Climate Change Impacts on Metal Leaching and Acid Rock Drainage at Canadian Mines – Risks for Operation and Closure

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Abstract
Previous studies on climate change in Canada have identified a range of potential impacts on the natural resource sectors, including the mining sector. Mine operators have always had to contend with challenging environmental conditions, including extreme weather events. There is a need to better understand how and when climate change will affects today's mines (or mines being planned today), what impacts can be adapted to reactively, and what impacts are potential 'game-changers' or could significantly affect the bottom line. This paper describes an assessment, conducted on behalf of the MEND program (Mining Environment Neutral Drainage), of the risks specifically associated with metal leaching and acid rock drainage (ML/ARD). These are risks arising from the impacts that a changing climate may have on water management structures and activities, on waste impoundment structures, and on the hydrologic/ hydrogeologic/geochemical conditions affecting ARD/ML. The assessment was a high-level risk analysis, and not a detailed technical study, aimed at identifying priority areas for further discussion and inquiry. Potential impacts before and after mine closure were characterized in terms of measures required to prevent additional ML/ARD and maintain environmental protection. Indicative estimates of cost impacts were developed for significant and higher likelihood scenarios.

Key Words: adaptation, tailings, covers, dams, permafrost

Introduction
Climate change poses a number of risks to mining operations. Extreme weather events and changes in precipitation patterns may lead to interruptions in production and damage to mining infrastructure. Permafrost degradation and increases in precipitation may compromise the integrity of waste containment structures such as dams and tailings covers. Drought conditions may lead to a shortage of water required for processing and waste management (e.g. water covers). Climate change may also affect the broader energy and transportation infrastructure on which the mining sector depends to deliver electricity, labour, and supplies, and to ship products.

Climate change is being addressed in the design of some new mines, in closure planning, and in certain regulatory processes such as environmental assessment. However, studies suggest that long-term adaptation planning is largely not occurring in the mining sector (David Suzuki Foundation 2009). A recent survey of mine closure policies in Canada and in foreign jurisdictions (Cowan Minerals Ltd., 2010) identified gaps related to requirements that could help address climate change impacts, including risk assessments for sites under long-term/perpetual care where environmental failure remains a possibility, and specific consideration of catastrophic events.

This assessment focuses on risks associated with metal leaching and acid rock drainage (ML/ARD). For simplicity in this report, this drainage is referred to as ARD. At mine sites, the prevention and management of ARD includes the management of water, tailings and waste rock. Therefore, the climate change risks related to ARD arise from the impacts that a changing climate has on water management structures and activities, on waste impoundment structures, and on the hydrologic/ hydrogeologic/ geochemical conditions affecting the generation and transport of contaminants.

Mining activity occurs across Canada, so mining operations will be exposed to the broad range of regional impacts that are projected by climate models, including more pronounced impacts in the north. Previous studies on climate change impacts in Canada have identified a range of potential impacts for the mining sector, including impacts related to ARD. This assessment builds on previous work by looking more closely at the impacts for specific infrastructure elements and determining which of these impacts are most likely and significant for mining operations and for society.

Approach

This assessment used a risk-based approach drawing on the professional judgment of a multi-disciplinary team (engineering, sustainability, and finance), technical insights from a small set of interviews with external experts, and a review of recent reports on the impacts of climate change in Canada and more specifically on climate change and the mining sector. Potential impacts were identified by imposing a set of climate change conditions onto the mining infrastructure and activities most relevant to the prevention and management of ARD. Indicative estimates of cost impacts were developed for more significant and likely scenarios – presented in terms of net present value (NPV).

Scope and key assumptions

Assessing ARD-related impacts relative to other potential impacts caused by climate change (e.g. impacts on mining transportation networks or energy infrastructure) was beyond the scope of this work.

The timeframe considered in this assessment is for mining operations that are being planned or built today or that are currently active. The following assumptions were made:

- The majority of mines that are being planned or that are under construction will be in production within 5 - 10 years; and
- The majority of mines that are currently active, planned, or under construction will have an operating life of 20 years or less.

Projections for the 2050s time horizon are used in this assessment (Intergovernmental Panel on Climate Change 1999, Natural Resources Canada 2008). A key implication of the assumptions above is that by the time more significant climate change impacts materialize (i.e. 2050s); the majority of today's mining operations will be in the post-closure phase.

In considering the potential risks associated with the impacts of climate change on ARD, it is assumed that mine owners will take measures to maintain regulatory compliance and that infrastructure will be designed and operated in accordance with good engineering practice. Therefore, the impacts discussed are largely cost impacts resulting from pro-active or reactive adaptation measures taken by mining companies (during operation or at closure) or by government agencies (post-closure).

Climate change conditions

Four climate change conditions were identified that were considered to be most relevant to ARD processes and control at Canadian mining operations.

1. *Increase in average temperature* – In addition to being a factor for the impacts listed below, temperature has a direct impact on the sulphide oxidation process that leads to ARD, and on evapotranspiration rates for vegetated waste covers.
2. *Change in mean annual precipitation (MAP)* – Water balance is a key consideration in the design of water management structures, tailings covers, and dams. Furthermore, changes in receiving waters (e.g. increasing or decreasing stream flow) may influence how ARD is assimilated by the environment.
3. *Increase in frequency and intensity of extreme weather events* – Extreme precipitation events govern the design of tailings dams and other aspects of a mine's water management system.

4. *Permafrost degradation* – Certain mine structures depend on permafrost for stability (i.e. dams) or as an infiltration barrier (i.e. tailings cover). Permafrost degradation may reduce the performance of these structures or cause them to fail.

The four conditions are functional categories of physical impacts that cover a wide range of interrelated impacts described in climate change literature. NRCan (2008) indicates that the magnitude and nature of impacts vary across the country. Bruce (2011) summarizes the observed climate trends to date and provides projections to 2050 for 18 sub-regions of Canada.

Increase in Average Temperature
During the past century, temperature increases in Canada were approximately double the global average (National Round Table on the Environment and the Economy (NRTEE) 2010). This pattern is expected to continue, with Canada as a whole warming at approximately 1.5 times the global average, and the arctic at a rate of up to 3 times the global average. Metal mines in Canada are located in regions (NRTEE 2011) where temperatures are expected to increase by 2.5 to 3.5 °C (NRTEE 2010), with the exception of mines in southern BC and parts of southern Alberta. Coal mines are located primarily in regions (southern half of Saskatchewan and Alberta, eastern BC) where temperatures are expected to increase by 2 to 3 °C.

Changes in Mean Annual Precipitation
Most regions of Canada are expected to experience increases in precipitation by 2050 (NRCan, 2008), especially during the winter months. Seasonal changes will generally have greater impact on a regional scale than annual totals. Because of enhanced evapotranspiration, driven by higher temperature, many regions will experience moisture deficits despite higher annual precipitation. Another important change will be an increase in the percentage of precipitation falling as rain instead of snow.

Extreme Weather Events
There is an indication from both theoretical and climate models that changes in rainfall resulting from thermodynamic processes will lead to more frequent and perhaps more intense extreme events, especially in regions with increases in mean precipitation (Jakob *et al.* 2009). The climate projections for 2050 for most regions of Canada include increases in mean precipitation and more severe and frequent intense precipitation events (Bruce 2011). However, there remains considerable uncertainty in how climate change will affect estimates of probable maximum precipitation (PMP) and probable maximum flood (PMF) used for dam and spillway design (Jakob *et al.* 2009). At the time of this assessment, officials from Hydro-Québec and BC Hydro, indicated their organizations would be exploring this issue together in the near future (René Roy, Hydro-Québec, pers comm; Stephanie Smith, BC Hydro pers comm)

Mine elements relevant to ARD
Figure 1 shows the range of infrastructure and activity elements relevant to ARD for the post-closure phase. For an operational mine, ditches and storage ponds are in use, waste covers are not fully implemented, and pumping systems may be active to prevent the mine from flooding. Otherwise, the list of ARD-related elements is similar to Figure 1.

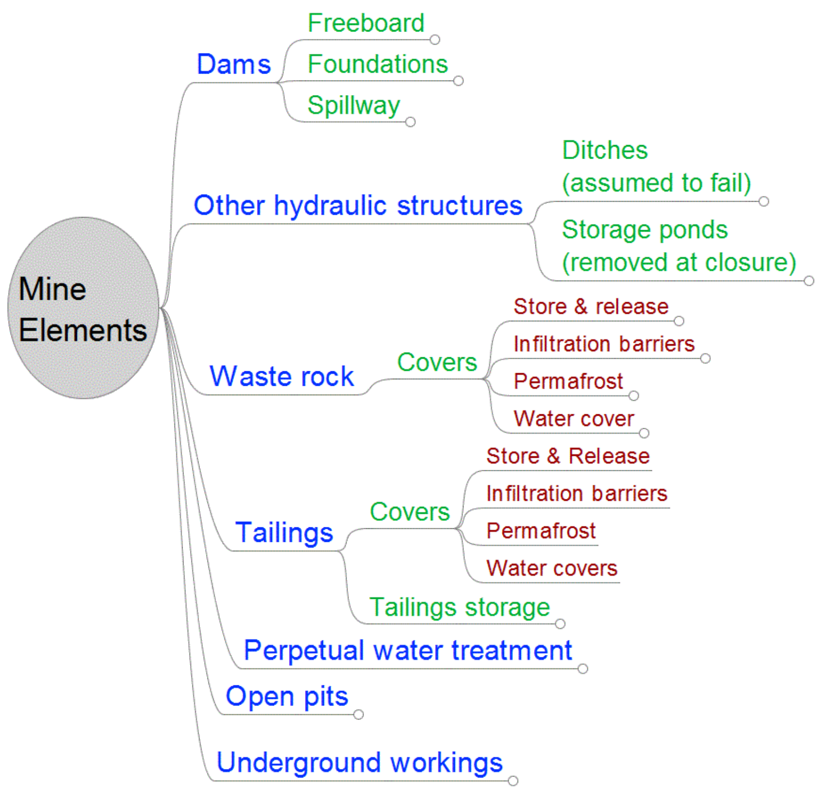

Figure 1. Post-closure mine elements relevant to ARD

Assessment of Climate Change Impacts on ARD

Table 1 presents a range of potential impacts from applying the four climate change conditions to the ARD-related mine elements presented above. Each impact is characterized in terms of the climate change conditions that drive the impact and the timeframe during which the impact is considered to be most significant (operation or post-closure).

Table 1. Potential impacts of climate change on mine ARD

ELEMENT / Sub-element	Description of Potential Direct Impact	Most Relevant Climate Change Condition(s)				Most Likely Timeframe	
		Temperature	Mean Annual Precipitation	Extreme Precipitation	Permafrost Degradation	Operation	Post-closure
DAMS							
Foundation	Settlement				✓		✓
	Increased seepage		✓	✓	✓	✓	✓
	Slope failure due to rising phreatic surface		✓	✓			✓
Freeboard / Spillway	Overtopping			✓		✓	✓

ELEMENT / Sub-element	Description of Potential Direct Impact	Most Relevant Climate Change Condition(s)				Most Likely Timeframe	
		Temperature	Mean Annual Precipitation	Extreme Precipitation	Permafrost Degradation	Operation	Post-closure
WASTE PILES AND TAILINGS							
Store and release cover	Storage capacity exceeded, increased percolation		✓	✓			✓
	Vegetation poorly adapted (increased percolation, erosion, or metal uptake). Vegetation may also be impacted by an increase in forest fires.	✓	✓	✓			✓
	Cover is eroded, increased percolation		✓	✓			✓
Infiltration barrier – soil	Cover is eroded, increased percolation		✓	✓			✓
Infiltration barrier – synthetic	Protection layer is eroded, increasing risk of damage to synthetic layer, minimal impact on ARD			✓			✓
Permafrost cover	Permafrost degrades, increased percolation				✓		✓
Water cover (tailings or pit)	Increased MAP may reduce risk of drought effects but also increase risk of emergency discharge. In some regions where more seasonal drought periods are projected, increased risk of exposure of tailings to air.	✓	✓			✓	✓
Tailings storage	Less entrained ice and less settlement of future reclaimed surface (positive impact)	✓					✓
WATER TREATMENT							
	Increased hydraulic loading (linked to failure/ underperformance of other components)		✓	✓		✓	✓
	Increased chemical loading (linked to failure/ underperformance of other components)	✓				✓	✓
OPEN PITS							
	Increased flooding of pit and need for pumping and treatment (see Water Treatment) or emergency releases. Changes in chemical loading to pit water.			✓		✓	✓
UNDERGROUND WORKINGS							
	Increased flooding of underground and need for pumping and treatment (see Water Treatment).			✓		✓	✓
OTHER HYDRAULIC STRUCTURES (DITCHES, DIVERSIONS, HOLDING PONDS)							
	Diversion ditches and channels are undersized resulting in more infiltration into or contact with acid generating material.			✓		✓	
ARD BIOCHEMICAL PROCESSES (I.E. SULPHIDE OXIDATION RATE)							
	Increase in rate of sulphide oxidation process due to higher average temperature (other factors considered constant)	✓					✓

Table 1 shows that most impacts are expected to occur during the post-closure phase. Overall, extreme precipitation is the most relevant climate condition.

Discussion

Assuming that most mines have an operational period of 20 years or less (some mines have reserves that would extend mine life beyond 20 years, however regulatory mine planning is generally still based on a 20-year timeframe), climate change effects are expected to be negligible on the hydraulic capacity (design flow) of mine components (ditches, water management ponds, spillways, water treatment plant, tailings pond supernatant volume) during operation. Although it may be appropriate for engineers to incorporate adjustment for anticipated climate change effects in the design of the operational components of a mine, these are expected to be small refinements and not material in the overall economic viability of a given mine. The reason for this is that during the operation phase, most climate parameters in most regions are projected to change within, or close to within, a range which is already accounted for by conventional engineering design.

The effects of climate change on the mining industry are expected to be most significant in the design of post-closure mine components, which include all mine features remaining after the mine is reclaimed and closed. This prediction arises because mine closure design must consider the long-term future of a site, a future that extends into the timeframe when the magnitude of climate change effects will become more significant. Therefore, this discussion focuses on climate change effects on mine closure design and performance.

The post-closure effects of climate change can be summarized as follows:

- Larger flows through hydraulic structures such as spillways and ditches, and in the extreme case the risk of a dam failure due to insufficient capacity of the spillway;
- Increased percolation through covers (especially store and release, and simple single-layer covers), which in turn causes increased flushing of contaminants from under the cover;
- Increased percolation and/or erosion for soil covers on potentially-acid generating (PAG) mine waste;
- Changes in vegetation types on covers;
- Thawing of frozen cores causing settling of, or increased seepage through, tailings dams; and
- Thawing of permafrost causing increased percolation in permafrost covers.

The above impacts on the post-closure infrastructure, if not mitigated, could result in increased contaminated runoff from the mine site, and in the extreme case, a catastrophic release of tailings if a dam were to fail. However, it is assumed that mine owners or operators will continuously and actively work towards mitigating these potential impacts.

If mitigation is reactive (i.e. **reactive adaptation**), because the impacts described above have occurred, the following activities may be required:

- Increased maintenance, repair, or replacement of covers due to erosion damage or modification of cover;
- Increased maintenance or modification (e.g. buttress, thermosyphons) of frozen core dams to limit or compensate for permafrost degradation;
- Increased burden on water treatment activities (if post-closure treatment is required) in the form of chemical loading (higher concentration) and/or hydraulic loading (higher flow); and
- Clean-up and repair of infrastructure above due to extreme, unexpected events.

The design parameters most relevant to these impacts are the following:

- Cover thickness and type (on tailings or waste rock);
- Spillway capacity for tailings dams; and
- Aggregate volume of water to be managed in perpetual water treatment systems.

Anticipatory adaptation would involve designing infrastructure for post-closure climate change conditions at or before closure. In general, this is the preferred approach as more effective options for minimizing ARD are available earlier in the mine life (International Network for Acid Prevention 2010). Similarly, climate change adaptation measures are more effective and less costly when developed and integrated at the planning and design phase. The following sections provide additional commentary on the nature of impacts and potential mitigations in these areas.

Ditches and spillways
Given the uncertainty in the extent to which climate change will affect flood flow and that impacts will likely be highly site specific, different mitigation strategies are suggested. One option is to design with future expansion in mind but only build for current conditions. This approach may still leave a contingent liability for future generations. The preferred approach is to build for plausible future conditions (based on predicted climate change effects) and/or incorporate additional conservatism (safety factors) into the design. The challenge lies in determining how to implement this approach – an initial approach may be to increase the level of the design's Canadian Dam Association (CDA) dam classification (CDA Dam Safety Guidelines 2007).

Soil cover vegetation
Climate change projections suggest that increased MAP is primarily delivered in winter (non-growing) months, and in a proportionally increasing non-frozen form (rain instead of snow). Given these assumptions, coupled with projected higher temperatures and CO_2 levels, it is expected that plant growth rate and evapotranspiration may increase. However, this increase will need to be supported by an increased use of soil water. As a corresponding increase in water will not be delivered during the growing season, vegetation may develop deeper root systems, where possible, to acquire water during moisture-limiting periods in the growing season. These changes may also be accompanied by vegetation shifts, as plants more suited to warmer growing seasons with more drought are favoured over plants found in current conditions.

It is predicted that growth rate would marginally increase, and that plant types would potentially shift towards plants more tolerant of drier growing seasons (e.g., grasses instead of trees), and that root penetration would marginally increase. Deeper root penetration may not be desirable for geotechnical or other reasons. This would also have an effect on the designed thickness of the cover material as root penetration should be limited to the cover layer and not go into the waste material below.

Soil cover erosion effects
Climate change projections suggest an increase in extreme daily precipitation, and these extremes are disproportionately responsible for surface erosion, as overland flow and detachment of soil particles occurs when precipitation rates exceed soil infiltration rates (i.e. in extreme events). As discussed above, increased precipitation is expected to be delivered primarily in winter months (and more as rain), when plants are not transpiring and there is little evaporative demand at the soil surface, due to reduced insolation (solar radiation energy). Therefore, an increase in delivered water may not be proportionately removed by evapotranspirational mechanisms, and may result in both increased net percolation and increased surface erosion.

Surface erosion of covers is probably the most serious process leading to long-term loss of cover performance. Quantitative predictions of effects and design are beyond the scope of this report. However, the gradual deepening of gullies and erosion of a cover is something which can readily be monitored, and if necessary, repairs undertaken. These types of problems, if they occur, will likely be localized effects and not affect the entire cover area. Consequently, in terms of the overall cost of the cover, the future maintenance issue is likely to be primarily limited to local repairs on an infrequent basis (i.e. once per decade). A modest provision of a $1/m^2/decade multiplied by the area of the cover should provide sufficient means for future generations to manage any issues should they arise (consistent with responsible maintenance funding for long-term maintenance involving infrequent repairs).

One might expect increases in cover maintenance costs to be roughly proportional to the relative increases expected in extreme daily precipitation. This increase could potentially be mitigated by use of more aggressive surface-erosion control techniques, such as increased landform grading or bio-engineering.

Increased percolation through the cover could lead to flushing of the underlying contaminants. In cases of severe ARD risk, this could ultimately lead to the covered area yielding a greater volume of seepage and possibly at a higher metal concentration as stored oxidation products are flushed out. Additional measures to mitigate impacts to the receiving environment (e.g. water treatment) could be needed.

Implications for cover design

At Canadian mines, there are four broad categories of reclamation covers: simple or single-layer covers, infiltration barriers, store and release covers, and permafrost covers. Except for simple covers, all of the cover types are site-specific engineered structures which depend primarily upon two independent parameters: climate/water balance factors and availability of local materials for construction. Table 2 summarizes the most likely potential effects on each type of cover and the mitigation required.

Table 2: Potential impacts of climate change on reclamation covers

Cover Type	Purpose	Potential Impacts of Climate Change and Increased MAP
Simple	Aid in re-establishing vegetation	Little or none, possibly a shift in type of vegetation, or temporary loss of vegetation due to increased forest fire activity.
Infiltration Barrier (using geo-synthetic material)	Minimize flushing of metals	Negligible compared to other cover types. Potential need for thicker or more robust protective cover due to increased erosion.
Store & Release (soil cover which stores freshet/rain water for later release by evaporation/evapotranspiration)	Reduce flushing of metals	Increased MAP may lead to: • Cover will need to be modified (possibly greater storage capacity or more robust), increase may not be proportional to increased MAP due to increased evaporation/evapotranspiration) in longer/warmer summer • Cover thickness exceeding what can be released – in such a case a switch to barrier cover may be needed Also, potential temporary loss of vegetation due to increased forest fire activity.
Permafrost cover (rocky cover to induce and preserve permafrost)	Minimize flushing of metals	Warmer climate may lead to: • Cover will need to be thicker (deeper active layer), • Permafrost cover may be impractical – in such a case store & release or barrier cover may be required.

Sulphide oxidation rate

Temperature has a direct effect on the rate of abiotic and bacterially mediated sulphide oxidation. As a general rule, reaction rates approximately double for every 10°C increase in temperature (International Network for Acid Prevention 2009). However, the actual reaction rate will depend on a range of factors. Based on the temperature increases anticipated for the timeframe considered in this study, the impacts of increased temperature on sulphide oxidation rates alone is not anticipated to have a significant impact on treatment requirements. However, it is recognized that there are still gaps in understanding of how cold temperatures, ice, and permafrost degradation affect the dynamics of acid generation (Stratos 2009). SRK (2006) reported that limited research has been completed on the effect of low temperature on the performance of mine waste management facilities and recommended that more research in this area be conducted.

Most significant risks
Based on the discussion above, two types of scenarios have been identified as likely to pose the most significant risks related to ARD from climate change at Canadian mines. These risks are presented as scenarios in Table 3 below.

Table 3: Most significant risk scenarios related to climate change impacts on ARD

Scenario	Impacts	Timeline	Affected Groups	Other Considerations and Risks
To adapt to a changing climate, a mine operation must implement a reclamation cover design that is significantly more expensive than the original option (e.g. geo-synthetic cover instead of store and release cover)	a. Additional reclamation costs for mine owners.	Cost impacts occur during operation or closure.	Mine owner	The potential impacts of climate change on closure infrastructure may cause concern among mine stakeholders – less certainty in the long-term integrity of covers and increased likelihood of long-term treatment requirements.
	b. Cost of long-term/perpetual treatment required if cover deficiency not addressed.	Cost impacts occur post-closure.	Mine owner, government agency / society	
	c. Increased ARD and environmental impacts if not mitigated.	Environmental impacts occur post-closure.	Society, ecosystem	
More frequent and intense extreme weather events force temporary shut-downs and modification to water management structures (holding ponds, ditches, dam, spillway, treatment system) to address problems and prevent re-occurrences.	a. Cost impacts due to loss of production during shutdown and requirement for modifications	Cost impacts occur during operation.	Mine owner	Linking individual extreme weather events to climate change is challenging. However, this link will be made by stakeholder if water management structures and strategies consistently underperform during rainstorm events.
	b. Periodic releases of contaminated effluent (above permit limit) and associated environmental impacts if not mitigated	Environmental impacts occur during operation.	Society, ecosystem	

The financial costs of these scenarios are explored in more detail in the following section.

Financial modelling of climate change adaptation measures
Some basic financial modelling was conducted to obtain a sense of scale of the potential financial impacts of climate change adaptation measures on mines – focusing on a scenario where a significantly more

costly cover design (i.e. use of a geo-synthetic) is required to adapt to climate change conditions during post-closure. A basic financial model was developed of a hypothetical Canadian copper mine with characteristics similar to those that would be impacted by the need to adapt to climate change impacts. The difference in the mine's NPV was estimated based on the need to take adaptation measures by increasing the amount of funds set aside for reclamation purposes prior to production. The same analysis was then conducted for two other mine size scenarios – small (half the size of the base model) and large (twice the size of the base model).

Model assumptions
The model assumes a base case copper mine with the following characteristics:

- An open-pit copper mine with a total of 702,000 tonnes of copper reserves and a life of 10 years, at an average annual production rate of 70,200 t of copper;
- Capital costs and operating costs are derived from "rules of thumb" (Rudenno 2009)
  - Capital costs are calculated on the basis of $1300 per t of Cu produced;
  - Operating costs are calculated on the basis of $\$80*(1)^{0.6}$ per tonne for a mine of 1 million tpa and adjusted downwards for larger mines and upwards for smaller mines
- The model assumes a 2-year construction period with capital costs split evenly between the 2 years;
- Reclamation costs are $45 million dollars and paid at the end of year 2, prior to production (in the form of a bond or other security). Forty per cent of the reclamation costs represent a store and release cover at a cost of $8 per m^2 for 2.25 million m^2.
- The climate change scenario assumes that the store and release cover would need to be replaced by a polysynthetic cover at a cost of $35 per m^2, also paid at the end of year 2.
- The model assumes a tax rate of 25%, an average copper price of $4,500 per tonne and a discount rate of 10%.

Overview of results
A summary of the results is provided in Table 4 below:

Table 4: Impacts of climate change adaptation costs on NPV for hypothetical copper mine

	Base (Medium) Sized Copper Mine	Small Copper Mine Case	Large Copper Mine Case
Base Scenario (no climate change) NPV	$388.6 Million	$185.4 Million	$797 Million
Climate Change Adaptation Scenario NPV	$333.3 Million	$157.7 Million	$686.3 Million
Difference	$55.3 Million	$27.7 Million	$110.7 Million
% NPV Erosion from Climate Change Adaption	14.2%	14.9%	13.9%

The analysis indicates the following:

- The need to account for climate change impacts alone (by setting aside a higher level of funds for a more costly cover design at reclamation) would not make any of the mine size scenarios uneconomical. In all cases, NPV remains positive.
- Nevertheless, differences between the base and the climate change adaptation scenarios in all cases are significant – with NPV erosion ranging from 13.9% to 14.9%. **These would represent significant financial impacts to any mine developer.**
- The percentage difference in NPV erosion is slightly greater for smaller mines and slightly smaller for larger mines. This would be expected given the greater economies of scale that tend to exist for larger mines, all other factors being equal.

- The model assumes that climate change costs are absorbed within closure costs that are set aside prior to production, as is the norm in the Canadian context. The model would yield different results should these costs not be set aside prior to production and if any failure to properly plan for closure leads to tailings spills or other environmental impacts. Such impacts could lead to additional costs – clean up, liabilities, etc. – that would likely be borne by the mine owner, or in some cases (e.g. where the mine owner no longer exists) by the Crown.

A similar analysis for conducted for scenarios involving extreme weather events forcing several temporary shut-downs and the modification to the mine to address the problem and avoid a re-occurrence. The results are presented in Stratos (2011).

Conclusions

Mining companies and regulators are encouraged to incorporate the potential impacts of climate change on their designs and requirements related to ARD. Based on this assessment, reclamation cover design is a priority risk area with potentially significant impacts on closure costs. Water management during extreme precipitation events (in both operation and closure phases) is also an area of risk, based on the potential for shutdowns (loss of production) and/or emergency releases.

To better understand and quantify the potential impacts for a specific mining operation, these risks should be explored using appropriate risk management and financial analysis tools with mine-specific technical and financial information and regional-scale climate change projections. ARD-related infrastructure can then be adapted pro-actively where it matters most in terms of the financial performance of the mine, protecting the environment, and minimizing future liabilities.

Many organizations may postpone action to adapt their businesses and management activities to the changing climate because of uncertainties about future climatic conditions. However, planning horizons for mine closure align with (or go beyond) the 2050s time horizon for which modelled results are not very divergent – that is, different scenarios and models project similar results for this time horizon (Bruce, 2011). It is hoped that the risk areas highlighted in this assessment, when examined in a mine specific context with regional climate change projections, will assist in demystifying potential climate change impacts to permit initiation of pro-active adaptation measures.

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