availability of methods, techniques, case studies, templates and training would be extremely attractive for medium and junior sized mining companies and allow them to improve their EMS or more easily implement an EMS. This group is traditionally the most hesitant to implement leading-edge environmental initiatives for the reasons stated above (lack of the level of resources required, hesitant to invest in environmental practices as they are too heavily influenced by mineral price fluctuations, and top management unwillingness to due to lack of familiarity or support) and therefore this group must be targeted and equipped with the requisite educational, informational, and technological assistance to achieve higher levels of environmental performance. Significant environmental improvements can be made at these operations if EMSs are implemented. Industry organizations must bridge information, technologic, and economic gaps, and provide junior mining operations with the means—namely information and training—to design EMSs. With increased input from industry and government research units, even the smallest, most resource-deficient mining operations would be in improved positions to implement comprehensive EMS.

3. An established and familiar EMS framework, based on standard templates and procedures, would help reduce the uncertainty and mitigate risks associated with conducting audits or due diligences for potential partnerships, mergers, or acquisitions within the industry. A significant effort is spent in reviewing and becoming familiar with other companies existing environmental procedures and environmental performance to evaluate the liabilities prior to purchase or partnership. This effort can be reduced potentially with the industry having some common practices on common issues. This issue has already been identified in the United States and Australia and toolkits have already begun to be put into place that are available to all organizations (Refer to Section 3.8.2).
### 3.8.1.4.1 Implementing and Improving Access to High-Quality EMS Training Programs

A second recommendation, which is applicable to all sizes of organizations, is increasing availability, access, development, and implementation of high-quality EMS training programs. One of the most important aspects of an EMS due to system design is an environmentally-aware staff and a well-trained EMS Team to manage and maintain the system. All employees must understand their jobs and how their positions impact the environment. It cannot be underestimated how small changes that are undertaken by individuals based on even general awareness EMS training can lead to large cumulative impacts. To ensure these benefits are received, the EMS Team and Top Management must be trained on a continual basis to ensure that the most current information is communicated to each employee. Familiarizing employees with environmental issues best prepares the operation to deal with occurrences as they arise. Training can range from providing the tools to identify and prevent environmental incidents to simply reinforcing the emergency situation contact procedure. As long as individuals are prepared, the chances of any uncontrollable problem occurring are minimized. It is impractical, however, to assume that mining companies, individually, are capable of improving the quality of their EMS training programs without outside input. Industry associations can gain benefits by developing relationships and partnerships with agencies that are equipped with professionals capable of designing practical EMS training programs that are current and effective. Designing these trainings with industry-wide applicability can allow them to be used across multiple organizations therefore making EMSs more attractive to prospective adopters and mitigates the cost to current adopters.

### 3.8.2 Tools and Data


### 3.8.3 References

3.9 Tailings Management

3.9.1 Summary

Critical decisions have to be made during various phases of tailings management, from planning to operations and maintenance during and after closure. These decisions can be grouped as follows:

Technical:
- Selecting the design criteria (e.g., storm, earthquake, ultimate and staged capacity).
- Selecting a site.
- Selecting a deposition method (e.g., conventional, thickened, paste, filtered or co-disposed tailings).
- Selecting a dam construction method (e.g., cycloned tailings, waste rock, or borrow material).
- Selecting an embankment raise methodology (e.g., upstream, downstream, centerline or a combination of the three).
- Selecting an optimal water management scheme with consideration of both process and environmental requirements.
- Selecting the closure methodology (e.g., dry or wet covers, reclamation or pit backfilling).
- If needed, selecting a treatment methodology for effluent waters.

Environmental and health:
- Selecting the design components to improve environmental sustainability (e.g., dust mitigation, erosion prevention, water management).
- Selecting the design components to reduce human and ecological risks.
- Selecting the design components to prevent or reduce metal leaching (ML) and acidic drainage (AD).

Other important decisions for consideration include social-economic and financial.

3.9.1.1 Definition of Tailings

Tailings are the rejected materials after the process of separating the valuable fraction from the uneconomic fraction of an ore. Tailings are distinct from mine waste materials that are not classified as ore and have been displaced during mining without being processed (e.g., waste rock). Tailings are normally also distinct from slags, which are from pyrometallurgical processes (Engels, 2012), and sludges from the lime treatment plants.

Based on the above definition, tailings may generally include the rejected materials produced from the mill/separation process, leach residues from hydrometallurgical processes, and waste materials generated from purification/refinery process. Tailings are produced from the processes initially in slurry form, usually composed of a mixture of fine solid particles, water, and processing reagents. Tailings are typically the size of sand and silt.
sizes and are considered to have too low of an economical value for further processing (Engels, 2012).

3.9.1.2 Tailings Forms

The four main forms of tailings are:

- Conventional - Tailings that have high water content and are in a dilute slurry form (typically less than 45% by weight solids).
- Thickened - Tailings slurry that is dewatered using a high rate or compression thickener. These slurries have lower water content than conventional tailings but may still be transported using conventional pumping systems.
- Paste - Tailings that have been extensively dewatered (typically to greater than 65% weight solids) using “deep cone” or paste type thickeners. Paste tailings are of sufficient viscosity that they do not segregate upon deposition and produce minimal bleed water. Paste tailings have a lower water content than thickened tailings, and due to the higher viscosity are often transported using positive displacement type pumping systems.
- Filtered (Dry) - Tailings that are dewatered to the point where they are no longer fully saturated. There moisture content is typically between the plastic limit (PL) and the shrinkage limit (SL) consistency of the tailings.

3.9.1.3 Tailings Handling

Tailings can be transported to their final storage area in many different ways depending on the composition of the tailings, site conditions, and proximity of the storage site to the mill or processing facility and various other factors.

For conventional, thickened, and paste tailings, the common tailings transport systems are:

- Gravitation pipeline system – Tailings that are transported in a pipeline and flow by gravity (no pumps) to the storage area.
- Pumped pipeline system – Tailings that are pumped, using either centrifugal or positive displacement pumps, through a pipeline to the storage area.

For filtered (dry) tailings, the most common tailings transport systems used are (Engels, 2012):

- Conveyor – A conveyor belt is used to transport the tailings to the storage area.
- Trucks – A fleet of trucks is used to transport the tailing to the storage area.

3.9.1.4 Tailings Deposition Methods

Tailings deposition methods applied to mining operations may be categorized as two major types, namely sub-aerial and sub-aqueous deposition. An example of sub-aerial deposition
is the discharge of tailings from a spigotted pipeline along the perimeter embankment crest, which forms a gently sloping beach towards a supernatant pond within the impoundment. Alternatively, sub-aqueous deposition requires the deposition of tailings either into or below a body of water. Sub-aqueous deposition is commonly selected if the tailings mineralogy contains sulphides that may oxidize during the life of the operation, generating acid and potentially causing any contaminants in the tailings to become mobile (Engels, 2012).

Factors for selecting the deposition method and management system may include the following:

- Physical and geochemical characteristics of tailings (e.g., particle size distribution, density, rheology, mineralogy, geochemistry, potential of metal leaching and acid generation).
- Operational parameters (e.g., tailings production rate, solid content in slurry, water balance and overall deposition management).
- Site setting (e.g., climate, topography, hydrogeology, potential social and environmental impact).
- Embankment construction (e.g., methods, availability of materials).
- Closure concept (e.g., progressive reclamation, cover system).
- Financial analysis.
- Future expandability.

### 3.9.1.5 Tailings Management during Operation

Tailings management is an important aspect in the design and operation of mining projects and needs to balance a variety of considerations. These include:

- Potential environmental impacts.
- Health considerations.
- Economic costs.
- Social considerations.

Filtered (dry) tailings are usually deposited, spread, and compacted at the tailings storage area to form a partially saturated deposit similar to an overburden stockpile. The dry tailings are able to be placed in this manner as they have a lesser moisture content and trafficability is possible.

Conventional and thickened tailings are primarily stored in engineered structures or natural and/or man-made water bodies and are referred to as tailings storage facilities (TSF). A tailings impoundment area (TIA) is also a term widely used in the mining industry. The TSFs are created through the use of embankments, dams, berms, and natural features of the area such as valleys, hillsides, or depressions. The purpose is to contain the tailings to minimize the interactions between the tailings and the local environment. The TSFs perimeter embankments are often raised throughout the life of the facility to allow for the storage of additional tailings. The three principle raising techniques used are downstream, upstream, and centreline (Vick, 1990). In some cases a combination of the three methods is used.

Downstream raise construction involves building downstream embankment raises as shown in Figure 1. Typically, downstream raise construction requires more fill materials than upstream raise construction, but provides a more robust, stable embankment. The construction material would need to be inert fill as the seepage barrier system is commonly installed on the upstream slope (Vick, 1990)
Upstream raise construction involves building embankment raises by stepping onto the consolidated tailings directly adjacent to the perimeter embankments (Figure 2). The ability for the deposited tailings to support the upstream raise is a critical consideration to the success of this method. Upstream raises may limit the tailings store area which may require the construction of a larger impoundment area. The supernatant pond must be well managed with an operating criterion of a minimum setback distance of the pond from the embankment crest to ensure the stability of the embankment. Instruments should be installed to monitor the phreatic conditions within the tailings directly upstream of the raise, to enable early prediction of high pore pressures within the raise foundations (Vick, 1990).

For lower density, conventional tailings, the coarse particles segregate naturally from the fines upon deposition, with the coarser material settling closest to the discharge points. The fines are transported with the process water, eventually settling near the supernatant pond. Cyclones can be used to mechanically influence particle segregation for certain tailings, resulting in a coarse and fine tailings fraction streams. The coarse faction may be used to construct the perimeter embankments with the fines or slime fraction deposited into the centre of the impoundment. By using the coarse tailings to construct the embankment raise, savings over the use of more expensive inert fill as in the downstream construction method may be realised. The conventional method of upstream raises relies on no compaction of the tailings beach that forms the embankment shell (Vick, 1990).
The centreline raise construction method is a compromise between both the downstream and upstream raise methods (Figure 3). It is more stable than the upstream method but does not require as much construction material as the downstream design. When subsequent raises are required, material is placed on both the tailings and the existing embankment. The embankment crest is being raised vertically and does not move in relation to the upstream and downstream directions of subsequent raises. It offers a simple internal drainage design, greater long-term stability and better constructability relative to the upstream method (Vick, 1990).

Paste tailings are stored in a facility similar to conventional and thickened tailings. However, the tailings are often discharged from a higher elevation than the perimeter embankments, either using towers as is the case for central thickened discharge (CTD), or from topographical high points within the facility. The paste tailings form a much steeper beach than conventional or thickened tailings, which promotes drainage to the perimeter of the facility rather than the interior. By shedding the storm water to the perimeter, it allows for simpler management at closure. The conical post closure landform created by a paste storage facility also looks aesthetically more natural than the conventional or thickened options. The idea of thickened tailings disposal is to stack the pulp and form a self supporting conical pile thus reducing the height of perimeter containment embankments as illustrated on Figure 4 (Vick, 1990).
The advantages and disadvantage of the various forms of tailings management are outlined below:

**Conventional Tailings**

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Robust and easy to operate</td>
<td>Large fill volume needed to construct the perimeter embankments resulting from downstream or centreline construction.</td>
</tr>
<tr>
<td>Less risk of dam failure due to the dam needing to be raised using the downstream or centreline method:</td>
<td></td>
</tr>
<tr>
<td>Foundation conditions of the tailings below upstream raises may require sound ground improvement to support the raise.</td>
<td></td>
</tr>
<tr>
<td>Liquefaction is a common concern for upstream raises constructed on saturated coarse tailings in moderate to high seismic regions.</td>
<td></td>
</tr>
<tr>
<td>Low-operating costs to transport slurry.</td>
<td>Large footprint required.</td>
</tr>
<tr>
<td>Moderate dusting of exposed tailings beach (for sub-aerial options).</td>
<td>High initial capital costs for facility.</td>
</tr>
</tbody>
</table>
## Thickened Tailings

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Smaller starter containment required when compared to conventional tailings.</td>
<td>Large fill volume needed to construct the perimeter embankments if downstream or centreline construction is required.</td>
</tr>
<tr>
<td>Embankments may be raised using the upstream method depending on the properties of the tailings.</td>
<td>Risk of dam failure due to liquefaction or failure of internal drainage system if the upstream raise method is used.</td>
</tr>
<tr>
<td>Low-operating costs to transport slurry.</td>
<td>Large volume of supernatant and runoff water that needs to be managed and reclaimed at closure</td>
</tr>
<tr>
<td>Possible for progressive rehabilitation of the perimeter embankments if the upstream raise method is used.</td>
<td>Moderate to high dusting of exposed tailings beach.</td>
</tr>
<tr>
<td>Complexity of closure due to poorly consolidated fine grained tailings below the supernatant pond.</td>
<td></td>
</tr>
</tbody>
</table>

## Paste Tailings

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small fill volume required for containment embankments.</td>
<td>Expensive pumps and high pressure pipelines required to transport tailings to the storage area.</td>
</tr>
<tr>
<td>Water storage and retaining ponds can be significantly reduced or in some cases eliminated.</td>
<td>Higher maintenance costs due to wear on transport system (pipelines, pumps, etc.).</td>
</tr>
<tr>
<td>Reduced seepage from the stored paste.</td>
<td>Potential risk of liquefaction of paste tailings.</td>
</tr>
<tr>
<td>Simpler and easier to close and rehabilitate.</td>
<td>High potential for dusting of exposed tailings beach in arid environments.</td>
</tr>
</tbody>
</table>
### Filtered (Dry) Tailings

<table>
<thead>
<tr>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Progressive reclamation is possible.</td>
<td></td>
</tr>
<tr>
<td>Smaller tailings storage area footprint required.</td>
<td>High operating costs due to transport method (conveyor or truck) and earthmoving equipment required to place and compact the tailings.</td>
</tr>
<tr>
<td>Low risk of failure to stockpile due to the low moisture content of tailings material.</td>
<td>Tailings storage area needs to be close to process plant to make this a viable option.</td>
</tr>
<tr>
<td>Tailings are mostly dry and only runoff water needs to be reclaimed.</td>
<td>High dusting of exposed tailings surface in arid environments.</td>
</tr>
<tr>
<td>Lower cost and simpler to close and rehabilitate. Able to shape the tailings landform to more closely tie into the surrounding geomorphology.</td>
<td></td>
</tr>
</tbody>
</table>
3.9.1.6  Tailings Closure Management

The need to have a proper closure plan for a tailings storage facility is pertinent to the site’s long-term environmental sustainability and stability. The purpose of a closure plan is to not only restore the tailings facility to natural conditions but also to manage long-term environmental impacts such as AD and ML (INAP, 2012). There are many different closure methods available to the mining companies but the two main ones used for a tailings storage area are dry and wet covers. The dry cover method requires a low permeability or semi-pervious material (fill or a combination of fill/liner) placed above the tailings in order to minimize oxidation of the tailings and promote vegetation growth to reduce erosion (INAP, 2012).

Conversely, the wet cover requires submergence of the tailings underwater (sub-aqueous disposal), which limits the exposure of the tailings to oxygen and, therefore, prevents acid generation. Water covers, if designed correctly have been proven to reduce AD and ML (INAP, 2012). However, water covers may require ongoing maintenance to the embankments and may not be applicable for some of the more arid environments in northern Canada.

The need for proper long-term monitoring is essential for both methods to determine the effectiveness of the overall closure management strategy.

3.9.2  Tools and References

3.9.1.2  Current Practices during Operations

The Mining Association of Canada (MAC) tailings management guides were developed between 1996 and 2009 by the MAC Tailings Working Group. They were developed in response to concerns arising from a series of high profile international tailings storage facility failures that took place during the 1990s. The guides provide a basis for responsible tailings management, for the full life-cycle of mine operations from planning and design to final closure. Although the guides have been prepared by and for MAC members, they are intended to be applied throughout the mining industry in Canada and elsewhere.

The guides were updated during 2011/12 and are available in English and French (and soon in Spanish) on the MAC website, www.mining.ca, at the links below:

The French versions of the guides (Guides de L’AMC) are found on the MAC website as follows:


The Canadian Dam Association (CDA) Dam Safety Guidelines were revised to include tailings dams in 1999. These guidelines provide an overview of the processes and criteria for the management of dam safety in accordance with applicable principles.

3.9.2.2 Current Practices during Closure

The Mine Environmental Neutral Drainage (MEND) program was started in 1989 to develop technologies to prevent and control acidic drainage with a focus on Canadian national and regional informational needs related to preventing and controlling acidic drainage, with respect to closure management and many other areas. They provide many reports and case studies related to current closure practices and they can be found on the MEND website www.mend-nedem.org.

3.9.3 Conclusions

Based on current tailings management practices, further research and development is recommended in the following areas outlined below.

3.9.3.1 Operations

- Effects that grinding of the ore to maximize mineral liberation has on the overall management of tailings, its ability to be mechanically dewatered and its geochemical reactivity.
- Effects of production scale on the economics of paste and filtration tailings. Ore grades are deteriorating and tailings volumes increasing over time and the current dewatering technologies are economically limited to smaller throughputs.
- Biological effects and geochemical reactivity of tailings disposed in natural and man-made water bodies.
- Effect of climate change and adaptation on tailings management facilities in the Canadian arctic and sub-arctic environments.
• Understanding the limitations of using liners for tailings facilities (creating a bathtub of unconsolidated tailings rather than promoting controlled dewatering of tailings).

3.9.3.2 Closure

• Long-term closure concerns – How will tailings impoundments react in geological time with a focus on key physical, chemical and biological processes?

• Design of covers on mine wastes in cold regions.

• Opportunities to investigate co-disposed on pre-treated capping layers and the effectiveness on neutralizing acid generation or reducing borrow materials.

• Water recycling or processes for in-situ treatment of tailings geochemistry.

• Case studies for the verification of closure technologies and their application to the different environments in Canada. This includes both short and long-term monitoring data.

3.9.3.3 Risk Assessment

• Managing uncertainties for tailings impoundments (guide for risk management for operations and closure).

3.9.4 References


4. Conclusions

Based on review of this document and discussions held by the Environmental Stewardship Committee on November 27, 2012 the following are the conclusions and the identified research areas:

- **GHG and Climate Change/Adaptation:** It was felt that CMIC could have an impact on GHGs especially with smelting. However, it was agreed to try to address the issue of climate change/adaptation by integrating it within other sections of the report.

- **Biodiversity:** Preservation and rehabilitation would be the main issues for mining and biodiversity. There is a need to understand baseline and what is an acceptable change. It was felt that biodiversity could be incorporated into toxicology and long-term environmental management.

- **Erosion and Sedimentation:** This area has links related to closure (erosion of covers) and potentially a link to toxicology (modelling of total suspended solids and dissolved metals).

- **Long Term Environmental Management:** This was an area that was extracted from the Environmental Management and was identified as a theoretical concept of long-term environmental management that would incorporate the philosophy of managing a mine in a manner that you can create the perfect walkway scenario where the mine is rehabilitated and biodiversity created, maintained or restored. It was decided that although the concept is important, it was too complex to handle as one of the pioneer projects of the committee.

4.1 Identified Research Areas

**ARD – Sulphidic Tailings and Mine Waste:** MEND is looking for funds and have been doing primarily technology transfer since 1997, however ARD is still a major cost to mining companies.

- **Identified Research Area #1:** CMIC should consider developing a project in collaboration with MEND and INAP.

**Toxicology:** Concerns have been raised with new substances being added to the MMER deleterious substance list. There was the recognition that there is a considerable amount of work being done in academia on this subject.

- **Identified Research Area #2:** CMIC should consider aquatic toxicology as a potential research area.

**Water and Groundwater Supply:** It was recognized that we often don’t understand the groundwater regimes at mining sites and there may be tools that could be further developed, such as remote sensing and geophysics, to help us better define the local and regional regimes.

- **Identified Research Area #3:** CMIC should consider tools for better groundwater mapping as a potential research area.

**Integrated Environmental Management:** There is a need to develop a tool kit of standard practices to avoid duplication. This was viewed as a win both with regulators and industry although there is no real research component. Small companies would benefit directly from such a tool kit and bigger companies would benefit by plans being done right.

- **Identified Research Area #4:** CMIC to take this forward to next stage and evaluate this topic through a feasibility study.