Economic impacts of a changing climate on mine sites in Canada:

Assessing proactive adaptation investments against estimated reactive costs

30 June 2015

Produced through the Adaptation Platform’s Mining Working Group, with support from Natural Resources Canada
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Executive Summary
Executive Summary

Introduction

The key messages found in the 2014 Fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) are as follows:

- Human influence on the climate system is clear;
- The more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts; and,
- We have the means to limit climate change and build a more prosperous, sustainable future.¹

The 2014 Global Risk Survey, released each year by the World Economic Forum, includes extreme weather events and climate change as two of its top five global risks in terms of likelihood, and climate change and water crisis as two of the top five global risks in terms of impact.

This project studies the economic impact of climate change on mining operations, transportation and reclamation in Ontario and Quebec. Climate change impacts involve both sudden events (e.g., from extreme weather) and longer term environmental shocks such as melting permafrost, change in biodiversity, rise in temperatures and change in rainfall patterns. The study forecasts the economic costs associated with improving the climate change resiliency of mine operations and in closure plans, as well as the costs of responding to impacts when they occur. An economic modelling tool was developed to calculate the net present value of investing in adaptation measures today, versus responding to impacts when their full effect becomes known.

In collaboration with the Adaptation Platform’s Mining Working Group, with the support of Natural Resources Canada (NRCan), Ernst & Young LLP (EY) created a modelling tool to assist business analysts and decision-makers in Canada’s mining industry forecast the estimated economic costs of climate change risks at the specific-site level, and potential investments in risk mitigating adaptation measures. The Economic Model for Mining Investment Scenarios (EMMIS) helps decision-makers prioritize those sites operating in Canada that will be most impacted by climate change, and identify the potential investments for mitigation against expected future damage. The modelling tool works by calculating the cost-benefit of investing in protective measures against each climate risk, versus a “do nothing” scenario in which repair and remediation costs are incurred should a projected weather event and related damage transpire. The result allows decision-makers to compare “climate change-adjusted” costs under a business as usual scenario to those associated with a climate change resiliency strategy.

Research methodology

In-person workshops were conducted at four mine sites located in Quebec and Ontario to obtain input data to test the functionality and decision-making capability of EMMIS. EY facilitators walked the workshop participants through a prepared list of climate change risks to identify those most relevant to the case study sites based on the perspectives and experience of relevant site personnel, and to identify risks missing from the prepared list. During the workshops, site personnel estimated the costs associated with each risk, developed options for mitigating risks, and estimated the costs associated with each option. The sites shared capital expenditure, operating costs and cash flows in order that EY could calculate the cost-benefit of the potential investments.

The sample risk, investment and cost data from each of the four case studies were input into the economic modelling tool under high, medium and low emissions scenarios to identify the point at which there is a business case for investing in adaptation measures at certain sites.

Mining in Canada under a changing climate

According to the IPCC's Fifth Assessment report, released in 2014: “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.”

Understanding these changes in weather patterns, and the associated impacts on corporate financial performance, is one of most challenging components of a valuation assessment for both corporate decision makers, and their investors.

A useful assessment of climate change impacts, costs and investments in resiliency requires global weather projections to be analyzed in the context of local weather patterns to help project the likelihood of expected impacts from climate change. Since 1948, Canada has experienced an average temperature increase of 1.3°C. This warming rate is approximately twice the global average. Similarly, national trends in precipitation indicate that mean precipitation has increased by 12% since 1950, translating to approximately 20 additional days with rain. These patterns are expected to continue into the future, with more frequent and severe precipitation events projected for most regions in Canada by 2050. Changes in temperature, rainfall and extreme weather events associated with climate change will have important consequences for mining companies operating across Canada. Specifically, changes in mean and maximum annual precipitation levels will pose important physical and operational risks to mine sites.

These risks cannot be viewed in isolation, as the occurrence of one event may increase the likelihood or impact of another or the likelihood of more than one event occurring simultaneously. The image below demonstrates the interaction between global, macro risks and site-specific risks. Understanding the relationship between them can help corporate risk managers and decision-makers develop likelihood / impact scenarios on the most impactful risks to them, and better predict the point in which any one risk becomes more likely to occur. The challenge with planning for such risks, and potential investments to

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enhance resilience against such risks, is that the impacts of these global, macro risks are not yet known.

Interactions between macro and micro risks

Source: EY, 2014 (Adapted from Global Risks 2014, WEF)

Research study limitations

Comprehensive simulation data and accurate inputs from sites are required for EMMIS to generate reliable investment consideration results. In building EMMIS and working with the case study sites, the following limitations were observed. These limitations can be addressed through robust preparation for individual site analysis.

- Limited number of simulation runs;
- Unreliable data for each of the mine site case studies;
- Data presented was not confirmed through engineering specifications or scientific projections;
- Simulation data was limited to temperature, precipitation, snow and wind; other factors such as lightning are not included in the current version of the model;
- Site risks were identified based on historical information; and,
- Adaptation investment costs are assumed to be incurred by one site rather than shared amongst multiple parties or sites.
Findings and recommendations

Mining sector professionals are increasingly accepting that the climate is changing. How this change will impact their specific site operations and surrounding regions, and when, is less clear. This lack of clarity renders the risks difficult to address. A key component of assessing the impact of climate change entails identifying ‘time of emergence’ signals for climate change impacts. This resonated with site professionals during our workshops, who want to understand how they can identify the early warning signs of these risks. Research to date is fairly confident on what the weather will look like in 2050 and 2100, but not how the incrementally changing weather patterns will impact us in the interim as we transition to the scenario timeframe. For example, a site with deep permafrost may have no permafrost in 2100; what year between now and then will it experience the tipping point of the decline?

In the absence of such early warning signals, the simulation data available through Environment Canada, based on IPCC future emissions scenarios, is an extremely helpful input in investment decision-making models. As noted in Section 3.11, however, the data is still limited. More comprehensive data will improve the accuracy and reliability of results. The data that exists today could feasibly be run thousands of time for a particular region to obtain the number of simulations required to improve the model. This, however, is resource intense in terms of both time and money, and is unlikely to be undertaken by any one site. Collaboration with governments, civil society and industry peers, will help to overcome this challenge.

Observations through the four case studies indicated that no one site is adequately prepared for the possibility of a range of weather-related impacts. This varied across regions, however, with the northern sites located in Ontario and Quebec more active in developing resilience to climate change than those along Central Canada’s southern borders. As the northern sites are already experiencing climate change, this makes sense. The southern sites may actually be at greater risk due to their lack of preparedness, although this will depend on how quickly and forcefully impacts occur.

In the case of all four sites, closure or restoration scenarios that are “active” i.e., that require continuous human intervention such as ongoing maintenance of a water management and treatment plant in order to avoid environmental damage, are not appropriate for a changing and uncertain climate. It is evident, albeit based on a limited sample, that restoration asset retirement obligations (AROs) are not taking into account the full life of the mine. Remediation plans were similarly inconsistent and unlikely to cover the full costs that will be required. Where remediation costs are prohibitive, sites will remain open in perpetuity, which may place governments and banks (to the extent that banks are on the hook for the securitized loans) at risk should companies dissolve before remediation takes place. This situation will occur at the point in which it becomes economically expedient to dissolve the entire company rather than continue care and maintenance on some sites within a profitable portfolio of operational sites.

At the site level, the analysis indicates that northern sites are likely to benefit from a review and possible redesign of water management systems to mitigate the risk of excessive snowmelt. The assessment suggests that this type of investment is not yet required for sites located along the southern borders of Central Canada, although ongoing monitoring of temperature and precipitation to identify changes in weather patterns, which may trigger a different investment decision is warranted.
All sites studied should also regularly review tailing ponds capacity in the context of changing weather to identify the point at which an investment to take remedial measures may be warranted.

Although the model resulted in a positive net present value (NPV) for many of the investments in the average simulation run, for most of the options, the lowest result was negative. This negative result, even if it’s less likely to occur, indicates that these investments are risky in that there is a chance the sites could lose money. The better investment choices are the ones that result in a zero or positive NPV in all scenarios. At some sites, none of the investment options had a positive NPV for all scenarios, which is what a decision-maker would prefer in going forward on an investment. The upside would have to be extremely compelling to warrant the risk of making an investment with the potential for loss. For other sites, positive NPV for all scenarios was observed. These investments are as follows:

- Increasing tailing pond capacity;
- Designing new water management systems; and,
- Installing dust barriers and spraying sealant.

The sites with a negative NPV on the investment options listed above, even if only in the highest cost-benefit result scenario, may determine that the prudent path forward is to delay the investment and continue to monitor weather for indications of changing patterns. The need for continuous monitoring further emphasizes the utility of a set of indicators of 'emerging risks' that can serve as signals for climate change impacts, and trigger a re-evaluation of investment options. As climate change impact and cost data becomes more reliable, mining company decision-makers will be able to make more informed investment decisions.

The results demonstrate the necessity of managing weather-related events associated with climate change risk, including proactive investment in climate change adaptation strategies, at the regional level. This regional focus, however, presents a challenge when considering the magnitude, complexity and global relevance of such an enormous risk with still nebulous impacts.
Introduction
1. Introduction

1.1 Background

The key messages found in the 2014 fifth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) are as follows:

► Human influence on the climate system is clear;
► The more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts; and,
► We have the means to limit climate change and build a more prosperous, sustainable future.

The 2014 Global Risk Survey, released each year by the World Economic Forum, includes extreme weather events and climate change as two of its top five global risks in terms of likelihood, and climate change and water crisis as two of the top five global risks in terms of impact.

As a result of the global acceptance of climate change science, leaders from government, business, civil society and research are actively considering how these changes will impact our geographical landscape and economic prosperity. Research and analysis to assess the economic impacts of climate change risks to business have prioritized those industries that are most vulnerable to severe and changing weather.

The challenge with assessing climate change risks at an industry level is that the impacts will not be uniformly felt across all regions in which the industry operates. This is a particular challenge for extractives industries, including mining. Mining is a vital industry to Canada’s economy, which makes understanding the economic costs associated with climate change to mining a priority for industry leaders and governments alike.

In a country as vast as Canada, assessing the economic costs of climate change, and developing strategies to mitigate those costs, requires a regional approach. Temperature increases during winter months are projected to be most pronounced, for example, in northern Ontario and Quebec, whereas the southern border of these provinces will experience larger temperature increases in summer. Precipitation is projected to increase significantly in the northern regions of Ontario and Quebec in the summer and decrease along the southern half of the Ontario border. Across Canada it is likely that an increased percentage of total annual precipitation will fall as rain rather than snow, and the literature indicates that there will be an increase in extreme 24-hour precipitation events.

Understanding the extent to which the mining sector is sensitive to these projections will help the industry develop strategies to become more resilient. The return on investment (ROI) to companies from climate change adaptation investments is difficult to measure, due to the uncertainties around the timing, magnitude and level of impact of climatic events, and climate simulation data. Tackling these challenges to identify the most economically expedient i.e., positive net present value (NPV) adaptation investments based on projected costs of impacts will help mining companies protect their substantial assets and surrounding environment.

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1.2 Project overview

This project studies the economic impact of climate change on mining operations, transportation and reclamation in Ontario and Quebec. The impact of adapting to climate change involves both sudden events (e.g., from extreme weather) as well as longer term impacts such as melting permafrost, change in biodiversity, rise in temperatures and change in rainfall patterns. The study forecasts the economic costs associated with improving the resiliency of mine operations and in closure plans, as well as the costs of responding to impacts when they occur. An economic modelling tool was developed to calculate the net present value of investing in adaptation measures today, versus responding to impacts when their full effect becomes known.

Project objective

In collaboration with Natural Resources Canada (NRCan), Ernst & Young LLP (EY) created a modelling tool to assist business analysts and decision-makers in Canada’s mining industry to forecast the estimated economic costs of climate change risks at the specific-site level, and potential investments in risk mitigation adaptation measures. The Economic Model for Mining Investment Scenarios (EMMIS) helps decision-makers prioritize those sites operating in Canada that will be most impacted by climate change, and identify the potential investments for mitigating the risk of future damage. The modelling tool works by calculating the cost-benefit of investing in protective measures against each climate risk, versus a “do nothing” scenario in which repair and remediation costs are incurred in the case that a projected weather event and related damage transpire. The result allows decision-makers to compare “climate change-adjusted” costs under a business as usual scenario to those associated with a climate change resiliency strategy.

The modelling tool is flexible to accommodate mine-specific risks and costs, and scalable to allow for variability in the size and number of sites. Excel is used to store variable user inputs, perform calculations and summarize results, which makes the tool easy to use by offering a familiar user experience. A Microsoft SQL Server database is used as a data repository to accommodate the large quantity of simulation data from the Representative Concentration Pathways (RCP) scenarios. The tool is pre-populated with SQL queries to determine the relevant data to be loaded into Excel, and focuses only on measurements that would trigger climatic events. This structure ensures minimal input time at the site level as the functions are ready to calculate cost-benefit ratios based on user-specific data such as the mine’s risks and their associated costs.
1.3 Project methodology

As depicted in Figure 1.1, we have undertaken three key steps to conduct our research study.

Figure 1.1: Research study

In-person workshops were conducted at four mine sites located in northern Quebec and Ontario to obtain input data to test the functionality and decision-making capability of EMMIS. EY facilitators walked the workshop participants through a prepared list of climate change risks to identify those most relevant to the case study sites based on the perspectives and experience of relevant site personnel, and to identify risks missing from the prepared list. During the workshops, site personnel estimated the costs associated with each risk, developed options for risk mitigation measures, and estimated the costs associated with each measure. Capital expenditure, operating costs and cash flows for each site were shared with EY to calculate the cost-benefit of the potential investments. A list of the professionals (based on position within the company) who participated in each of the four workshops is provided in Appendix B.

The sample risk, investment and cost data from each of the four case studies were input into the economic modelling tool (EMMIS, described above) under high, medium and low RCP scenarios to identify the point at which there is a business case for investing in adaptation measures at the site level. The tool assumes greenhouse gas levels according to an IPCC Special Report: Emission Scenarios (SRES), described in Table 1.1.
Table 1.1: IPCC Climate Change scenarios

<table>
<thead>
<tr>
<th>SRES</th>
<th>Description</th>
<th>Average temperature increase by 2100</th>
</tr>
</thead>
</table>
| B1   | Convergent world  
* Global population that peaks in mid-century and declines thereafter  
* Rapid changes in economic structures toward a service and information economy, with reductions in material intensity  
* Global solutions to economic, social, and environmental sustainability, including improved equity, but without additional climate initiatives  
* Introduction of clean and resource-efficient technologies | +1.98°C |
| A1B  | Future world of very rapid economic growth  
* Global population peaks in mid-century and declines thereafter  
* Rapid introduction of new and more efficient technologies  
* Substantial reduction in regional differences in per capita income through convergence among regions, capacity building, and increased cultural and social interactions  
* Balanced use of fossil and non-fossil energy sources | +2.95°C |
| A2   | Heterogeneous world  
* Fertility patterns across regions converge very slowly, which results in continuously increasing global population  
* Economic development is primarily regionally oriented and per capita economic growth  
* The underlying theme is self-reliance and preservation of local identities  
* Technological change is fragmented and slow | +3.79°C |

Source: IPCC

EMMIS incorporates Representative Concentration Pathways (RCPs), which are four greenhouse gas concentration trajectories adopted by the IPCC for its fifth Assessment Report (AR5), superseding the Special Report on Emissions Scenarios. RCPs are produced through a collaborative scientific effort that, by referencing IPCC future greenhouse gas policy scenarios to take into account various levels of climate change mitigation, estimates the effect on the climate system, including interactions between atmosphere, biosphere, ice circle and ocean (Figure 1.2).

Figure 1.2: General Circulation Model (CGM) interactions

RCPs begin in year 2006 and continue through the end of year 2300. The RCPs are labeled according to the approximate target radiative forcing at year ~2100 (i.e., the change in energy in the atmosphere due to GHG emissions by year 2100). Further information on the use of RCP data is available on Environment Canada’s website (www.ec.gc.ca).

The extent to which regions across North America will experience climate change impacts depends upon the IPCC scenario under which we continue to develop our industries and societies. As some sites are already experiencing the effects of climate change, the analysis assumes that climate change risks will occur even under a low emission scenario (RCP 2.6).

In partnership with the Dr. Rebecca Zhang, postdoctoral researcher who is developing climate change indexes at the University of Toronto, EY obtained 100 years of daily results from five simulation runs across three RCP scenarios, for each of the four mining locations in this study, encompassing 60 data sets in total. Using these simulations as hypothetical outcomes, EMMIS calculated the cost-benefit of investing in protection against each risk.

EMMIS uses the output data from RCP 2.6, RCP 4.5, RCP 8.5, which represent a range from low to medium and high emission scenarios, respectively.

1.3.1 Overview of the Economic Model for Mining Investment Scenarios

EMMIS is an enhanced Microsoft Excel tool with an adjunct Microsoft SQL Server database that serves as a data repository. SQL queries determine the relevant data to be loaded into Excel, focusing only on measurements that would trigger climatic events. Using information from the mine site workshops, thresholds were determined for the levels of precipitation, wind, snow and temperature that would cause damage to mine site infrastructure, or result in interruptions to operations. Where such data was unavailable, thresholds were estimated based on publicly available research. Further data obtained at each site was as follows:

- Cost of damage associated with each risk;
- Preferred interest rate for time-value of money;
- The time of the investment;
- The mine lifespan; and,
- The timeline for maintenance costs.

Once the data is input (Figure 1.3), the tool uses the RCP simulation data to calculate the worst, average and best case scenarios for cost savings based on the climatic conditions specified by the RCP simulation outcomes (see Section 1.3.2 for further detail).
A complete description of the methodology to assess the cost-benefit of investments in adaptation measures is provided in Appendix A.

1.3.2 Scope of study

The study focused on building a tool that can be used at the site level to accommodate the variances between sites, such as the operational stage of site, type of mine and location. Seven risks were identified through site workshops for input to demonstrate the tool. These risks can be expanded as required by individual sites. The seven risks selected for demonstration purposes are as follows:

Operations and reclamation:
- Tailing pond overflow;
- Dyke rupture;
- Damage to water management system;
- Permafrost degradation;
- Dust pollution; and
- Power outage.

Transportation
- Road closure

EMMIS models the likelihood of events that increase the risk of the impacts listed above. The specific events modelled are outlined below in Table 1.2 along with the resulting impacts.
Table 1.2: Climate change events and associated impacts

<table>
<thead>
<tr>
<th>Impact</th>
<th>Event</th>
<th>Adaptation measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tailing pond overflow</td>
<td>Snowmelt, Heavy rains, Permafrost degradation</td>
<td>Increase tailings pond capacity</td>
</tr>
<tr>
<td>Damage to water management system</td>
<td>Snowmelt, Heavy rains, Permafrost degradation</td>
<td>Water management system redesign, Revise tailing pond overflows</td>
</tr>
<tr>
<td>Permafrost degradation</td>
<td># of days above freezing (0°C)</td>
<td>Increase tailings pond capacity</td>
</tr>
<tr>
<td>Dust pollution</td>
<td>High winds and extreme, dry temperatures (site specific), High winds and low temperatures (site specific)</td>
<td>Spray sealant, Install dust barriers</td>
</tr>
<tr>
<td>Power outage</td>
<td>Fire, Wind, Ice, Lightning</td>
<td>Brush under power lines, Install fire barriers, Stock up on diesel, propane and food</td>
</tr>
<tr>
<td>Road closure</td>
<td>Heavy precipitation</td>
<td>Staff training, shift planning, partnership with government to reduce local road closure impacts, Increase inventory of chemicals</td>
</tr>
</tbody>
</table>

The interdependency of identified risks were also considered i.e., how the realization of one risk impacts the likelihood of another. The user stipulates a trigger level (level of climatic event that results in infrastructure damage or interruption to operations) in EMMIS along with a secondary trigger level to account for risks that result from a combination of two environmental factors. For example, high wind may cause a tailings pond overflow with less precipitation than normal (as the wind creates waves). Please see Appendix A for further detail on the calculation methodology.

Section 2.3 describes risk management frameworks for climate change risks, including identifying and managing the interconnectedness of such risks. Please see Appendix B for the risk registers that were developed with each of the case study sites. Findings from the economic assessment of potential investments to mitigate these risks are described in Section 3.

The reputational impact that a climate-related catastrophic release of toxic material into the environment can have on a site’s local license to operate and, potentially, share price was not included in the scope of this study. Consideration of reputational impacts in the investment assessment requires a detailed quantitative analysis of various scenarios for context (e.g., shareholder base), extent of damage (e.g., high profile, noncompliance with legislation, etc.) and existing circumstances in surrounding communities (e.g., isolated / populated). These are inputs that can be incorporated in EMMIS in future assessments. The plethora of examples in the mining sector of the financial consequences associated with reputational damage demonstrates that incorporating such a risk into
the assessment is a worthy exercise. It also leads to significant uncertainties as the forecasted extent of the damage is highly sensitive to a number of varying assumptions.

Estimated costs associated with environmental transgressions on the part of mining companies can be considered as proxies in future assessments of climate change-related damages to mine sites. Although many of the environmental disasters, such as crumbling tailing pond dams, are not specifically related to climate change, it is likely that more severe weather patterns will exacerbate the negative impacts of existing weak mine infrastructure i.e., the risk of environmental damage resulting from improper maintenance will increase as the effects of climate change become more frequent. Estimating the impact on share price from an environmental disaster will depend on the company being assessed: The more significant the project is to the company’s overall production volumes and corresponding revenues, the greater the likely impact on share price should the project be delayed or cancelled due to environmental concerns.

The extent to which the company engages with surrounding communities and the level of “goodwill” in the community are also key factors when estimating the impact to share price of a potential disaster. A 2011 study by Witold Henisz at the Wharton Business School entitled Spinning Gold: The Financial Returns to External Stakeholder Engagement found that gold miners trade at an average discount of 72% to their actual value, and that almost 83% of the discount can be explained by low levels of stakeholder engagement.

Contributors to the study
This study would not be possible without the input from four mine sites (Appendix B), and the contributions of the people listed below, who provided valuable insights in the following areas:

- **RCP simulation data:**
  Rebecca Zhang, Ph. D, Postdoctoral researcher, University of Toronto, Department of Geography

- **Research and model review (Graduate students, University of Toronto):**
  Simeran Bachra
  Fariha Husain
  Megan McQuillan
  Lu Zheng, P.Eng.
Mining in Canada under a changing climate
2. Mining in Canada under a changing climate

2.1 Global Climate Change

According to the IPCC’s Fifth Assessment report, released in 2014: “Warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and oceans have warmed, the amounts of snow and ice have diminished, sea level has risen, and the concentrations of greenhouse gases have increased.”

Understanding these changes in weather patterns, and the associated impacts on corporate financial performance, is one of most challenging components of a valuation assessment for both corporate decision makers, and their investors.

The first step in the assessment is to understand how temperature is changing globally. Observed changes in global mean temperature are presented in Figure 2.1 below, alongside projected changes under a low emission scenario (RCP 2.6) and high emission scenario (RCP 8.5).

Figure 2.1: Observed and projected temperature changes globally


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6 RCP scenarios are described in Section 1.4: Methodology, above.
The projected weather-related changes are further broken out in Figure 2.2, which depicts average surface temperature, precipitation and sea level globally under the low and high emissions scenarios between 2081 – 2100, relative to 1986 – 2005.

Climate-related risks associated with these projected temperature changes, as identified by the IPCC, are presented on a global scale in Figure 2.3.

![Figure 2.3: Risks associated with temperature increases](image)

Source (2.2 and 2.3): IPCC (2014) Synthesis Report

While there is greater acceptance today on the validity of climatic research and outcomes, uncertainty on how changing weather will impact corporate financial performance remains. Generic impacts applied globally provide limited insight on the level of risk each impact has at the site level, and the timing in which the risk will occur. Such an assessment depends on the nature of the operations, surrounding infrastructure, socio-economic factors within the surrounding communities, and climatic conditions of the specific region in which the site operates.
2.2 Climate change impacts on Canadian mine sites

The Canadian landscape is suffused with mine sites (Figure 2.4), which makes changes in aspects that impact mining, such as laws, regulations and physical weather, a key risk for the sector.

Figure 2.4: Overview of mining in Canada


Operations in Canada's northern regions are vulnerable to a changing climate due largely to the remote and harsh conditions of many mine sites, large capital infrastructure and a lack of redundant transportation and energy systems. In the current economic climate, however, corporate profits that are already strained by low commodity prices and increasing operating costs leave little funds available for capital expenditures, including investments in adapting to climate change. Mining executives have available to them a body of knowledge that identifies the vulnerabilities and threats of climate change, but are hesitant to act as there is little analysis on the economic costs of adaptation and the value of acting now versus waiting until the impact occurs.

The severity of climate change risks to mine sites is driven by three factors: The impact on the natural environment, built assets surrounding the mine, and the type of mine e.g., minerals extracted, operational design, supply chain, etc. There is not, therefore, one "climate change solution" to fit all mines. Further exacerbating the problem is a lack of available scenarios for the particular challenges companies will face when extreme weather events start to escalate or the early warning signals that indicate escalation has begun.
A useful assessment of climate change impacts, costs and investments in resiliency requires global weather projections to be analyzed in the context of local weather patterns to help project the likelihood of expected impacts from climate change. Since 1948, Canada has experienced an average temperature increase of 1.3°C. This warming rate is approximately twice the global average. Similarly, national trends in precipitation indicate that mean precipitation has increased by 12% since 1950, translating to approximately 20 additional days with rain. These patterns are expected to continue into the future, with more frequent and severe precipitation events projected for most regions in Canada by 2050. Changes in temperature, rainfall and extreme weather events associated with climate change will have important consequences for mining companies operating across Canada. Specifically, changes in mean and maximum annual precipitation levels will pose important physical and operational risks to mine sites.

Examining extreme precipitation events from 1950 – 2010 across Canada has enabled NRCAN to observe whether extreme weather event-related trends are increasing or decreasing, and where such changes are occurring (Figure 2.5). Such research can help companies plan for weather-related losses. The insurance industry, for example, views sanitary and surface water systems as vulnerable under increasing levels of precipitation, and insurance companies are responding to increased precipitation projections with higher premiums, greater deductibles and product changes to help reduce the economic impact of climate change.

Figure 2.5: Trends in extreme precipitation from 1950 – 2010 (relative to 1961 – 1990).

Source:

Assessing temperature and precipitation trends, and the potential correlation between the two, can help analysts estimate the likelihood of increased precipitation events based on projected temperature increases under various emissions scenarios.

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7 NRCan: An Overview of Canada’s Changing Climate
Figure 2.6 depicts a multi-model mean projected temperature and precipitation data on an annual timescale for two of the four sites that served as case studies. The annual values of temperature and precipitation, using the high (A2), medium (A1B) and low (B1) IPCC scenarios for the sites were plotted using values obtained from the Canadian Climate Data and Scenarios website\(^8\), which uses the NCARPCM – Mean model to generate mean air temperature and total precipitation data for 2001 – 2100, using 20 year averages. Results indicate that, over an extended time period, both the mean air temperature and total precipitation will increase at both of the case study sites, but not in the same way. The impact on air temperature and precipitation will vary depending on geographical differences such as an average annual temperature of \(-14^\circ \text{C}\) at Site 3 versus \(-1^\circ \text{C}\) at Site 1 (based on the past 40 years of available data).

Site 3 will experience a 19% greater increase in air temperature and a 62.5% greater increase in precipitation compared to Site 1.

Figure 2.6: Temperature and precipitation trends for two different sites in Quebec under the three IPCC emissions scenarios.

\(^8\) [http://ccds-dscc.ec.gc.ca/?page=viz-timeseries](http://ccds-dscc.ec.gc.ca/?page=viz-timeseries) Data points are a result of averaging annual average temperature and precipitation data for a period of 20 years across all available data points (1960 – 2100).
The trending observed does not necessarily indicate a correlation between precipitation and temperature increases, although it is evident that Canada has experienced increases in both, as described above. Regular monitoring of temperature and precipitation, and identifying the early warning signals of future risks can help site managers anticipate risks and adjust risk mitigation strategies accordingly (see Box 2.1 below for a case study assessment of the 1996 Saguenay Flood).

**Box 2.1: How likely is an extreme event to occur?**

The 1996 Saguenay Flood occurring from July 18 to 21 caused $1.7 billion in losses to the province of Quebec. At least one operational mine was impacted by the floods, although the physical and operational damages sustained by the mine are undisclosed. A number of studies have since examined the likelihood that such an event, characterized by an unprecedented amount of precipitation in a 48-hour period, will recur in Quebec. Environment Canada has reported that 24- and 48-hour extreme rainfall accumulation events have a recurrence interval of 100 years at weather stations located in Saguenay, Charlevoix, Laurentides Park, Upper North Shore, and Lower St. Lawrence regions, although some regions may experience a 24-hour heavy rainfall recurrence interval of 50 years.

Three meteorological factors that were seen across 11 of the most severe storms were reviewed. The first factor identified is the presence of a steady mixture of warm, moist air from the Southern U.S., Gulf of Mexico, and the Antilles. Second, the report identifies the transportation, lifting, and rapid condensation of this warm air, usually caused by a low-pressure system. The final factor common to the most severe storms was the presence of a blocking mechanism that slows, stalls, or diverts the path of the low-pressure system and pushes it to precipitate over a small area. The report also identifies that topography plays an important role on rainfall. Areas in which slopes occur in the topography of the land are exposed to prevailing winds, which causes rainfall to become heavier in the area. If these meteorological events occur simultaneously in a susceptible region then the precipitation event could be “exceptional.”


Projections of temperature and precipitation trends are becoming increasingly localized, allowing for more robust monitoring at the site level. Figure 2.7 depicts NRCan’s estimated temperature increases for Northern Quebec, relative to 1960 – 1981.

**Figure 2.7 Projected mean temperature in Northern Quebec (NCARPCM)**
Insurance companies, which serve as a benchmark for weather-related risks, are adjusting their models to account for increasing trends in extreme weather events. According to the Insurance Bureau of Canada, in 2012 insurance agencies paid out approximately $1.19 billion in claims for severe weather events in Canada.\(^9\) There has been a 20-fold increase in the value of claims related to disasters since the 1970s. It is estimated that this number increased to $3.2 billion in 2013 due to ice storms and flooding in that year.\(^10\) These large payouts have prompted the insurance industry to re-evaluate their policies and consider how to best manage future potential risks posed by climate change. In the last three decades the number of weather-related loss events has increased five-fold in North America, compared to a two-fold increase in Europe and four-fold increase in Asia.\(^11\) It is widely accepted by the industry that climate change is occurring and there will be an increase in the frequency of extreme weather events. Insurance companies are likely to change their policies to account for patterns of rising temperatures and extreme precipitation events.

To manage uninsurable risks, companies are increasingly relying on self-insurance as a method of managing risk by setting aside money to be used if an unexpected loss occurs. If corporate decision-makers know that they are likely to suffer a loss, they may make use of self-insurance to avoid paying high premiums to a third party insurance company, often in conjunction with a commercial insurance policy to manage larger losses. The need for alternatives to insurance is steadily increasing: In 2011, wind and thunderstorm events cost the insurance industry $340 million across Ontario, Quebec and New Brunswick.\(^12\) In Quebec alone, the Insurance Bureau of Canada forecasts that, by 2050:

- The number of hot days per summer (currently approximately 8 days) will increase by an approximate 60%.
- One in 20-year heavy precipitation events will become more frequent, and are projected to become one in 10-year events.
- Projections for the Ottawa-Montreal-Quebec City regions show a 50% increase in the number of freezing rain events of more than four hours. Events of more than six hours are projected to increase by close to 80%.

These changes are expected to result in:

- More claims due to more severe weather more frequently;
- Mid-to long-term potential issues of availability and affordability of insurance;
- Infrastructure investment (most of Canada’s infrastructure is designed for the “extremes” of the past); and,
- A need for the industry to look to the future and re-evaluate the risk e.g., Yesterday’s 1 in 40 year event could be today’s 1 in 6 event.

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2.3 Managing climate risk: An integrated approach

Risk assessment is a process for understanding the impact of various interdependent forces and assessing their potential consequences and likelihoods. Identifying a risk primarily entails the following three considerations: What can go wrong? What is the likelihood of it occurring? What are the consequences?

Risks cannot be viewed in isolation, as the occurrence of one event may increase the likelihood or impact of another or the likelihood of more than one event occurring simultaneously. Figure 2.8 shows a sample of interdependencies of the top global risks, and their interactions with climate change.

Figure 2.8: Global Risks 2014 Interconnections Map
Figure 2.9 demonstrates the interaction between global, macro risks and site-specific risks. Understanding the relationship between them can help corporate risk managers and decision-makers develop likelihood / impact scenarios on the most impactful risks to them, and better predict the point in which any one risk becomes more likely to occur. The challenge with planning for such risks, and potential investments to enhance resilience against such risks, is that the impacts of these global, macro risks are not yet known. Should an impact of a particular global risk become known, its influence on probability and, potentially, cost inputs, can then be modelled to assess how such a risk may translate into local events.

Figure 2.9: Interactions between macro and micro risks

Source: EY, 2014 (Adapted from Global Risks 2014, WEF)

Interpreting the impact of global events on site-level performance is an exercise that can be undertaken through a collaborative effort between sites either within one province, or throughout Canada. A statistical approach that provides for interdependency can be used to determine the quantifiable impact of climate risks to mining operations in a specific region. Examples of assessment models are provided in Box 2.2.
To appreciate how interdependencies can lead to unforeseen impacts, the International Risk Governance Council (IRGC) created a Risk Governance Framework. The Framework integrates scientific, economic, social and cultural aspects, and includes the engagement of stakeholders (see Figure 2.10). This framework considers the different roles of a range of players in coordinating and taking responsibility for certain risks. It allows for an assessment and risk management plan that accounts for not only the mine site and company, but also governments, nongovernmental organizations (NGOs), businesses and society as a whole. Communication is critical to this framework, ensuring that all players have the same understanding of the risks that affect their environment.

Firms are typically much more aware than they were even a few years ago of how interdependencies can lead to shocks affecting them in unexpected ways. For instance, historically a crisis befalling a competitor might have been regarded principally as an opportunity to gain market share; today, there is an awareness of the possibility of knock-on consequences, such as governments responding with hasty and ill-considered regulatory changes affecting the entire industry. Regulators are as prone as other decision-makers to the bias of placing too much emphasis on recent experiences.\(^{15}\)

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Mining companies with operations in the same regions can benefit from collaboration on reducing risks associated with climatic weather events. As it is still extremely challenging to predict the full impact of a weather event, ensuring cooperation and communication between companies, sites and regional suppliers will help all sites manage these risks. In the longer term, mining companies should consider collaboratively adapting operations, site design, technologies and emergency procedures to help all sites become more resilient against risks posed by climate change.

Figure 2.10: Integrative risk management approach\textsuperscript{16}

\textsuperscript{16} Renn, Ortwin. (2006). Risk Governance Towards an Integrative Approach. (International Risk Governance Council),
Findings
3. Findings

3.1 Findings overview

The primary challenge with developing a climate change risk assessment and mitigation strategy is the collection and analysis of abundant and still nebulous data. Forces such as complexity of climatic models, multiplicity of potential factors influencing similar risks, number of entities affecting resilience (e.g., corporations, ministries, NGOs, cultural biases and the extent to which local, ongoing climatic changes are monitored) all influence the development of an effective investment strategy.

The economic modelling tool created for this assessment (EMMIS) provides users with the opportunity to organize and assess multiple factors influencing the investment decision making, including weather projections, anticipated costs in the event of a weather-related impact occurrence, estimated costs of investments to mitigate the extent of the impact, and the current value of money. In order to achieve a reliable “go / no go” investment decision, the estimates used must be as accurate as possible, which entails consideration of the interdependency of myriad forces such as those listed above.

Data obtained from case study workshops was used to help build the tool. The findings are presented in this section of the report for demonstration purposes. The tool can be customized per site through the input of site-specific estimations on impact thresholds and costs. RCP simulations on precipitation, snow, temperature and wind were selected for demonstration purposes and prepopulated in the tool to estimate the likelihood of risk events. The likelihood of other events, such as lightning, can be assessed through RCP simulation data as well; the tool in its current state is however limited to forecasting the four weather events listed above. Events that were identified by case study participants as a risk, such as lightning, but not prepopulated in the tool through RCP simulation data, were modelled using Monte Carlo simulations. The likelihood of such events will be more accurately modelled, however, using the appropriate RCP data simulations. Based on the information provided by case study participants, impacts of the risks identified i.e., extreme precipitation, snow, temperature and wind (using RCP simulations), as well as lightning (using Monte Carlo) are as follows:

► Tailing pond overflow;
► Dyke rupture;
► Permafrost degradation;
► Dust pollution;
► Power outage; and,
► Road closure.

Impact thresholds, estimated costs and likelihood of impact for each of the listed options were modelled with illustrative site-specific results presented in Figure 3.1 and described below. Cost-benefit results incorporate both the cost of the investment and realized savings based on the probability of the impact occurring.
The model is designed to calculate the NPV of each investment option, presented in thousands of dollars.

Each investment analysis assumes the mine will remain open (operating or care and maintenance) until the year 2100. Of the 15 simulation runs, the lowest and highest cost-benefit NPV results are shown in the “low” and “high” columns, respectively, and the average of all the results is shown in the “average column”.

Figure 3.1: Summary of cost / benefits results for identified climate change adaptation investment options

- Increase tailings ponds' maximum capacity
- Install dust barriers and spray sealant
- Staff training, shift planning & Gov't partnerships
  
  Brushing, emergency equipment storage plans
  Increase inventory max capacity
  Designing new water management systems
3.2 Risk of overflow in tailing ponds

Increasing tailing pond capacity was identified as the primary investment to mitigate the risk of an overflow in tailing ponds. The investment was modelled using the following inputs:

- One-time investment cost of $4M
- Damage cost of $5M per storm
- Threshold of 75mm\(^{17}\) of rain in 24 hours
- Protection probability\(^{18}\) of 75%

This adaptation investment was relevant to three of the four case study sites. Modelling data received from the three sites resulted in the cost-benefit results depicted below.

<table>
<thead>
<tr>
<th>Site</th>
<th>Lowest</th>
<th>Average</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1 - Increase tailing pond capacity to prevent tailing pond overflow</td>
<td>-$639.76</td>
<td>$6,154.52</td>
<td>$16,895.18</td>
</tr>
<tr>
<td>Site 2 - Increase tailing pond capacity to prevent tailing pond overflow</td>
<td>$2,509.21</td>
<td>$14,085.26</td>
<td>$28,311.18</td>
</tr>
<tr>
<td>Site 4 - Increase tailing pond capacity to prevent tailing pond overflow</td>
<td>-$3,960.59</td>
<td>$3,071.86</td>
<td>$14,474.34</td>
</tr>
</tbody>
</table>

The results indicate that Site 2 is the most likely candidate of the four case studies for increasing tailing pond capacity as RCP simulation results determined that Site 2 will have the largest number of severe storms. The greater the number of storms at a particular site, the more times the cost savings is added to the cost-benefit calculation, resulting in the greatest cost-benefit ration on this investment for this site.

The same inputs were used for all 3 sites to demonstrate the variability between sites based on the location-specific weather simulation data. Data provided by Site 1, however, indicated that the site would require 200mm of rain in a 24-hour period to cause a tailing pond overflow. Such a scenario was not observed in even the most severe climate change scenario, RCP 8.5. If the data is correct, an investment case to protect against tailing pond vulnerabilities cannot be made. Sites 2 and 4 did not have estimates on the amount of rainfall that would cause damage, but based on the 75mm tolerance used above, the model indicates that the investment is worth consideration.

Though not included in the data provided by Sites 1, 2 or 4, snowmelt may also factor into the tailing pond capacity, in addition to rainfall. Future use of the model for specific sites may wish to model snowmelt in addition to precipitation.

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\(^{17}\) A 75 mm threshold was selected for this sample as it is the approximate point when the investments shift from negative to positive returns and therefore an ideal input when comparing the value of the investment across sites.

\(^{18}\) Probability that the adaptation measure protects from damage when the storm occurs.
3.3 The risk of dyke rupture

Case study participants identified two potential investments to mitigate dyke rupture. Both were modelled to determine the effectiveness of each potential investment. These investments would be considered to mitigate the risk of a dyke rupture, which would incur a greater financial impact than the overflow discussed in 3.2.

1. Re-channelling tailing pond overflows to better control the movement of contaminated water
2. Implement a complete redesign of the water management system

The following inputs were used:

► Threshold of 100 mm\(^{19}\) of rain in 24 hours
► Cost of $3M for revising overflows, and $150M for system redesign
► Including an additional cost savings of $1M/year for system redesign based on an assumption of operational savings due to improved system
► Damage cost of $75M
► Protection probability of 100% for redesign, 50% for revising overflows channels

The following cost-benefit results comparison for case study site 1 demonstrates that the less expensive upfront investment is a more cost-effective choice.

<table>
<thead>
<tr>
<th></th>
<th>Lowest</th>
<th>Average</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1 - Definite restoration of tailing ponds to prevent dyke rupture</td>
<td>-$109,985.60</td>
<td>-$92,033.15</td>
<td>$7,852.24</td>
</tr>
<tr>
<td>Site 1 - Enhance spillway resilience by revising overflows</td>
<td>-$2,970.44</td>
<td>$3,000.24</td>
<td>$64,405.49</td>
</tr>
</tbody>
</table>

3.4 Risk of damage to water management system

Site 3 was the only site that identified potential damage to the water management system as a potential risk. Of the four sites, Site 3 was the most vulnerable to water system damages from weather-related impacts due to its exposure to permafrost degradation and snowmelt. Redesign of the existing water management system was identified by Site 3 as the primary investment to mitigate this risk. The investment was modelled using the following inputs:

► Tolerance of 150 days with temperature above freezing
► Tolerance of 260mm (water equivalent) of snowfall
► Estimated\(^{20}\) mitigation cost of $9M and damage cost of $1M
► Protection probability of 75%

\(^{19}\) A 100 mm threshold for rain was set to account for the higher level of rain that it would take to rupture a dyke than result in a tailing pond overflow.

\(^{20}\) Estimates are used in the absence of data.
Figure 3.2 demonstrates the increasing risk of permafrost degradation based on number of days above freezing.

Figure 3.2: Number of days above freezing

Redesigning the water management system at this site would mitigate both the risk of permafrost degradation and of heavy snowmelt, both of which would cause tailing pond overflow. The risks were modelled together as they share one cost of an estimated $9 million to redesign the site’s water management system.

Permafrost degradation was modeled as the number of days in a year with an average temperature above freezing. Snowmelt was modeled as the sum of snowfall between December and June.

<table>
<thead>
<tr>
<th></th>
<th>Lowest</th>
<th>Average</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 3 - New water management design to mitigate permafrost degradation</td>
<td>-$5,136.66</td>
<td>$1,041.14</td>
<td>$8,590.23</td>
</tr>
<tr>
<td>Site 3 - New water management design to mitigate excessive snowmelt</td>
<td>$0.00</td>
<td>$2,911.14</td>
<td>$17,476.02</td>
</tr>
</tbody>
</table>

Results demonstrate that redesigning the management system is likely to be a good investment choice for Site 3 to protect against weather-related vulnerabilities in its current system.

3.5 Risk of dust pollution due to high winds

The risk of dust pollution due to high winds was identified by case study participants at Sites 2 and 4, however, the cause of high winds vary between the two sites. At Site 2, the risk of high winds increases with hot weather, while at Site 4, the risk increases with cold. Both sites agree that dry weather conditions exacerbate this risk.

A possible mitigation strategy for both sites is to spray sealant on the tailing ponds and install dust barriers. As dust barriers have already been installed at both sites, only the cost of spraying is included in the model.
This risk was modeled as the number of days the temperature fell within the range specified by the case study participants, when the maximum daily wind speed was also above the threshold specified. As wind speed data at each site was not available, EY ran the model based on a minimum wind speed of 50 km/hr at both sites. Humidity was not included as a factor, although future models may wish to consider adding this simulation data to model that factor as well.

The following inputs were used:

- Yearly mitigation cost of $30K at site 2
- Yearly mitigation cost $15K at site 4
- Minimum wind speed of 50 km/h at both sites
- Maximum temperature of -5 °C at Site 4 and minimum temperature of 20°C at Site 2
- Protection probability of 90% because some wind storms will be too extreme for this mitigation strategy

The results demonstrate that the addition of spray sealant is an unfavourable investment with an assumed wind speed of 50 km/hr. Because actual wind speed data was not available, EY ran the model again to compare the 50 km/hr assumption with a 40 km/hr assumption. In adjusting the model by only 10 km/h, it was noted that the result is highly sensitive to the tolerance level for wind. Using an input of 40 km/h produced a favourable result for the investment, as demonstrated below.

Radically different results from slight adjustments in input values underscore the importance of carefully measured, reliable data for appropriate investment decision-making. Unreliable data, for example erroneous assumptions about, or unmeasured wind speed data at the site level may lead to inaccurate valuation results.

### 3.6 Risk of power outage

Each of the four mines depends on the availability of power from the power grid. If power goes out, the cost is calculated as [number of hours of down time X revenue per hour]. Down time is modeled using a Monte Carlo approach, with a uniform random variable (from 4 to 500) representing the number of hours of down time. Site 4 was an ideal candidate to model the risk of power outage as forest fires brought down the whole power distribution network that parallels 45 km of private roads in 2011. Twenty-six poles and power lines had to be replaced, the mine was evacuated and the major highway was blocked due to safety issues with a bridge. Production was shut down for 20 days with no grid
connection. The damage cost was $750K for poles and power lines (for which the mine was responsible), in addition to $50K/hour (opportunity cost of production being shut down) for 20 days. Such historical events lend credibility to cost of damage and likelihood estimates.

Power lines can be damaged by forest fires, lightning, wind storms, and ice storms. All four have the same mitigation strategy: stocking up on the most important survival materials (e.g., food, diesel fuel, propane). In the case of fire, brushing under power lines and installing fire barriers are also options. The first risk (fire) also has the option of brushing under power lines.

A one-time cost of $750K is attributed to each fire-related power outage (based on the 2011 damage at Site 4). As Site 4 had already installed numerous fire barriers, the one-time cost for such an installation was not included in the model.

Damage costs are not included for power lines that require repair as, with such risks, the damage will occur regardless of risk mitigation measures. The model instead incorporates only the opportunity cost of production that is saved by stocking up on key materials.

The following inputs were used:

- Damage cost of $50K/hour of downtime
- Inventory cost of $40K one time, plus $60K/year
- Brushing cost of $400K once every two years for fire
- Protection probability of 100% because the increased inventory levels are guaranteed to prevent the mine from shutting down
- For fire:
  - a. Minimum wind speed of 40 km/h
  - b. Minimum temperature of 20°C
- For wind:
  - c. Minimum wind speed of 90 km/h
- For ice:
  - d. Minimum of 80mm of precipitation
  - e. Average temperature between -2°C and 2°C
- For lightning:
  - f. Requires a rain storm of 70mm or more
  - g. Assumption that lightning damages power lines with a probability of 1% (using a Monte Carlo approach to sample from a random distribution for each storm)

<table>
<thead>
<tr>
<th>2.3 Power Outage</th>
<th>Lowest</th>
<th>Average</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 4 - Brush under lines to mitigate forest fires, stock up on supplies to mitigate power outage</td>
<td>-$10,859.47</td>
<td>-$3,030.81</td>
<td>$12,173.50</td>
</tr>
<tr>
<td>Site 4 - Stock up on food, diesel, propane to prevent power outage from wind</td>
<td>$0.00</td>
<td>$2,182.36</td>
<td>$13,584.91</td>
</tr>
<tr>
<td>Site 4 - Stock up on food, diesel, propane to prevent power outage from lightning</td>
<td>$0.00</td>
<td>$389.28</td>
<td>$4,062.91</td>
</tr>
<tr>
<td>Site 4 - Stock up on food, diesel, propane to prevent power outage from freezing rain</td>
<td>$0.00</td>
<td>$1,222.74</td>
<td>$13,179.85</td>
</tr>
</tbody>
</table>

The last three risks show a zero cost-benefit result in the worst case scenario, which may appear to be a compelling investment, however, the cost of stocking up on supplies is only registered once for all four risks, because they all share the same mitigation strategy. Zero cost-benefit, in the worst case scenario for the bottom three risks, depicts the loss of wasted inventory. Overall, however, the results
indicate that a positive NPV from the simple act of stocking up on key commodities creates a compelling investment case.

3.7 Risk to transportation due to storms

Two mitigation approaches were used when addressing risks to transportation due to storms:

1. Local transportation disruption: Staff training, shift planning and partnership with the government to reduce local road closure impacts
2. Regional transportation disruption: Increasing inventory levels of key materials to reduce the time of lost production

These risks were modelled only for Site 1 as case study participants at this site were very focused on transportation risks. At Site 1, however, there are several local roads leading to the mine, including an additional access road that could be reopened in the event that all open roads were somehow simultaneously closed. Despite the resiliency of the local transportation network, some climatic events may cause travel delays or absenteeism, which have the potential to slow or shut down operations. The probability of such a transportation disruption was modelled as a function to the level of precipitation (any form) in a 24 hour period. On the regional level, the risk was modelled in the same way, but a higher threshold was used to trigger the climatic event. The length of the disruption was modeled as a uniformly distributed amount of time between 0 and 100 hours, for both the local and regional level.

The following inputs were used:

- **Local:**
  - 80mm of rain in 24 hours triggers the event
  - Protection probability of 50% because not all training initiatives and partnership are guaranteed to be effective
  - One-time cost of $100K for mitigation
  - Damage cost of $1,000/hour of disruption

- **Regional**
  - 90mm of rain in 24 hours triggers the event
  - Protection probability of 100%
  - One-time cost of $1M and a recurring cost of $250K
  - Damage cost equivalent to the full opportunity cost of production, $40K/hour

From the results presented above, the risk mitigating investment option has a compelling upside on the local level; averaging better than breaking even.

On the regional level, the option to increase inventory levels of key materials is expensive. Using the same inputs, EY continued reducing the level of rain in a 24-hour period until the model yielded a
positive NPV for all simulation outcomes. This positive NPV scenario occurred at the point in which sites would experience transportation interruptions with as little as 75 mm of rain in a 24-hour period. Delivery risks caused by as little as 75 mm of rain would render it in the best interest of the sites to stock up on inventory. This level of precipitation, however, is unlikely to block transportation on well-developed transport infrastructure e.g., highways. As three of the four mines reviewed were accessible by developed, Government-maintained roads, running out of required inventory was not considered a significant risk.

3.8 Risk to transportation due to fire

Case study participants at Site 4 identified a risk of a forest fire shutting down a key access road, which would require materials to be brought in by airplane.

The mitigation option for this risk is also to increase inventory of key supplies: food, fuel and operating materials. The cost is modeled as a one-time increase in transportation expenses due to the higher cost of air transportation. This risk is modeled as a 1% probability that on a hot day (with the threshold specified by the case study participant / user) a forest fire would disrupt traffic.

The following inputs were used:

- Minimum temperature of 20°C
- Damage cost of $50K per event
- One-time cost of $50K to increase inventory of key supplies, and a maintenance cost of $5K/year
- Protection probability of 100% because the increased inventory levels are guaranteed to prevent the need for air transportation

<table>
<thead>
<tr>
<th>2.2 Transportation</th>
<th>Lowest</th>
<th>Average</th>
<th>Highest</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 4 - Stock up on operating materials to mitigate air transportation costs due to fire</td>
<td>-$251.06</td>
<td>-$185.41</td>
<td>-$45.76</td>
</tr>
</tbody>
</table>

This scenario shows a negative return in all of the simulation runs, which suggests that an investment in increased inventory levels would not be justified based on the likelihood of the risk involved.

3.9 Risk to transportation due to permafrost degradation

The impact of permafrost degradation on transportation was not modelled. For example, degradation of permafrost can prevent larger planes from landing, which impacts transportation in and out of the site. To invest in mitigation would require extremely accurate data such as that provided by a climate scientist to provide forecasts on timing that can be considered against the cost of construction.

Permafrost degradation also has the potential to cause widespread road damage. As with the landing strip example above, this requires a one-time investment in infrastructure, which can only be considered with the help of a detailed location-specific climate science analysis. While climate change effects would be considered, simulation data alone is not enough to merit a decision on such a significant investment.
3.10 Interpreting results

EMMIS provides decision-makers with a useful tool for estimating the present day value of a potential investment. The tool can also help prioritize risks assuming estimated impact costs are accurate. If the cost of potential damage is significant, and the simulation data indicates that the event can be expected to occur, a high-priced investment becomes feasible. The low-priced investments, on the other hand, may not be worth the effort if the risk has a low financial impact, or is less likely to occur. The NPV results from the model for each investment option provide insight on prioritization, allowing decision-makers to establish a portfolio of climate change adaption measures with a multi-year investment strategy. While many of the options resulted in a positive NPV in an average of all simulations (loosely referred to as a “most likely” scenario), the fact that the lowest scenario resulted in a negative NPV for many of the options indicates that these options are higher risk investments, however, the estimated financial impacts used were those provided by the sites and do not account for potential costs associated with reputational damage. Costs also rely on the assumption that data provided by the sites, such as existing tailings pond capacity, is accurate. These two limitations are further discussed below.

Interpretations of risk very much depend on each individual decision maker’s tolerance for risk.

Data availability and accuracy

Comprehensive simulation data and accurate inputs from sites are required for EMMIS to generate reliable investment consideration results. The lack of both is discussed in more detail in Section 3.11: Modelling limitations, and summarized below. The limited information available for these investment option assessments is primarily due to the following two circumstances.

A. **Number of simulations.** The simulations run through EMMIS were based on scientific modelling of projected weather outcomes under three scenarios (high emissions, stable emissions, reduced emissions), specific to the regions in which the sites are located. Each of the high, stable and reduced emission scenarios were further assessed through five variations in starting conditions, resulting in a total of 15 simulations for each region. Financial modelling will generally run hundreds or thousands of simulations in order to explore all possible combinations of outcomes from variable inputs e.g., sales, cost of materials, etc. which results in a smooth distribution of outcomes. This distribution provides decision-makers with the percentage of times they will break even with the investment, and allows them to make the final decision based on these results.

A total of 15 simulation outcomes limits the study to only high / medium / low results, which does not allow for a reliable confidence interval (i.e., percentage of time the NPV falls within a specified range). In the absence of numerous weather scenarios to provide a more reliable assessment of what may occur, decision-makers are more likely to err on the side of being conservative, which requires a zero and/or positive NPV for all outcomes.

As the number of potential weather scenarios based on scientific data per region and over the 2015 – 2100 timeframe increases, investment valuation analysis will become more robust, thereby providing decision-makers with an improved reliable assessment of all possible outcomes.
Further discussion on this limitation is available under “Number of simulation runs” in Section 3.11.

B. Potentially unreliable input data. Information on climate change-related risks, costs of risks, and how sites are mitigating these risks was provided by the case study sites. For example, in assessing the risk of a tailing pond overflow, Site 1 indicated that it would have to experience 200mm of rain or more in a 24-hour period to cause a tailing pond overflow. As noted in Section 3.2, such a scenario was not observed in even the most severe climate change scenario. The fact that Site 1’s tailing pond could withstand up to 200 mm of rain, however, was not verified by independent engineering reports. Sites 2 and 4 did not provide data on the threshold of rain their tailing ponds could withstand, and so, in the absence of actual data, a 75mm tolerance was assumed. Under this scenario, an investment to increase tailing pond capacity at Sites 2 and 4 was considered to be worth consideration based on the assumption of a one-time investment cost of $4 million, damage cost of $5 million per storm, and a protection probability of 75%.

It was also noted that Site 2 is the most likely candidate for this investment as the weather scenario analysis indicates that Site 2 will face the largest number of severe storms over a 25-year period, compared to the other case study sites. This finding, however, is based on an assumed threshold capacity of 75mm, as data on actual capacity was not available for this site. Section 3.2 provides further detail on this analysis.

The corollary of this data gap is that specific and consistent data at the site level are required, along with confirmation of the data provided (e.g., supported by independent scientific or engineering reports) in order to create an accurate assessment of the potential investment’s validity.

Collaboration

In some cases, adaptation measures for some risks are best managed in collaboration e.g., with Government, communities, suppliers, customers and sector peers. Such adaptation measures are therefore difficult to model, but can be beneficial to all parties. For example, flights into some sites can be delayed due to fog, which can result in depleted supplies or disruptions to staff transport. While the projected increase in fog can be modelled, adapting to increasing fog scenarios by investing in sensory equipment improvements on planes requires collaboration with, and an investment from, suppliers.

As an energy-intensive industry, mining companies are facing pressure from global emission reduction agreements and country-specific strategies. This will increase costs for all mining companies as almost 40 countries and 20 cities or states implement carbon pricing mechanisms in the form of a carbon tax or emissions trading scheme. These global pressures are expected to result in a financial cost to mining companies, including pressure to change their energy mix.

The primary physical impacts of climate change identified by each of four sites were those associated with increased frequency and intensity of storm events, which could require changes to mine design and increase the risk of operational disruption. Greater disruption or loss from wildfires was also considered, as were increased post-closure liabilities and supply chain disruptions.
There are, however, other impacts that were not identified by sites. These are listed below, and could be included as appropriate for an in-depth investment valuation on a site-by-site basis.

► Increased water stress;
► More extremes in operating temperatures requiring more protection for employees and equipment;
► Greater variation in customer demand; and,
► Workforce exposure to new diseases.

Some of these impacts are more likely to affect regions outside of Canada where Canadian headquartered mining companies operate, rather than within Canada itself. Many of the sites are located in the same region, and even share production rights. In such cases, adaptation measures for the region can be developed and financed through collaborative approaches. Strategies to manage site-specific risks can likewise be developed through collaborative funding of scientific and planning reports.

For the case study sites in this study, the impact of climate change to transportation disruption was not considered the responsibility of sites that have access to public roads. Collaborating with the relevant government bodies to ensure resilient road infrastructure is an opportunity for companies to remain ahead of identified transportation risks.

Developing climate change resilient studies, plans and infrastructure for local communities also presents an opportunity to collaborate for mining companies operating in the same region.

Discussions with case study participants, supplemented by external research indicates that the mining and metals sector is only now developing strategies to eliminate or avoid the risks listed above, to mitigate or protect against these risks, or to plan to remedy the impacts.

Risk interdependencies

The interconnectedness of risks was qualitatively considered, but was not modelled. Section 2.3 provides several frameworks for which mining professionals can account for interconnected risks, ideally in collaboration with sector peers as many global risks impacting climate change are not ones any one site can mitigate against on its own. Shifting climate change legislation is a regional concern as an increasing number of jurisdictions develop and implement their own strategies to stall the increase in greenhouse gases. As all materials are becoming increasingly more difficult to extract, emissions associated with production will increase in direct contrast to the global efforts to establish emission reduction targets. Such targets may increase the costs of mining to the point that, in conjunction with other factors, it is no longer economically feasible to continue operations.

The realization of global risks, such as ecosystem collapse or man-made catastrophes, is in turn likely to increase legislative and reputational risks for mine sites. The challenge is to understand and predict how, and when.

The model does capture the interdependency of adaption investment options through the one cost application for a measure to protect against multiple risks. Redesigning the water management system to mitigate the risks of permafrost degradation and heavy snowmelt is one example.
Although a positive NPV for many of the investments was observed in the average of all simulation runs, the lowest result for most of the options was negative. The fact that the investment has a potential to lose money makes it higher risk, even if the more likely scenario is that such investments will mitigate the risk of negative financial impacts over the site’s lifetime. Proceeding with the investment depends on the risk tolerance of the decision-maker. Expanding inputs into EMMIS to include revenue losses and potential negative impacts to share price will provide a more complete assessment of the worst case scenario.

The upside of protecting site infrastructure and the natural environment surrounding it over the life of the mine and beyond may warrant the risk of making an investment with the potential for loss. As demonstrated above, there is a wide range between the lowest and highest result. This is due to the nature of modelling climate change impacts, which can be extremely significant, but may never occur, or may occur once in 20, 50 or 100 years. The challenge for all risk managers in managing climate change is that the future associated impacts are difficult to predict. Figure 3.3 depicts this challenge compared to other critical risks. (Note that only the risk of terrorism comes close to the climate change probability scale.)

**Figure 3.3: Probability / impact of global risks (2010)**

![Figure 3.3: Probability / impact of global risks (2010)](image)


Investments with a positive NPV for some sites in all scenarios should be considered:

- Increasing tailing pond capacity
- Installing dust barriers and spraying sealant

The sites with a negative NPV on the investment options listed above, even if in a less likely scenario, may determine that the prudent path forward is to delay the investment and continue to monitor weather for indications of changing patterns. This further emphasises the utility of a set of indicators of ‘emerging risk’ that can serve as signals for climate change impacts and trigger a re-evaluation of investment options. As climate change impact and cost data becomes more reliable, mining company decision-makers will be able to make more informed investment decisions.
The results demonstrate the necessity of managing weather-related events associated with climate change risk, including proactive investment in climate change adaptation strategies, at the regional level. This regional focus, however, presents a challenge when considering the magnitude, complexity and global relevance of such a potentially enormous risk with still nebulous impacts.

3.11 Modelling limitations

In building EMMIS and working with the case study sites, the following limitations were observed. These limitations can be addressed through robust preparation for individual site analysis.

1. Number of simulation runs
   Fifteen runs of simulation data, such as exists in EMMIS, do not provide a smooth result. Minimum/average/maximum results can still inform an investment decision, but not as reliably as running the same calculation thousands of times. These results will improve as more data becomes available.

   Figure 3.3: Investment gain (loss) forecast

   For example, when the model produces 5000 results, the histogram represented in Figure 3.3 can be produced. Each bar represents a range, e.g., a savings amount between $0 and $0.5M. The number of times (simulation runs) the savings falls in that range is the height of the bar (in the graph above, those heights are then scaled down with a scaling factor so that the sum of all the heights is 1, but the height is always proportional to the number of times the savings fell in the given range). This graph shows depicts all very extreme possibilities over many runs of the simulation. It also allows the calculation of any confidence interval. The range in which 95% of the outcomes fall can be determined directly from the underlying data in this graph, which will allow conclusions such as a 95% probability that actual savings for an investment option will be, for example, between $3M and $8M.

2. Variable damages
The impact of risks will involve varying costs depending on the severity of the weather-related event. Accurate cost ranges from each site would allow modellers to shift from a damage “cost” for each risk to a damage “matrix”. The matrix would provide insight into a range of costs within the same probability scenarios.

3. Modelling complexity
Monte Carlo is used in place of simulation data for some factors e.g., humidity. The selection of simulation data to add depends on site-specific conditions, and should be developed accordingly. In addition to humidity, the following parameters could be modelled:
   a. How high the temperature will rise, and how long it will stay high;
   b. Snow melt cycles; and,
   c. Lightning and fire events.

4. Limited time with each case study participant
Conducting a single workshop to collect data limits the accuracy of the input data. Cost estimates and speculations on impact were made in place of absent data. These deductions were not substantiated with empirical evidence, engineering specifications or scientific projections. Use of the tool to inform a real life investment decision will require greater duration of time spent in developing inputs to generate more reliable results.

5. Planning based on historical information
It was noted during the workshops that the probability of weather events and their impact was in part based on historical performance or experience, which may not be indicative of the impacts and costs associated with a future climatic event. When an event had not yet occurred, it was more difficult for the participants to estimate impacts and costs of the event.

6. Investment costs
The demonstration assumes all costs are incurred by the site. Where costs can be shared, for example with other sites or municipalities, the percent allocated to the site will be the input to reflect contributions by other third-parties thereby increasing NPV.

7. RCP data
EMMIS currently contains RCP data for four weather conditions (temperature, precipitation, wind and snow). Other weather conditions e.g., lightning are modelled through Monte Carlo simulations. RCP data for additional weather-related events can be input to enhance the model should these factors be relevant to the investment decision-maker for more accurate results.

In addition to the suggestions outlined above to address the various limitations, the following model enhancements can be made to assess site-specific investments depending on the type of investment, regional weather conditions and the mine characteristics.

   a. Dry, extreme weather and high wind:
The mine sites noted that damage is more severe in dry weather. Humidity simulation data can be added to the model to allow for humidity levels as another input to fine-tune the analysis.

   b. Permafrost Degradation:
Using a model of the number of days above freezing could be expanded into a more
complex calculation that takes into account how high the temperature rises, and how long it stays high.

c. Heavy snowmelt causing tailing pond overflow:
This model compares the amount of snow collected over winter and spring to the capacity of the tailing ponds. This could be expanded to consider the various melt cycles throughout the melting season, depending on temperature, length of warm spells, etc.

d. Storms causing regional road closure:
The downtime was modeled using a simple uniform distribution. Additional refinement may include a concept of the most likely time of no operation, thereby refining the accuracy of the maximum or minimum time, etc.

e. Interruptions to operations due to fire:
This model bases the forest fire likelihood on the temperature in conjunction with a Monte Carlo probability factor. Location-specific simulation data is being generated in the academic world that models the arrival of fire in a more scientific way for similar projects.

f. Power outage:
Location-specific lightning and fire data would improve the model’s accuracy. In the current version of the tool, lightning events were modelled based on storm frequency, and fire events were based on wind and temperature.
Risks and measures to address climate change in the global mining industry
Risks of and measures to address climate change in the global mining industry

All of the case study participants considered climate change risks to the end of life, and on closure costs. In reality, however, few sites actually close fully remediated. Costs are prohibitive and even measures to guarantee such costs, such as securitized loans, might not be sufficient. This may result in a larger portfolio of abandoned mines dotted throughout Canada, for which neither the Government, nor the taxpayer, is prepared. Case study interviews and supplementary research have revealed that divestment of sites still plays largely in corporate strategy. Divestment may become increasingly challenging as impacts of climate change become more widely understood; today, most institutional investors, particularly in the UK and Europe but increasingly in North America as well, are including climate change assessments in their financial due diligence.

In Canada, one of the greatest risks of climate change is the plethora of abandoned mines and the responsibility for ongoing remediation, which is already and will continue to become more of a financial burden for Government. High profile examples include the Giant Mine in the Northwest Territories and the Faro Mine in the Yukon. Plans for the long term management of the highly lethal arsenic trioxide at Giant Mine were approved in August of this year by the Federal Government, which entail the permanent freezing of the arsenic trioxide dust using technology similar to that used in ice hockey rinks. The strategy, which is currently estimated to costs taxpayers close to CAD 1 billion, will both impact and be impacted by climate change. The full extent of this impact is not factored into its current price.

The contaminated sites program that is managed by Aboriginal and Northern Affairs Canada is starting to incorporate considerations of climate change impacts into its ongoing mine remediation strategy including for the Giant Mine in the North West Territories and the Faro Mine in the Yukon.  

Of Canada’s operating mines, those located in Northern Canada were found to be more likely to integrate climate change considerations into the design and operation of sites. In the four case studies considered in this research, investments to make infrastructure and operations more resilient to climate change are being undertaken or considered for the two sites along the northern borders of Ontario and Quebec. Climate change adaptation was found to be significantly less of a priority for the other two case studies, located in Southern Quebec. Case study participants in Canada’s more northern regions stated that they are already feeling the impacts of climate change, and therefore see a business case for adaptation and resilience investments. Two diamond mines operating in the Lac de Gras region of the North West Territories - the Ekati Diamond Mine and Rio Tinto’s Diavik Diamond Mine - have also integrated adaptive measures in response to climate change events, specifically the unusually warm conditions in 2006, which limited transportation of freight via the seasonal ice road network. Sites farther south, on the other hand, are on more of a “wait and see” path, which may place them at greater risk in the event that unexpected weather extremes become more frequent in

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22 EBA Engineering Consultants Limited: Climate change impacts and adaptation: Case studies of roads in Northern Canada; 2008.
future decades.

The challenge with climate change is that it will not impact all regions in the same way. Several global companies are considering measures to adapt site design and operations to make their sites more resilient to the risks associated with changing weather based on a site-by-site assessment and investment strategy. Measures undertaken depend on a prioritization exercise that considers company-specific exposure to global increases in temperature, changes in precipitation, and extreme weather events, all of which factor into how mining companies are integrating long-term climate change adaptation planning.

Several companies (e.g., Kumba Iron Ore, Alumina, Kinross and Norsk Hydro) are assessing the engineering design and construction standards for site facilities to ensure that critical site infrastructure will be able to withstand extreme weather events as they become more frequent and severe.²³

Peer practices to address climate change provide the sector with lessons learned and the potential to identify opportunities for collaboration. Below is a selection of examples from the global mining industry.

1. **Nyrstar**: Following a severe rainfall event and flood in 2006 that cost $4 million in lost production and $850K in new equipment costs, Nyrstar invested in its physical infrastructure, transportation assets, site water management and monitoring systems at its Myra Falls operations on Vancouver Island. These investments include the installation of a second effluent discharge line to ensure that during intense precipitation events, peak flows through the water treatment system can be managed. The company also invested in doubling its underground pumping capacity, constructed bulkheads in pit areas deemed vulnerable to flooding, developed strategic equipment storage plans for severe weather events, and enhanced monitoring tools and equipment.²⁴

2. Anglo American: In 2008, the company partnered with Imperial College London to model changes in temperature and precipitation patterns that could have a physical impact on the company’s operations. The company’s projections form the basis of its risk inventory for current and future operations, and informed the development of site level adaptation strategies. Based on initial climate change impact assessments, the company also worked with the UK Met Office to prioritize projects across the company based on assessments of when climate change ‘time of emergence’ signals will occur. The company currently requires all of its operations to undergo a climate change vulnerability assessment to determine the level of risk at each site. All sites that meet the risk ranking criteria for climate change risk are then subject to a climate change impact assessment. The company plans to integrate a ‘climate test’ into its capital expenditure approval process.

3. Exxaro: Exxaro launched the Exxaro Chair in Business and Climate Change initiative in 2008. Using downscaled general circulation models, the study evaluated climate change impacts on Exxaro’s operations, specifically in South Africa. The study examined natural climate hazards and the vulnerability of mine infrastructure. With regard to insurance and planning for future climatic events, Exxaro has established an onshore captive insurance company to accumulate reserves to provide for future uninsurable risks.

4. Vale: Vale commissioned the National Institute for Space Research of Brazil to measure vulnerability under different climate change scenarios in northern and southern Brazil. Specifically, the assessment examines the effects of climate scenarios on factors including water availability and biodiversity. Vale has also implemented enhanced weather monitoring systems, including a radar-supported system, in order to detect and forecast storms in time to shut down and secure critical equipment and infrastructure.

Access to capital to fund investments in adaptation activities is a significant challenge for the mining sector. Exacerbating this challenge is the limited opportunity to replicate investments across a portfolio of sites. Climate change adaptation strategies can vary significantly, given the differences in the geographical location and severity of risks identified for each mining site.

Availability of various financing programs for adaptation measures will encourage adaptation and help protect the private and public sector from unexpected losses. At present, there are a limited number of financing programs available specifically designed for the mining industry and those funding programs that are available are primarily focused on exploration and developmental stages of mining. The two exceptions identified, which provide some financing opportunities in climate change-related research and are CANMET Mining and Mineral Sciences Laboratories (CANMET-MMSL) and Sustainable Development Technology Canada (SDTC).

28 Ibid.
Reasons for the limited existence of funding opportunities for climate change adaptation strategies include:

1. Most federal programs require priorities to be identified and roadmaps and strategies to be developed. Currently, the mining industry is largely focused on funding opportunities related to mining exploration, with limited attention being given to climate change and adaptation funding.

2. At this stage, climate change is presenting more of a risk to mines operating in Canada's far northern regions. Investments in climate change adaptation for Canada's southern mine sites are still quite risky from a cost-benefit perspective.

3. The uncertainty and unpredictability of climate change impacts generate hesitation in allocating resources towards adaptation. "What if" scenarios (describing the potential effects of climate change) during the case study workshops were considered hypothetical without empirical evidence to justify them.

Mining companies that are already experiencing effects of climate change are investing in research and development related to its effects, with a special focus on emerging technologies to mitigate future climate change risks. Their R&D efforts include funding academic research on climate change risk management practices.

Cross-sector collaboration on regional adaptation strategies may present opportunities to share information and costs for climate modeling, best practices, and implementation of large-scale adaptation strategies. Vale, for example, is involved in the "Company for the Climate" initiative in Brazil, in which private companies meet monthly to discuss climate information and learn from peer efforts to develop mitigation and adaptation strategies.
Summary of observations and recommendations
Mining sector professionals are increasingly accepting that the climate is changing. How this change will impact their specific site operations and surrounding regions, and when, is less clear. This lack of clarity renders the risks difficult to address. In the Anglo American example provided in Section 4, a key component of the work entails identifying ‘time of emergence’ signals for climate change impacts. This resonated with site professionals during the workshops conducted for this project, who want to understand how they can identify the early warning signs of these risks. Research to date is fairly confident on what the weather will look like in 2050 and 2100, but not how the incrementally changing weather patterns will impact us in the interim as we transition to the scenario timeframe. For example, a site with deep permafrost may have no permafrost in 2100; what year between now and then will it experience the tipping point of the decline?

In the absence of such early warning signals, the simulation data available through Environment Canada, based on IPCC future emissions scenarios, is an extremely helpful input in investment decision-making models. As noted in Section 3.11, however, the data is still limited. More comprehensive data will improve the accuracy and reliability of results. The data that exists today could feasibly be run thousands of time for a particular region to obtain the number of simulations required to improve the model. This, however, is resource intense in terms of both time and money, and is unlikely to be undertaken by any one site. Collaboration with governments, civil society and industry peers, will help to overcome this challenge.

The need to collaborate is an important theme during any discussion of global, interconnected risks, such as those presented in Section 2.3. One company is unlikely to gain access to such enormous amounts of data, and have enough internal competencies to account for all of the complexities in the analysis. Another reason for the need to collaborate is that adapting to become more resilient to these risks is often not within the control of any one single entity. An example is the improvement to plane sensory equipment to adapt to increasing levels of fog as described in Section 3.10, or the impact (positive or negative) one entity’s activities can have on another, again beyond one’s control.

Observations through the four case studies indicated that no one site is adequately prepared for the possibility of a range of weather-related impacts. This varied across regions, however, with the northern sites located in Ontario and Quebec more active in developing resilience to climate change than those along the southern border of Central Canada. As the northern sites are already experiencing climate change, this makes sense. The southern sites may actually be at greater risk due to their lack of preparedness, although this will depend on how quickly and forcefully impacts occur.

In the case of all four sites, the closure or restoration scenarios that are “active” i.e., that require continuous human intervention such as ongoing maintenance of a water management and treatment plant in order to avoid environmental damage do not reflect a changing and uncertain climate. It is evident, albeit based on a limited sample, that restoration asset retirement obligations (AROs) are not taking into account the full life of the mine. Remediation plans were similarly inconsistent and unlikely to cover the full costs that will be required. Where remediation costs are prohibitive, sites will remain open in perpetuity, which may place governments and banks (to the extent that banks are on the hook for the securitized loans) at risk should companies dissolve before remediation takes place. This situation will occur at the point in which it becomes economically expedient to dissolve rather than...
continue care and maintenance on some sites within a profitable portfolio of operational sites.

At the site level, the analysis indicates that northern sites are likely to benefit from a proactive review and possible investment in the redesign of their water management systems to mitigate the risk of excessive snowmelt. All sites studied should also regularly review tailing ponds capacity in the context of changing weather to identify the point at which an investment to take remedial measures may be warranted. Such investment options are at a higher risk of incurring losses for sites located along Canada’s southern border. A more reactive adaptation strategy may be justified, although with more rigorous monitoring to identify those “time of emergence” signals discussed in the Anglo-American example provided in Section 4.

Ultimately, a strategy to manage weather-related events associated with climate change risk, including proactive investments in climate change adaptation strategies, can only be effectively developed and implemented at the regional level. This regional focus, however, presents a challenge when considering the magnitude, complexity and global relevance of climate change risk.

5.1 Recommendations for EMMIS’ application throughout the mining sector

The benefit of the economic modelling tool is that it provides mine site decision-makers with a process and calculation methodology for assessing the effectiveness of and potential returns on climate change adaption investments. The tool recalculates each time a user selects alternate values for the inputs, including:

- Year-by-year costs for mitigation options;
- Expected cost of damage;
- Time to invest (investment not required today – any year in the future can be entered);
- Trigger level for the input variable (e.g., 100 mm of rain triggers the event);
- RCP climate change scenario (including all scenarios at once); and,
- Discount rate for future cash flows.

Location-specific simulation results can be imported into the tool to customize the calculations to a different mine site. Probability calculations are based on raw simulation output data for extreme events, costs and savings are discounted to consider the time-value of money and best, average and worst case scenarios are calculated based on the user’s choice of input variables.

The economic modelling tool can be used by any mine site in the world. Mine site professionals can be efficient with their time by only inputting the risks associated with their own distinct operations. Where simulation data does not exist or it is too resource-intense to obtain, Monte Carlo simulation has been incorporated to provide an approximate probability assessment. Monte Carlo can also be used in tandem with the existing weather scenarios (available in Canada but not in all other countries) to increase the number of simulations, providing decision makers with a reliable confidence interval (see discussion in Section 3.10). Depending on the complexity of the environmental trigger, however, geologists and climate scientists may be required to validate site-specific geographical risks and/or help identify such risks in the first place.
Recommendations for applying the model to investment considerations for Canada’s mining sector are summarized below.

► Select one or more Canadian based mining companies with both Canadian and international sites to determine exposure to climate change across different regions. Assessing costs that depend on such variable factors as climate, political will and surrounding communities will provide insight to the Mining Working Group on how climate change will affect Canadian companies operating globally.

► Validate climate change-related risks using a combination of corporate personnel, stakeholders, and scientific experts. This will expand the list of potential risks to be modelled, and may identify results not previously considered by mining personnel. Risks identified by the sites in this study were disruptions or loss from storm events, wildfires and supply chain interruptions, as well as increased post-closure liabilities. Other risks worth consideration are increased water stress, impact of extreme temperatures on employees and equipment, customer demand and, workforce exposure to new diseases.

► Independently validate risk mitigating structures. The capacity of tailings ponds, and/or the ability of structures to withstand high winds were not confirmed by independent experts in this study. Outcomes of different precipitation and wind scenarios would be more accurate with reliable thresholds of existing infrastructure.

► Develop a range of costs for each probability scenario. A range will help decision-makers better understand potential impacts and will increase the number of simulation runs to allow for a confidence interval (i.e., the number of times NPV is likely to be positive for a specific investment consideration). This study considered a fixed cost for each impact as provided by the sites.

► Develop a range of timelines for life of mine. In this study, many of the impacts were found to be not likely to occur based on the limited RCP data available over the life of the mine, as provided to the study’s analysis by mine site personnel. Costs of closure and available funding to finance all remediation and other closure requirements should be assessed to develop a more accurate “life of mine” scenario in the event that the site will remain the responsibility of the company in care and maintenance for longer than expected.

► Increase the number of simulation runs. This can be achieved through access to greater RCP data as it becomes available, which will yield the most accurate assessment results. In the absence of such data, Monte Carlo simulations can be used to estimate the likelihood of IPPC’s probable climatic events within various timelines, by region.

► Estimate costs associated with reputational damage. Estimates can rely on existing information as proxies for costs associated with damages. These include settlements to governments and local communities, interruptions to operations through project delays, and share price declines.
Incorporate risk interdependencies. The interdependence of risks can be challenging to model as to do so significantly increases the number of variables and assumptions. Understanding and factoring risk interdependence will, however, help decision-makers more accurately identify “time of emergence” signals in which climate events become more likely to occur. Factoring interdependence in the investment assessment is described in more detail in Section 2.3.

Identify opportunities for collaboration. Collaboration can help offset costs to any one particular site, thereby improving the feasibility of the investment under consideration.

EMMIS has been created to accommodate the inputs listed above in addition to those described in this study. Proper use of this investment valuation tool requires time on the part of mining decision-makers to accurately assess risks, independently validate risk mitigating structures e.g., capacity of tailings ponds, develop a reliable range of costs associated with the potential impacts of risks, including reputational impacts, and financing to run the assessment.

Continuous review of inputs to appropriately factor in future-oriented considerations will improve the accuracy of results. Cost-benefit outcomes will improve with the identification of cost-sharing opportunities and implementation of a multi-year investment strategy by mining executives.
Appendices
Appendix A  Calculation methodology

In partnership with Rebecca Zhang, Ph. D, Postdoctoral researcher at the University of Toronto, EY obtained 100 years of daily results from five simulation runs in each of three “Representative Concentration Pathway” (RCP) simulations; 15 data sets in total. These simulations generate weather measurements by location. Using these simulations as hypothetical outcomes, EMMIS calculates the cost-benefit of investing in protection against climate change risks to mine sites as identified by mine site case studies (Appendix B). This allows for a “go / no go” decision to be made for the adaptation investment being considered, allowing executives to select, from a portfolio of adaption initiatives, only those that are economically viable for their site(s). The most important (and greatest time investment) component of the model’s use is the collection of the input data and model parameters, which are represented by steps 1-5.

Cost savings associated with each of the adaptation investment options are calculated through the seven steps detailed below.

1. Mine site participants provide the company’s desired interest rate, which is input in the Setup tab to incorporate the discount rate of future cash flows.

2. Additional site-specific inputs are captured. The following are the primary factors in the cost-benefit calculation currently designed within EMMIS, however, if required additional input factors can be added for a more accurate calculation for each site.

<table>
<thead>
<tr>
<th>Factor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year of implementation</td>
<td>Climatic events that occur before the date of implementation are considered costs.</td>
</tr>
<tr>
<td>Last year of operation</td>
<td>Climatic events or preventive costs that occur after the last year of operation are excluded from the cost-benefit calculation.</td>
</tr>
<tr>
<td>Trigger level</td>
<td>The user’s choice of the trigger level (level of climatic event that results in infrastructure damage or interruption to operations) is critical because it governs whether or not the weather data equates to a climatic event.</td>
</tr>
<tr>
<td>Secondary trigger level</td>
<td>Some risks result from the combination of two environmental factors (e.g., high wind combined with higher temperatures lead to an increase in dust pollution).</td>
</tr>
<tr>
<td>Damage cost (fixed)</td>
<td>Determines either the fixed amount of savings if a climatic event occurs in the event of an adaptation investment, or if the investment was not made, the estimated cost of the damage incurred.</td>
</tr>
<tr>
<td>Factor</td>
<td>Description</td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Damage cost / hour</td>
<td>In some cases (e.g., power outage) the damage cost depends on the length of downtime.</td>
</tr>
<tr>
<td>Likelihood reduction value</td>
<td>When a climatic event occurs, some preventive measures are not guaranteed to protect against damages. A value of 100%, for example, means the damage will always be avoided. A value of 80% means the damage will be avoided for 4 out of 5 events in the long run. For each climatic event, EMMIS generates a uniform random variable between 0 and 1, and compares that to the “Likelihood reduction value” to decide if damages occurred. If they occur, that will be a cost in the final calculation. Otherwise it is a savings.</td>
</tr>
<tr>
<td>Timeline of costs to implement and sustain preventative measures</td>
<td>Each cost may have an upfront investment as well as maintenance costs. The user inputs the costs over time for each risk in the Site Inputs tab.</td>
</tr>
</tbody>
</table>

The image below depicts the technical expression of the process for calculating the “likelihood reduction value” in the tool, which is hidden from the user as it only performs calculations and does not take inputs or display summary information. The formula bar in the image below demonstrates the tool comparing a standard uniform random variable to the “likelihood reduction value”.

Likelihood reduction value

<table>
<thead>
<tr>
<th>G9</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>RCP26</td>
<td>R1_11_P1</td>
<td>1</td>
<td>27/09/2017</td>
<td>82.77270126</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>3</td>
<td>RCP25</td>
<td>R1_11_P1</td>
<td>1</td>
<td>09/10/2016</td>
<td>67.08938986</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>4</td>
<td>RCP25</td>
<td>R1_11_P1</td>
<td>1</td>
<td>22/10/2017</td>
<td>73.06774003</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>RCP25</td>
<td>R1_11_P1</td>
<td>1</td>
<td>30/11/2016</td>
<td>62.12583894</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>6</td>
<td>RCP25</td>
<td>R1_11_P1</td>
<td>1</td>
<td>23/09/2018</td>
<td>64.36085483</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>7</td>
<td>RCP25</td>
<td>R1_11_P1</td>
<td>1</td>
<td>20/09/2019</td>
<td>72.36599022</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>8</td>
<td>RCP25</td>
<td>R1_11_P1</td>
<td>1</td>
<td>13/03/2017</td>
<td>74.60251951</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>9</td>
<td>RCP26</td>
<td>R1_11_P1</td>
<td>1</td>
<td>26/05/2017</td>
<td>86.58508241</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>RCP26</td>
<td>R1_11_P1</td>
<td>2</td>
<td>23/10/2017</td>
<td>61.47873116</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

---

30 Downtime is modeled using a simplified uniform distribution, which can be improved through further analysis of data from historical power outages.
The image below demonstrates how the user inputs costs over time. This functionality can also assess investments that are incurred in the future versus today.

**Timeline of costs**

3. Determine the user’s simulation preference. In the “Results” tab, the drop-down menu offers the choice between RCP 2.5 (low emissions scenario), 4.5 (medium emissions scenario) or 8.5 (high emissions scenario). If the user(s) select “ALL”, each simulation is considered equally likely when calculating cost-benefit results.

4. Discount costs back to the present day. The calculation is presented in the “Results” tab and the cost in terms of year 2015 dollars is reflected in column “S” shown below. The user has the option of selecting what point in the year costs are incurred or the year to which the costs are discounted to, by changing the discount period. Users can also prorate a cost for a fraction of a year, by changing the partial period.
5. Incorporate climatic events. Simulation results are utilized to determine if costs or savings are appropriate. Climatic events are considered if the thresholds, as stipulated by the user, are triggered. The daily measurements e.g., amount of precipitation or maximum wind speed each day are populated in the excel file. Each day is represented by a row of simulation data. The formula determines if damage occurred by comparing the input to the simulation result e.g., capacity of a tailing pond (input) to the rain level (simulation result).

Calculations of sample costs associated with climatic events are demonstrated below. The highlighted cell of this Results tab allows the user to choose his/her own RCP scenario. The daily simulation data is pre-loaded for all three RCP scenarios. Once a scenario is selected in the drop-down menu, the user is ignoring the data associated with the other two scenarios.

RCP data for four climate-related events are currently included in the model (i.e., temperature, precipitation, snow and wind). Further enhances would have to be made to the model to incorporate additional climate-related events.

6. Costs or savings for each simulation run are calculated. There are 15 separate runs, 5 for each RCP scenario. Runs 1-5 are from RCP 2.6, runs 6-10 are from RCP 4.5, and runs 11-15 are from RCP 8.5.

RCPs (representative concentration pathways) are referred to as pathways in order to emphasize that their primary purpose is to provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. The term pathway is meant to emphasize that it is not only a specific long-term concentration or radiative forcing outcome, such as a stabilization level, that is of interest but also the trajectory that is taken over time to reach that outcome. They are representative in that they are one of several different scenarios that have similar radiative forcing and emissions characteristics.  

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The RCP data was originally obtained from Environment Canada by Dr. Rebecca Zhang, postdoctoral researcher at the University of Toronto. From Dr. Zhang, EY obtained 100 years of daily results from five simulation runs in each of the three RCP scenarios used. The RCP simulation data calculates the likelihood of an event occurring based on these simulation results.

7. Summarize lowest, average and highest cost savings in the Results tab.

- The “Lowest” column shows the worst cost-benefit outcome for all of the simulation runs (the NPV of 15 simulation runs (Figure 1.15)).
- The “Average” column incorporates the mean of all simulation runs, considering each to be equally likely.
- The “Highest” column shows the best cost-benefit outcome for all 15 simulation runs.

If a certain simulation is specified by the user, only the weather events from that simulation will be considered. The image below demonstrates the formula by which the NVP of costs and the costs and savings from the simulation runs are combined to provide average cost savings.

Figure 1.15: Total cost-benefit of investment options
Appendix B  Case Study Summaries

Climate change workshops at four mining sites owned by three different companies were carried out to collect information related to the climate change risks and related economic impacts on the mines. Three of the sites are located in the Province of Quebec and one in Ontario. The main objectives of these workshops were to:

► Identify risks related to climatic events that have occurred at the site level;
► Identify risks related to extreme climatic conditions that may occur in the future; and,
► Identify tools & strategies to adapt to climate change.

The following approach was adopted to develop a risk inventory:

► Understand the site, focussing on site operations, transportation and reclamation and related costs.
► Understand the impact of climate change on the site. An overview of future climatic conditions at the site and impacts of extreme events by considering a range of variables: temperature, precipitation, wind, etc.
► Identify potential vulnerabilities at the site, based on the above steps.
► Understand reclamation strategies and forecasted costs.
► Conduct workshops to do the following:
  ► Validate the risks identified;
  ► Identify other vulnerabilities related to operations, reclamation and transportation;
  ► Identify the climatic event related risks and related cost implications of the risks; and,
  ► Identify mitigation measures and related costs.

Based on the information collected, a risk inventory was prepared with the help of site personnel. The risk inventories include different scenarios assessing costs resulting from climatic events, both in terms of preventive and remediation costs required to maintain and/or recover the full operability of a mine after extreme events associated to climate.

Workshop participants

Workshop participants were comprised of representatives responsible for environment, safety, sustainability, operations, supply chain, accounting, and tailings management. Including participants with various responsibilities helped provide a holistic approach in preparing risk inventories.

Overall results

The factors affecting climate change risk at each of the sites are classified under three categories:

► Surrounding environment of the mines;
► Local climatic conditions at each mine site; and,
► Operation specificities at each mine site.
Surrounding environment of the mine

Each of the four mine case studies was unique. The severity of a particular risk identified at one site was different from the severity of a similar risk at the other sites. For example, the ability of site #1 to adapt to climate change was higher than that of other sites because of its surrounding environment. There is a cluster of mines surrounding this particular mine which presents numerous advantages when it comes to vulnerabilities to climate change.

► There are multiple roads going to the mine. This increases the resiliency of the mine towards risks related to transportation.
► There are many suppliers in the region that can provide materials and equipment for mining activities. This increases supply resiliency of essential chemical and reactants.
► Staff is scattered in the region around the mine and mine workers have multiple ways of accessing the mine, again increasing the resiliency of staff transportation systems.

The surrounding environment plays a vital role in increasing the mine’s resiliency towards climatic change risks. Site #3 and #4 in comparison have less adaptation opportunities as they are located in remote areas that can only be accessed by one road and do not have other mine sites at close proximity similar to site #1. Site #2 relies on international transportation for its supplies and is therefore also less able to adapt. To overcome these challenges, site #3 and #4 have built substantial storage facilities and their own road networks.

Local Climatic Conditions

Analysing future local climatic conditions for each of the sites is an important component of assessing the risks and vulnerabilities that a site is exposed to. Analysis of weather data for each of the site’s locations indicate that both temperature and precipitation will increase with time.

Rise in temperature represents a more significant risk for site #3 compared to the other sites. Site #3 relies on permafrost for its water and tailings management. The permafrost maintains a temperature of -5 to -7C year-round and acts as a barrier against water infiltration in underground galleries, which could otherwise result in water contamination. In addition, permafrost holds the ground together, which reduces the need for underground support structures. Increase in temperature will lead to permafrost degradation, which will further result in discharge of contaminated water into the environment. Permafrost degradation may also lead to increased damage to the existing road network, which may result in increased maintenance costs.

Rise in temperature is not as significant a concern for site #1 compared to increases in precipitation. A preliminary review of climate change impacts in the region indicates a 15-20% precipitation increase is expected in winter and spring . The risk of tailing pond overload due to climate change-induced heavy precipitation is a significant climate change risk at this site as the tailing ponds at the mine site store contaminated water from runoffs. Water is continuously pumped and treated to manage water levels and avoid spillage of contaminated water in the environment due to tailing pond overload. In comparison to site #1, higher levels of precipitation is not as great a risk to site #4, as Site #4’s tailing ponds have relatively less contaminated water and rely on wetlands for the final treatment of water.

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Operation specificities of each of the mines

Although sites 1 and 4 produce the same ore, their operations differ greatly. The tailings pond water at site #4 is less contaminated than #1 resulting in site #1 needing to focus on increasing tailing pond capacity, whereas the more significant risk at site #4 is the power line on which the entire operations depend. The site has an unstable power line that is affected by high winds or storms. Understanding operation specificities at the site is crucial to appropriately identify risk priorities to be addressed.

Other related factors

The impact of climate change risks varies in magnitude for each mine depending on geological and location characteristics of the mine and surrounding area. For example, dust at site #2 has higher cost implications than site #4 because site #2 is situated relatively closer to a residential neighbourhood. Site #2 must implement preventive measures to avoid any kind of environmental fines related to dust, whereas site #4 may not experience the same level of cost implications related to dust given its remote location.

Reactive versus proactive management of climate change

Site #3 more proactively managed climate change compared to the rest of the sites. This site is located in the extreme northern region of Quebec and, according to the workshop participants has already experienced impacts of climate change. For example, the ice-free season is already up to 6 weeks longer than in past decades. According to workshop participants, the site is preparing for climate change risk that it is currently experiencing and may experience in the future. This mine has created a Steering Committee comprised of external experts and members of the community to study the impacts of climate change on the mine and identify solutions. The site has implemented experimental designs for their tailings ponds to test options in real conditions. Finally, there is interest in emerging technologies, such as desulfurization. According to site personnel, efforts in Research & Development (R&D) could create new opportunities by the time the mine reaches the end of its life. The mine site is investing in R&D efforts in universities as well as in partnership with the steering Committee. These efforts cost $600,000 a year as one component of risk management practices.

The remaining three mine sites are taking more of a reactive approach towards climate change. Workshop participants at site #4, for example had mixed opinions about climate change. Some believed in the science; some did not. These mines are creating preventive measures based on the historic events that have occurred in the past due to uncertainty of climate change effects. Robust climatic data is required to create an understanding of the future projections weather impacts.

Limitations

Observations from the workshops indicated that data availability related to climate change effects on extreme events is critical to assess climate change induced risks. Workshop participants were cautious about sharing existing climate change estimated costs due to the uncertain nature of climate-related events and scenarios, lack of records of past climatic event consequences and privacy concerns.

None of the sites had an existing risk inventory for climate change. Workshop discussions focused on, “what if” scenarios for the sites to think through various site vulnerabilities and risks.
Case study #1

Site overview

This site is easily accessible year round by existing paved roads. Roadways are the main mode of transportation although the mine does receive some of its supplies through railways and seaways. There are multiple access roads to the mine. The final product is transported by roadways. Employees who work on the site live in the nearby towns and villages and use roadways to commute to the site. Several critical chemicals are received on a daily basis, which makes continuous accessibility to the site important. Electricity and natural gas are used for operating the mine site. Electricity is required year round whereas natural gas is required from November to May for heating purposes. Tailing ponds at the mine site are used to store contaminated water from runoffs. Water is continuously pumped and treated to manage water levels and avoid spillage of contaminated water in the environment due to tailing pond overload. Managing water levels in the tailing ponds during spring is an important factor that requires monitoring as the water load due to melting snow is high.

Main risk factors

Tailing ponds are considered active as closure is costly. Active management is therefore vulnerable to short and long term climate change impacts. Tailings pond management techniques increase the vulnerability to winter and spring precipitations.

Factors impacting resiliency

Dykes and soil stability are monitored on a continuous basis to detect vulnerabilities that would result from gradual degradation. Increased erosion of soil and dykes resulting from slowly increasing precipitation, stronger winds and more frequent freeze-thaw cycles is a risk.

Historical events

In 1962, heavy rains along with thunderstorm with rain reaching 200 mm over a 24-hour period.

Risk identification table

The table below classifies the risks identified related to severe weather events.
<table>
<thead>
<tr>
<th>#</th>
<th>Risk</th>
<th>Damage description</th>
<th>Preventive action</th>
<th>Likelihood</th>
</tr>
</thead>
</table>
| 1a | Heavy rains in winter or spring resulting into overflow of tailing ponds | ▶ Discharge of contaminated water in spillway  
▶ Limited land contamination. | ▶ Increase tailing ponds design capacity                                           | Medium/High    |
| 1b | Heavy rains in winter or spring resulting into dyke rupture          | ▶ Failure of safety valve in spillway and dyke rupture  
▶ Huge environmental disaster: add and toxic water and tailings discharged in stream and nearby lake that will lead to acidification and fish stock collapse amongst other. | ▶ Enhance spillway resilience by revising overflows                                | Low            |
| 1c | Severe ice storm in spring                                           | ▶ Power failure  
▶ Controlled discharge of untreated water in the environment | ▶ Increase contaminated water pumping capabilities during blackout  
▶ Increase water retention capabilities                                          | Medium         |
| 2  | Road closure due to severe ice snow storm or floods                  | ▶ Partial road closure  
▶ Staff living in nearby towns cannot access the mine  
▶ Staff absenteeism impacts mine production  
▶ Disruption of burnt time supply during peak demand  
▶ Water treatment plant unable to operate  
▶ Concentrator unable to operate once water retention ponds reach maximum capacity | ▶ Collaborate with Ministry of transportation to assess the transportation risk  
▶ Develop emergency transportation plans to decrease absenteeism.  
▶ Increase capacity for staff to live at the mine  
▶ Increase tailing ponds capacity                                               | High           |
| 3  | Severe ice storm                                                     | ▶ Power failure  
▶ Production at the mine halted when concentrator fails  
▶ After 30 hours of power failure, the mine is unable to keep galleries dry which leads to underground flooding and evacuation | ▶ Assess climate change induced risk regarding power disruption in collaboration with Hydro-Québec  
▶ Increase power generation capacity at the mine                               | High           |
Case study #2

Site overview

This site is an underground mine that is easily accessible by existing paved roads. The mine is surrounded by a combination of forest and farms.

Most of the supplies are shipped to the nearest port and then trucked to the site. The mine is in a semi-urban zone so, despite a preferred access road, there are no road bottlenecks during short disruptive events. The mine workers live in nearby villages and all drive to work. There is no onsite accommodation for the mine workers.

There is an available water supply, as well as a hydroelectric generated power supply from the regional power grid. The mine operates on electricity and requires natural gas in the winter. Underground equipment is mostly diesel powered, which requires large mechanized vents.

Historical events

Weather events that the mine has faced in the past include:

► Extreme cold in 2013: The mine experienced propane shortage due to a low supply in Quebec. There were no direct cost implications to the mine as they have a long term supply contractual agreement.
► Flood in 1996: Although transportation was delayed for few days, the mine was not affected. An historical analysis of cost increases was not available.
► Earthquake in 1988: A 6.1 Richter scale earthquake did not have any major consequences on the mine other than a requirement for evacuation.
► Landslide - 1971: A 400m landslide resulted in the assessment of a future landslide, which could affect the main water intake. A map is being built to identify surrounding region vulnerabilities to future landslides.

Main risk factors

Risks identified during the workshop are primarily related to operations. The mine operations are dependent on electricity and any event causing loss of power will result in interruptions to mine operations.

The mine has a complex upstream supply chain. Some of the chemicals required for mine operations are easily available, while some of the chemicals need to be sourced around the world. The mine has inventories to cover two days at most.

Any shortage in energy (propane or grid electricity) or water would result in production interruptions. Transportation and reclamation risks were considered secondary.

Risk identification table

The following table encloses and classifies some of the risks related to severe weather events.
<table>
<thead>
<tr>
<th>#</th>
<th>Risk</th>
<th>Damage description</th>
<th>Preventive measures</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Forest fires approaching the tailings</td>
<td>Fire up the banks and on the reclaimed tailings</td>
<td>None, as there are already numerous fire barriers</td>
<td>Low</td>
</tr>
<tr>
<td>2a</td>
<td>Ice storm - Total road closure</td>
<td>Disruption of supply of material to the mine</td>
<td>Increasing the material and reactant inventory capacity</td>
<td>Medium</td>
</tr>
<tr>
<td>2b</td>
<td>Ice storm - Total road closure</td>
<td>Transport of final product out of mine, leading to stockpiling of final good</td>
<td>Increasing storage capabilities of final product is not an option because mine will run out of reactants first.</td>
<td>Low</td>
</tr>
<tr>
<td>2c</td>
<td>Ice storm - Total road closure</td>
<td>High staff absenteeism</td>
<td>Collaborate with Ministry of transportation to assess the transportation risk</td>
<td>Low</td>
</tr>
<tr>
<td>3a</td>
<td>Earthquake on site</td>
<td>Likely liquefaction of active tailing pond</td>
<td>Increase stability and solidity of pond</td>
<td>Low</td>
</tr>
<tr>
<td>3b</td>
<td>Earthquake on site - Road closure</td>
<td>Same as 2a,b,c</td>
<td>Same as 2a,b,c</td>
<td>Low</td>
</tr>
<tr>
<td>4a</td>
<td>Extreme cold - propane shortage</td>
<td>Mine stoppage when temperature underground goes below 2°C</td>
<td>Decrease dependency on propane for heating purposes. Mine is considering retrofitting its vent for bi-energy (woodchips down to -1.5°C, combined with propane when colder). Currently the retrofitting option is in feasibility and risk analysis phase.</td>
<td>High</td>
</tr>
<tr>
<td>5a</td>
<td>Dry, hot weather combined to high wind (+15km/h): Tailings become dry and dusty</td>
<td>Dust created and spread over surrounding houses and fields</td>
<td>Install dust barriers and spray sealant</td>
<td>Low</td>
</tr>
<tr>
<td>6a</td>
<td>Heavy rains - On tailings</td>
<td>Tailing pond failure</td>
<td>Increase stability and solidity of pond</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Excessive erosion around the tailings</td>
<td>Increase capacity of the tailing pond</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Repair, re-vegetate, rent bulldozer</td>
<td></td>
</tr>
<tr>
<td>6b</td>
<td>Heavy rains - Road on site damaged</td>
<td>Roads on site destroyed</td>
<td>Increase maintenance of the road</td>
<td></td>
</tr>
<tr>
<td>7a</td>
<td>Heavy Snow</td>
<td>Same as 2a,b,c</td>
<td>Same as 2a,b,c</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Case study #3

Site overview

This mine is situated in a remote location and can only be accessed by plane or boat. The main gravel landing strip is designed to withstand jumbo jets. Planes are used to bring staff and material (such as fresh food) to the site. The mine operates on a fly-in fly-out model. Materials are supplied to the mine by vessels. Seaways are also used to transport concentrate produced from the mine to the smelter. Ships used by the mine are a class IV icebreaker which allows for year round transportation.

Historical events

The mine has experienced the following climatic events in the past:
► 1-3 day blizzards are common
► Avalanche (slush flows) on the road

Main risk factors

The main climate change risk is permafrost degradation. The permafrost acts as a barrier against water infiltration in underground galleries that could otherwise result in water contamination. In addition, permafrost holds the ground together which reduces the need for underground support structures. Increase in temperature will lead to permafrost degradation which will further result in discharge of contaminated water in to the environment.

This risk is mitigated through the following:
► Recent infrastructure takes into account actual climatic conditions in their design. Such infrastructure is more resilient to extreme events than older infrastructure.
► The company develops mine sites in succession i.e., a new underground mine is opened when the existing one is close to exhaustion.

The following factors affect resiliency:
► The mine already faces extreme events and is used to deal with important climate variability and operates in nearly total isolation.
► The “walk-away” restoration policy which means a restoration strategy that will ultimately no longer need intervention from human reduces the exposure of the mine to adverse effects after mine closure and limits climate change induced reclamation risks.

Mine controls its transportation network, whereas in other case studies, mines depend on public transportation system, operated and maintained by the government. It implies that the mine can work on the network as it sees fit. The transportation network is continuously monitored and maintained on ongoing basis (e.g. culvert replacement).

Risk identification table

Workshop participants favour a combined proactive and reactive approach to climate change risk management. Risks are listed in the table below.
► Risks 1, 3 and 4 are those for which the mine favours a proactive approach.
► Risks 2, 5 and 6 are those for which the mine favours a reactive approach.
<table>
<thead>
<tr>
<th>#</th>
<th>Risk</th>
<th>Damage description</th>
<th>Preventive measures</th>
<th>Likelihood</th>
</tr>
</thead>
</table>
| 1  | Temperature increase results in permafrost active layer to be more than 2.4m deep | Failure of current tailing management design                                        | R&D in tailing design & management (This measure has already been implemented) Implement alternative tailing management solutions  
    - Option 1: Increase the thickness of the layer cover  
    - Option 2: Geomembrane  
    - Option 3: Bentonite layer                                      | Very high                           |
| 2a | Temperature increase results in permafrost degradation               | Partial failure of water management system: Limited discharge of contaminated water in the environment | Review designs of future pit water management systems adapted to future climatic conditions | Medium     |
| 2b | Excessive water load in spring due to heavy snowmelt and spring precipitation | Same as 2a                                                                         | Same as 2a                                                                          | Same as 2a |
| 3  | Change in precipitation and in temperature pattern creates slush flows (avalanche) on road to Deception Bay | If a truck is on the road when the slush flows happen, it creates a risk for the personnel (low probability but severe consequences) | Option 1: Modify road design  
    - Option 2: Implement a dedicated risk management system (dynamite the slush to create a control slush flow) | Low        |
| 4  | Increase in precipitation frequency  
Or Increase in fog (low visibility)                                   | Increase in the frequency of cancelled planes due to poor weather conditions (low visibility) | Increase pilot training and logistical planning  
    - Implant latest on-board instrumentation technologies  
    - Note: Measures already in place                                | High       |
| 5  | Increase in temperature creates reduced lift for planes             | Decrease in maximum transport capacity per plane, thus increasing the flight frequency | Use smaller cheaper planes and increase trip frequency  
    - Increase logistical planning                                   | High       |
| 6  | Permafrost degradation                                              | Increased damage to the road network                                               | Redesign road network to be more resilient                                           | High       |
Case study #4

Site overview

This mine is surrounded by mixed forests and lakes and operates on a fly-in fly-out model. The plane is a turbo-prop that is owned by the mining company and crewed and maintained by an external firm.

This mine is connected to the grid. Multiple generators on the site have supplied power in the past and are currently serving as back-up generators. The concentrator, however, cannot work without power, which means a power outage will cause production interruptions. Large propane farms are used for processing and heating air pumped down in the winter.

The mine’s product can be stockpiled if required. Food and fuel are transported via a 200km, paved road that joins the nearest community and is publicly maintained. A relatively short private gravel road links the paved road to the site. The mine performs its own maintenance on the private road. The site has capacity to store propane and diesel for three to four days, and requires food delivery twice a week. Road closures therefore affect food and fuel supplies on a weekly basis. Other critical supplies such as reactants and other chemical compounds last for over a month are therefore less vulnerable to road closures.

The tailing pond is designed in a way that facilitates the natural water flow from the tailings through the spillway. Water from the tailings is discharged only in summer. There is no chemical treatment to the tailing pond water; tailing water is treated through a physical separation process in which solids are separated from the water itself. According to workshop participants, the ore does not have high levels of mercury or arsenic; hence a chemical treatment on the water from the tailings is not required.

Historical events

The mine has experienced the following climatic events in the past:

► 2011: Forest fires brought down the whole power distribution network that parallels the private road, which led to full-scale evacuation. The electricity was down for twenty days.
► 2009: Springtime runoffs and floods resulted in a major culvert failure on the private road.

Main risk factors

► The primary vulnerability identified is the dependency on electricity supply. The site is highly vulnerable to power outages.
► Tailing pond overflows.

Risk identification table

Most of the risks identified in the table below have already occurred and are therefore considered more likely by workshop participants.
<table>
<thead>
<tr>
<th>#</th>
<th>Risk</th>
<th>Damage description</th>
<th>Preventive measures</th>
<th>Likelihood</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>Forest fires close to mining site</td>
<td>- No production for several days&lt;br&gt;- Power lines damaged</td>
<td>Brush under the lines</td>
<td>High</td>
</tr>
<tr>
<td>1b</td>
<td>Forest fires on road network connecting the mining site</td>
<td>- Shortage of food and fuel (diesel and propane)</td>
<td>Increasing food and diesel inventory capacity</td>
<td>High</td>
</tr>
<tr>
<td>2a</td>
<td>High winds causing loss of power</td>
<td>Same as 1a</td>
<td>Not available</td>
<td>High</td>
</tr>
<tr>
<td>5a</td>
<td>Dry and very cold weather combined with high wind make the tailings dry and dusty.</td>
<td>Informal complaints from the local nearby communities concerning dust. The mine has not incurred any cost implications.</td>
<td>Preventive measures put in place to reduce dust:&lt;br&gt;- Daily inspections, watering, and use of dust suppressants (calcium chloride, magnesium or MOE approved dust suppressants)&lt;br&gt;- Dust collectors, conveyors</td>
<td>Medium</td>
</tr>
<tr>
<td>6a</td>
<td>Fog: Excessive fog and reduce visibility will make it difficult for the planes to fly or land.</td>
<td>Delay in flying in and out of the employees</td>
<td>Increase in pilot training&lt;br&gt;- Collaborate with aviation authorities&lt;br&gt;- Installation of equipment that allows pilots to perform a blind landing</td>
<td>High</td>
</tr>
<tr>
<td>7a</td>
<td>Heavy rains/Floods may lead to tailing ponds to overflow</td>
<td>Tailing ponds will overflow due to high water levels in the tailing pond</td>
<td>Increase capacity of the tailing ponds: According to the site team, this measure is under assessment.</td>
<td>Low</td>
</tr>
<tr>
<td>7b</td>
<td>Heavy rains/Floods may lead to culverts fail</td>
<td>Culverts will fail</td>
<td>The preventive measures have already taken. They are the installation of larger culverts, and the relocation of beaver houses.</td>
<td>Low</td>
</tr>
<tr>
<td>8b</td>
<td>Heavy Snow - Transportation; difficult to drive on the road due to heavy snow</td>
<td>Delays due to road transportation; Can take up to 3 days to clear. Standard of maintenance on the 193km road is minimum. It almost takes two days to get the road back to operations.</td>
<td>Increased maintenance of the roadways</td>
<td>Medium</td>
</tr>
</tbody>
</table>
Appendix C Bibliography

AIG (2012). Climate change: A call for weatherproofing the insurance industry. 


BSR: Adapting to climate change – A Guide for the Mining Industry 
http://www.bsr.org/reports/BSR_Climate_Adaptation_Issue_Brief_Mining.pdf


## Acronyms

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AROs</td>
<td>Asset retirement obligations</td>
</tr>
<tr>
<td>EMMIS</td>
<td>Economic Model for Mining Investment Scenarios</td>
</tr>
<tr>
<td>EY</td>
<td>Ernst &amp; Young LLP</td>
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<tr>
<td>IPCC</td>
<td>Intergovernmental Panel on Climate Change</td>
</tr>
<tr>
<td>IRGC</td>
<td>International Risk Governance Council</td>
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<tr>
<td>NGO</td>
<td>Nongovernmental organizations</td>
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<tr>
<td>NPV</td>
<td>Net present value</td>
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<td>NRCAN</td>
<td>Natural Resources Canada</td>
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<tr>
<td>RCP</td>
<td>Representative Concentration Pathways</td>
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<tr>
<td>ROI</td>
<td>Return on investment</td>
</tr>
<tr>
<td>SRES</td>
<td>IPCC Special Report: Emissions Scenarios</td>
</tr>
</tbody>
</table>
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